APJ

ARCHITECTURE & PLANNING JOURNAL

SPECIAL ISSUE

HYBRID SPACES OF THE METAVERSE

Architecture in the Age of the Metaverse Opportunities and Potentials

ASCAAD 2022

10TH International Conference of The Arab Society for Computation in Architecture, Art and Design

Debbieh, Lebanon
October 12-13, 2022
Hybrid Conference

OUSSAMA DIMACHKIEH

جامعة بيروت العربية
BEIRUT ARAB UNIVERSITY
Faculty of Architecture
Design & Built Environment

APJ

ARCHITECTURE & PLANNING JOURNAL **SPECIAL ISSUE**

The journal, being an additional educational method, has established itself and rapidly developed from a local to a regional and international scope, and is currently expanding its profile. Many authors, researchers, and writers have contributed their views, ideas, and thoughts, making APJ a valuable resource and supplier of knowledge, serving researchers, academics, and students within the dual field of Architecture and Urbanism, and thus contributing to the mission of the faculty as a whole.

All the published articles are peer reviewed by regional and international referees, experts in their domains or staff members from reputable universities in Europe, USA, South America, Far East, Middle East, and Africa.

Since 2019, APJ has been hosted by the international platform 'Elsevier - Digital Commons', who operates publishing academic journals. Every published paper in APJ has a digital object identifier (DOI), and the authors are identified by ORCID number on 'Elsevier - Digital Commons'.

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PROCEEDINGS

The 10th International Conference
of the Arab Society for Computation in Architecture, Art and Design

ONLINE CONFERENCE

12–13 October 2022
Beirut, Lebanon
Faculty of Architecture - Design & Built Environment
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Virtual Tour Website: http://virtualtour.bau.edu.lb/ascaad/

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WELCOME NOTE - BEIRUT ARAB UNIVERSITY

Dear Conference Participants

On behalf of Beirut Arab University and the organizing committee of ASCAAD 2022, we would like to welcome you to the International Conference on Hybrid Spaces of the Metaverse: Architecture in the Age of the Metaverse - Opportunities and Potentials. Beirut Arab University organizes this conference in partnership with Arab Society for Computation in Architecture, Art and Design (ASCAAD). The 10th ASCAAD International Conference (ASCAAD 2022) focuses on the theme of Hybrid Spaces of the Metaverse. It aims to envision new horizons of thoughts that can shift the architectural profession and education into new worlds of metaverse. Under the emergency cases such as pandemics, economic crises, and natural hazards, the virtual environments have become a resilient solution to connect between architect and client, instructor and student, designer and beholder. The power of metaverse may enable architects an infinite number of opportunities. This conference collects multi-disciplines of (Architecture, Artificial Intelligence, Virtual Reality, Computational Design, Computer Programming, Information Management, Gaming, etc). It presents a platform of new research papers that can be seeds for changing the future of architecture.

Prof. Amr Galal El-Adawi

Conference Honorary Chair
President of Beirut Arab Univeristy, Lebanon

WELCOME NOTE - FACULTY OF ARCHITECTURE - DESIGN & BUILT ENVIRONMENT, BAU

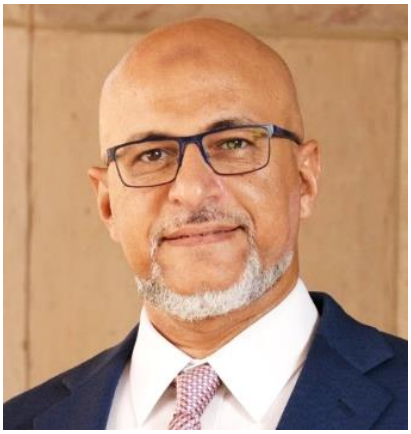
Since the beginning of the twenty-first century, the world has witnessed amazing developments in the use of information technology. Digital transformation has invaded various sectors of life such as medicine, industry, agriculture, education, and others. This information revolution in communications and media has contributed to breaking the barriers of distance and time between individuals and they were able to create new environments for communication through cyberspaces, whether to accomplish tasks, do homework or play games. Where previously dealing with these virtual environments was limited only to specialist programmers, the field is now available for everyone to engage in self- or group experiences. The user can create, build, navigate, and visit new realms with total freedom, which is known by Metaverse. In this context, the Faculty of Architecture at Beirut Arab University is honored to host the international conference (**Hybrid Spaces of the Metaverse: Architecture in the Age of the Metaverse - Opportunities and Potentials**), organized by BAU and ASCAAD. This conference invites architects and researchers to explore new visions about the potentials of using metaverse in architecture. Digital architecture, artificial intelligence, BIM and parametric design among many other technologies have become a channel to enter the world of metaverse and provide absolute freedom for the architect, student, or client to design new futuristic spaces that are more responsive to the needs of time, more resilient to withstand modern day challenges. The accepted papers are published in the conference proceedings as a special issue of the Architectural and Planning Journal (APJ).

Prof. Ibtihal Y. El-Bastawissi

Conference Chair
Dean, Faculty of Architecture - Design & Built Environment
Beirut Arab Univeristy (BAU)

FOREWORD – ASCAAD

Dear ASCAAD friends,



The 10th International Conference of the Arab Society for Computation in Architecture, Art and Design (ASCAAD 2022) has invited scholars, researchers and students worldwide to contribute with novel methodologies, processes and approaches within the theme of *Architecture in the Age of the Metaverse*. The ASCAAD community is thrilled to work on this exciting theme together with a leading institution in Lebanon and the Middle East; the Faculty of Architecture – Design & Built Environment at Beirut Arab University (BAU). Despite the virtual mode, a promising platform is in place for ASCAAD to develop stronger ties with its regional networks and tighter bonds with sister CAAD organizations.

As president of ASCAAD, I cannot but express my deep gratitude having worked closely with a superb and committed group of researchers, scholars and administrators within the Arab World and the Middle East. It is with this enthusiasm, dedication, devotion, and spirit that this conference has come to fruition, and by which ASCAAD will continue to affirm its presence in the region as an active player in the area of computational design and its role in academia and the built environment.

This conference would definitely have not been possible without the year-round amazing commitment and hard work of the conference committee members. Words are not enough to express the gratitude that ASCAAD owes to the Beirut Arab University exceptional team who have made this event such a success and source of pride to the ASCAAD community. Special thanks to the instrumental role that President Amr El-Adawi and Dean Ibtihal El-Bastawissi have played and their outstanding spirit of cooperation and generosity which has been exceptionally rewarding and key to the success of the conference, and to the wonderful team of professors and organizers behind this excellent effort. I am also extremely grateful to work alongside a remarkable Board of Directors who are incessantly going out of their way and pumping an enormous amount of effort and support for the making of this conference and other events.

I cannot but thank deeply all members of the CAAD community who have offered consistent support to ASCAAD. Special thanks and gratitude to ACADIA President Jenny Sabin, eCAADe president Rudi Stouffs, CAADRIA President Anastasia Globa, and SIGraDi President Marcelo Bernal for their endless endorsement and encouragement.

Dr. Sherif Abdelmohsen

Conference Co-Chair
President, Arab Society for Computation in Architecture, Art and Design (ASCAAD)

ABOUT ASCAAD

ASCAAD is a society of those who teach, conduct research and practice in computer-aided architectural design (CAAD) in the Arab World regions of West Asia, and North Africa. ASCAAD is also active in Central Asia, Sub-Sahara Africa, and the Mediterranean. The society holds conferences and educational events that will be hosted by a different University each time. The output of the conferences and contributions from the educational events be published as a Conference Proceedings book. ASCAAD aims to facilitate communication and information exchange regarding the use of digital design technology in architecture, planning and building science that are dramatically challenging our fundamental assumptions, theories, and practices of conventional design paradigm.

أسكاد هي جمعية لأساتذة التدريس والمهندسين والقائمين بالبحث في مجال التصميم المعماري بمساعدة الحاسوب في كليات العمارة والتصميم والهندسة في العالم العربي بشطريه في غرب قارة آسيا وشمال أفريقيا. تنشط أسكاد كذلك في مناطق وسط آسيا وجنوب الصحراء الأفريقية وحوض البحر الأبيض المتوسط. تعقد الجمعية المؤتمرات والفاعليات التعليمية التي ستستضيفها جامعة مختلفة كل مرة، ويتم نشر مخرجات المؤتمرات والمساهمات من الأحداث التعليمية ككتاب وقائع المؤتمر. وتهدف أسكاد إلى تسهيل التواصل وتبادل المعلومات فيما يتعلق باستخدام تكنولوجيا التصميم الرقمي في الهندسة المعمارية والتخطيط وعلوم البناء التي تتحدى بشكل كبير افتراضتنا ونظرياتنا وممارستنا لنموذج التصميم التقليدي.

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PREFACE

This special issue of Architecture and Planning Journal (APJ) comprises the Proceedings of the 10th International Conference of the Arab Society for Computation in Architecture, Art and Design (ASCAAD 2022), held as an online event, from October 12-13, 2022, at the Faculty of Architecture - Design and Built Environment, Beirut Arab University. The proceedings contain the 46 accepted papers. All papers are also available digitally at CumInCAD (Cumulative Index of Computer Aided Architectural Design) – http://papers.cumincad.org.

Conference Theme

The ASCAAD 2022 theme is ***ARCHITECTURE IN THE AGE OF THE METAVERSE – OPPORTUNITIES AND POTENTIALS.*** It focuses on the Hybrid Spaces of Metaverse, with the aim of unravelling the opportunities and potentials of architecture in the age of the Metaverse. Historically space was always the container of people's activities and memories; it is the collective reflection of their lifestyles. Walls, floors, and ceilings of architectural spaces witnessed the moments of joy and happiness, as well as moments of misery that changed human history - from the signing of the United Nations Declaration post WWII - to the first I-phone sold in the Apple store; history is written inside architectural spaces. The new era of the 4th industrial revolution, which is associated with digital transformation, will unlock new opportunities for architects, interior designers and whoever will enter the domain of the metaverse. The metaverse will not only serve as a portal to a new world, but also as an extension to new activities such as commercial, social, educational, and business activities that will thrive in the new virtual realm. The metaverse will act as the natural transcendence of technological advancements carrying new potentials to the architectural profession.

Active Worlds, Second Life, Roblox and Fortnite are all early versions of what we will witness in the next few years, shifting from entertainment to full commercial, official, and governmental activities; all will be hosted inside virtual and hybrid spaces. A new era will start inside virtual realms; real economy will rise inside virtual architecture but without the multiple physical or structural constraints that limit physicality anymore such as gravity, and day and night cycles; no oxygen is needed anymore. But this time, human activities will not only be recorded and saved but also attended and lived in real time. Computational design will continue to thrive and even evolve into new forms aligning with new changes and challenges of the metaverse.

Hybrid spaces are the spaces that will be built as a virtual extension of real spaces. They will be in connection to real spaces and reflecting their activities on a real time basis. On the other hand, pure virtual spaces will occur, trespassing time zones and geographical barriers. The importance of hybrid experiences was most realized after the pandemic lockdowns; and now is the time to invent new design methodologies and new theories as a natural transcendence of architecture profession. Hyperlinks portals replacing staircases and elevators, physically impossible structures, open budget interiors, teleportation are all new notions emerging with the new domain. Today, virtual spaces are hosted on various cloud services and registered as Non-Fungible Tokens (NFTs). They are experienced as immersed spaces using headsets or semi-immersed spaces presented through laptops and/or mobile screens. With the new accelerating pace of technology, there is high possibility for integration within our neural networks to be experienced in our minds with just closing our eyes in the near future.

With considerably very little scientific research presented in this new field, the need to such a contribution has become imminent. The 10th ASCAAD international conference tests and discusses novel ideas and design approaches that shape and transform metaverse environments, therefore setting new roadmaps and offering solutions to researchers, architects and designers, tech start-ups, educators, technologists and even thought leaders seeking a new role in the metaverse. ASCAAD 2022 has thus invited submissions of original research papers on the following topics related to Architecture in the Age of Metaverse environments:

Topic 1: Artificial Intelligence

- AI, Machine Learning and Deep learning
- Agent-based Modeling
- Generative Design

Topic 2: Information Management

- Building Information Modeling
- Non-Fungible Tokens (NFT) for Architectural Assets
- Internet of Buildings
- Decision Support Systems including Simulation, Prediction and Evaluation in Design

Topic 3: Parametric Design and Digital Fabrication

- Parametric and Algorithmic Design
- Innovative Materials and Digital Fabrication
- Robotics in Architecture and Automation

Topic 4: Virtual Environments and Emerging Realities

- Digital Representation and Visualization
- New Sustainable Approaches for Digital Design
- Digital Heritage
- Architecture for Gaming Industry and Interactive Design
- Virtual Reality, Augmented Reality and Mixed Realities
- Human-Computer Interaction

Topic 5: Computational Design Theory

- Computational Design Thinking and Creativity
- Internet of Things Centered Design
- Human Centered Design and User Experience
- Education in Hybrid Spaces

Topic 6: Hybrid Cities

- Smart Virtual Cities
- Cities Modeling and GIS
- Urban Analytics and Modeling of Virtual Cities
- Collaborative, Participative and/or Responsive Design
- Big Data Management in Architecture and Urban Design
- Mass Customization in Design

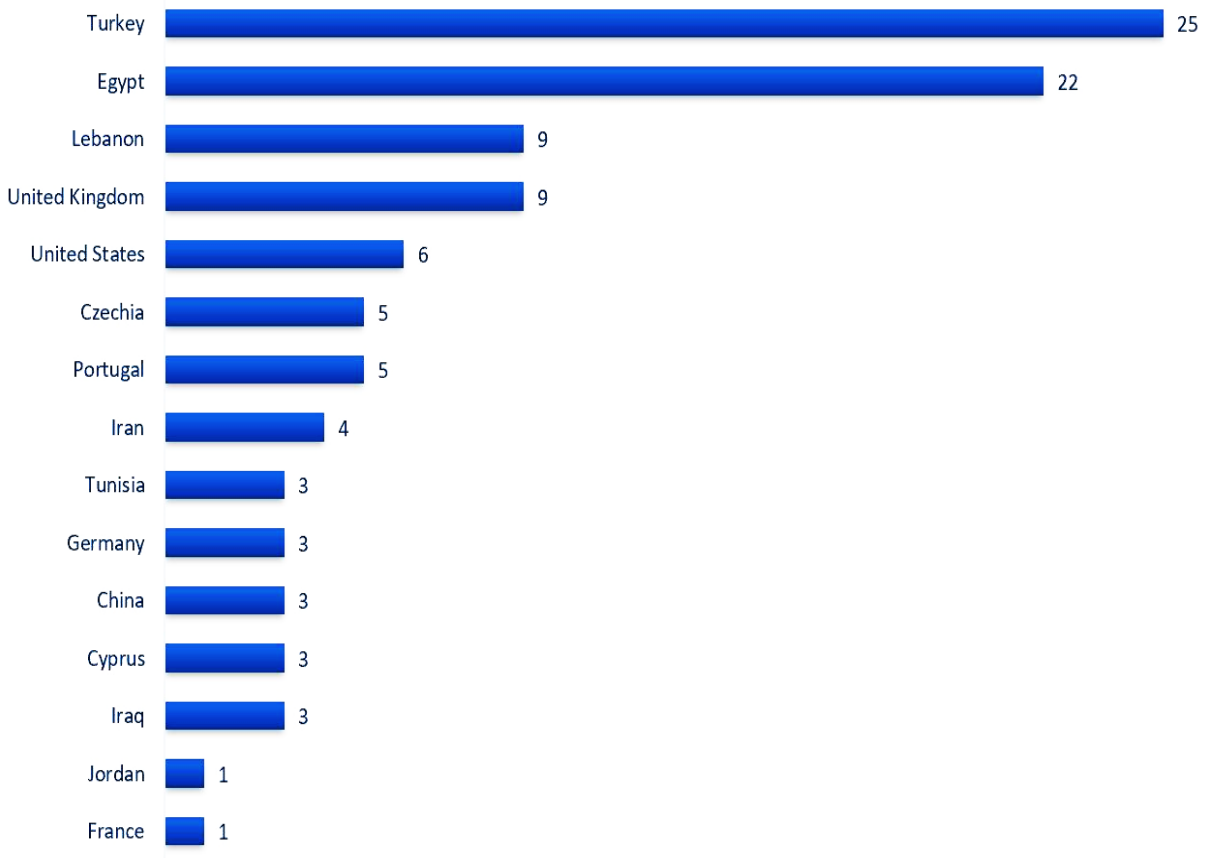
Submissions and Statistics

The Conference theme of ASCAAD 2022 at Beirut Arab University (BAU) has incited wide interest regionally and globally. A double-blind peer review process was implemented using the OpenConf system. In the first round of submissions, authors were asked to send abstracts (in English or Arabic) with a maximum of 500 words and one figure. We received in this stage **118 abstracts** by **228 authors** representing **22 countries**. All abstracts were sent anonymously to at least three international referees per abstract and were checked in accordance with the quality measures set out for submission by ASCAAD.

As a result, a total of **100 abstracts** were forwarded to the second round of peer review process, where they were invited to submit their full paper submissions. This included well-developed or completed research (3000-500 words).

The ASCAAD 2022 scientific committee asked authors at this stage to include an Arabic abstract in their full paper English submissions. The committee provided support where needed for non-native Arabic speakers. Full paper submissions were sent anonymously and were reviewed by two to three international referees. The review process was only possible with the generous and professional contribution of the reviewing committee consisting of a total of **70 expert** referees from around the globe.

A final number of **46 full papers** by **102 authors** representing **15 countries** from the Middle East, Europe, Asia, North America, South America, and Australia were identified by the ASCAAD 2022 scientific committee and were invited to submit camera-ready papers. The shown chart clarifies the number of authors by country.



ASCAAD 2022 Number of authors by country

THE VIRTUAL CONFERENCE

The ASCAAD 2022 conference was hosted virtually at the Faculty of Architecture - Design and Built Environment at Beirut Arab University (BAU) during the period October 12-13, 2022, the second-time experience for ASCAAD conferences, this time due to the unstable circumstances in Lebanon. The conference committee has chosen to move ASCAAD 2022 a virtual setup to ensure the continuity and sustainability of ASCAAD conferences. The six main conference topics were structured in 10 sessions that unfolded in parallel sessions over the course of two days (October 12th and October 13th), preceded by 5 pre-conference workshops, held on two days (October 10th and October 11th). This structure is also followed in the organization of the conference proceedings.

The OpenConf conference management system was used for both registration in the conference and workshops. We thank the Digital Transformation team at BAU for the support they provided with the OpenConf platform prior to the conference days. For the virtual conference setup, the conference committee had asked all authors with accepted full paper submissions to submit, in addition to camera-ready papers, a 10-minute pre-recorded video of their presentations and their bios, affiliations, and social media links. This allowed for creating a more engaging setup during the conference days.

During the "virtual social event" on October 12th, all registered participants were invited to log in to the virtual chatroom that was available thanks to the Spatial. Chat platform. This allowed for a more engaging informal experience and freely formed discussion clusters among conference participants, with some light oriental music and video streaming in the background.

Ibtihal Y. El-Bastawissi, Sherif Abdelmohsen

ASCAAD 2022 Conference Chairs

ACKNOWLEDGMENTS

First and foremost, we thank all paper authors whose work was featured in this virtual conference for their hard work, dedication, and commitment. We are grateful to our distinguished keynote speakers Professors Mark Clayton and Neil Leach and the architects Ms. Elif Erdine and Mr. Khaled Elashery for their extremely insightful talks and for their generous commitment to the conference.

We would also like to thank the pre-conference workshop moderators Yang Song, Fatima Belok, Laila Koubaa Turki, Samer El-Sayary, Adel Fernandez, Gretta Kelzi, Mostafa Khalifa, and Aly Magdy for the highly interesting workshop sessions they conducted prior to the conference. We would also like to extend our thanks and gratitude to all session moderators and rapporteurs for their dedication and commitment in controlling the parallel sessions and conserving equality of presentations' periods.

Many thanks to the members of the reviewing committee who have worked tirelessly to support the double-blind peer review process and the evaluation of 118 abstracts and 46 full papers. Such a demanding task in a tight timeline and working within challenging circumstances is highly appreciated.

At BAU, thanks are due to BAU President Prof. Amr Galal El-Adawi for his support since January 2022 in making this conference happen, and to all administration and academic members of Faculty of Architecture - Design and Built Environment, BAU.

All gratitude and thanks to conference sponsors (Oussama Dimachkieh, Dar Al-Omran, IGT, Saccal, Interoffice, Abillamaa - Petrolium & Water, and BANKERS). This conference would not have achieved this success and global recognition without their highly support.

All thanks to the dedicated conference committees' members and the support of ASCAAD members Huda Salman, Sema Alacam, Mostafa Alani and Samar Allam. Last but not least, all thanks to the BAU staring committee members Samer El-Sayary, Kareem Galal, and Osama Omar.

Beirut, October 2022

Ibtihal Y. El-Bastawissi, Sherif Abdelmohsen

ASCAAD 2022 Conference Chairs

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KEYNOTES

MARK CLAYTON
COLLEGE OF ARCHITECTURE, TEXAS A&M UNIVERSITY, USA

Mark Clayton is a William M. Pena Endowed Professor of Information Management at the Department of Architecture, and Director of the CRS Centre at the College of Architecture at Texas A&M University. Professor Clayton has been a faculty member at Texas A&M since 1995. He has served the College of Architecture as Executive Associate Dean and the Department of Architecture as Interim Head. He was also past president of ACADIA and a founding member of ASCAAD.

NEIL LEACH
DEPARTMENT OF ARCHITECTURE, COLLEGE OF COMMUNICATION, ARCHITECTURE + ARTS, FLORIDA INTERNATIONAL UNIVERSITY, USA

Neil Leach is a Professor at Florida International University (FIU), Tongji University, and the European Graduate School (EGS). He is an architect, curator, and writer. He has also taught at leading institutions including AA, IAAC, DIA, Columbia GSAPP, Cornell, Harvard GSD and Sci-Arc. He is also co-founder of DigitalFUTURES, and an academician in the Academy of Europe, and has published over 40 books on architectural theory and digital design.

ELIF ERDINE
AA SCHOOL OF ARCHITECTURE, LONDON, UK

Elif Erdine is an architect and researcher. Currently, she teaches at the Architectural Association (AA) School of Architecture, Emergent Technologies, and Design Graduate Programme. She is the Programme Director of AA DLAB Visiting School and AA Istanbul Visiting School. She has worked for Zaha Hadid Architects during 2006 - 2010. She received her BArch. degree from Istanbul Technical University in 2003 (High Honors), and M.Arch. degree from the AA Design Research Lab (AA DRL) in 2006. Her interests are the integration of algorithmic generative design with large-scale digital fabrication tools, and in physical computing.

KHALED ELASHRY
ASSOCIATE PARTNER AT THE APPLIED RESEARCH AND DEVELOPMENT
FOSTER + PARTNERS, UK

Khaled Elashry is as an Associate Partner at the Applied Research and Development (ARD) group at Foster + Partners in addition to teaching at the Bartlett school of architecture, University College London. His recent work bridges the gap between architecture practice and research applying state-of-the-art technological innovation to complex design challenges with expertise in optimization, fabrication, robotics, virtual reality, and data visualization. He recently worked on multiple state of the art architecture projects like the Mobility Pavilion in the UAE expo 2020, The Lusail stadium in Qatar and the UAE pavilion in Milan expo in addition to his research in robotics.

TECHNICAL WORKSHOPS

Workshop 1:

AR+DESIGN: AUGMENTED REALITY IMMERSIVE DESIGN METHOD

Workshop Moderator:

Yang Song, University of Liverpool, United Kingdom

This online workshop aims to introduce the knowledge of exploring immersive parametric design through the Augmented Reality (AR) environment. As the quintessential 3D-4D design field, architectural design has been limited throughout its history by 2D or cumbersome 3D representation. Even though computer-aided architectural design and modelling software is widely used to produce digital 3D models, the conventional screen-based visualization methods for design and analysis are restrictive to how well the user understands the space on a computer screen, as the design is done outside the building site, hence there might be disparities between the design and final. Ideas like exploring immersive design in AR, as well as real-time modification experience and interaction with the built environment and the metaverse, will therefore actuate as the central core for the research streams to reduce the current design methods. Participants will learn about the parametric design methods of brick-based structures as demonstrations, basic AR modelling logic, AR onsite holographic preview, AR real-time interactive functions, and basic AR input method knowledge. The participants will be able to learn the parametric design process and the AR immersive design by following the live demonstration in Grasshopper with the related plugin step by step. After that, participants will start to design, develop, and preview their own structures in the AR environment with setting-related interactive, immersive design inputs. The goal is to enable participants to learn and apply this immersive design method to architectural applications, such as walls, columns, pavilions, or other structures, and to customize design algorithms or related interventions for their designs in
the AR environment.

Workshop 2:

INTERACTIVE DIGITAL PARAMETRIC PATTERNS: RHINO AND GRASSHOPPER 3D

Workshop Moderator:

Fatima Belok, Beirut Arab University, Lebanon

The workshop main goal is learning how to design interactive digital parametric pattern. It is about designing different patterns on shadings or facades that could interact with sounds as an external factor assigned by the designer. The programs used will be Rhino 6 or 7 and Grasshopper 3D. In this online workshop we will work together and applied some examples on various surfaces, shading and facades for different patterns using Lunchbox, Weaverbird and Firefly. At the end of the workshop's participants will take a time to design their own interactive patterns on any shape such as building, facades, furniture, or shading. Participants will learn how to put a sound using firefly and will discover how the patterns will change based on the sound frequency. Thus, this workshop is important to improve participants skills that have basic knowledge in Rhino, Grasshopper 3D and various plugins.

Workshop 3:

GENERATIVE DESIGN BY BIM APPROACH

Workshop Moderator:

Laila Koubaa Turki, University of Carthage, Tunisia
Abdelkader Ben Saci, The National School of Architecture of Grenoble, France

This workshop will give basic exposure to generative design on BIM environment. It gives hands-on experience on how to create visual scripts and run a generative design process. Revit, Dynamo and Project refinery will be used to study the volumetry of a building through an iterative process

that generates outputs to satisfy certain constraints. The first step is to define inputs and variables depending on the ultimate goals. Then the last step is to select the optimal solution. The tools employed are Revit for BIM modelling and Dynamo for visual programming and Refinery for the Generative Design. Once the optimal solution has been determined, it is possible to import the results back into Revit environment to complete the BIM modelling study.

Workshop 4:
DESIGNING A BIM ENERGY-CONSUMPTION TEMPLATE TO CALCULATE AND ACHIEVE A NET-ZERO ENERGY HOUSE

Workshop Moderator:
Samer El-Sayary, Beirut Arab University, Lebanon

BIM is not simply a drafting tool or advanced CAD. BIM is a collaboratively generated and maintained data-rich information source, especially when it comes to the energy-calculation process and beyond. Due to growing awareness around energy conservation, numerous projects and initiatives have occurred to promote the development of low- and net-zero-energy homes. The widespread adoption of photovoltaic rooftop systems has shown that solar homes can be a effective solution to that energy demand; nowadays, the idea that BIM is not just software has been decided upon. In this paper, an innovative approach was used to calculate energy consumption using a BIM template designed for this purpose. The greatest value derived from BIM was in the template designed to neutralize energy consumption by calculating the number of photovoltaic panels needed to achieve a net-zero-energy house. The BIM prototype developed is considered a useful tool, intended to be used by every day, non-specialist users to aid and disseminate energy knowledge to achieve a zero-energy home, as well as to be used as a decision-support tool, incorporating energy simulation into the early design process of zero-energy buildings in architectural practice. Finally, the tool was tested on a group of users in order to fine-tune and develop the design parameters of the template.

Workshop 5:
GIS-BASED PARAMETRIC URBANISM: BRINGING REALITY TO DESIGNS USING GEOSPATIAL 3D MAPPING AND URBAN DESIGN TOOLS

Workshop Moderator:
Adel Fernandez; Gretta Kelzi, ESRI Lebanon

Cities are complex, dynamic, and interconnected, they need to attract investment, manage housing affordability, improve economic resiliency, and meet their sustainability goals. Technology can help shape how we build, while at the same time providing cities the ability to react at the pace in which things are changing. GIS provides the building blocks, and ArcGIS Urban can apply those building blocks to solve specific challenges that may all cities face. Therefore, we would like to start our session by giving you background on why we built such a toolset. Then we will get to what you are here for, and dive into a series of demonstrations and case studies.

CONTENTS

DAY 1 - PARALLEL SESSION 1

TOPIC 1 - ARTIFICIAL INTELLIGENCE

USING DEEP LEARNING TO GENERATE FRONT AND BACKYARDS IN LANDSCAPE ARCHITECTURE

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Abstract. The use of artificial intelligence (AI) engines in the design disciplines is a nascent field of research, which became very popular over the last decade. In particular, deep learning (DL) and related generative adversarial networks (GANs) proved to be very promising. While there are many research projects exploring AI in architecture and urban planning, e.g., in order to generate optimal floor layouts, massing models, evaluate image quality, etc., there are not many research projects in the area of landscape architecture - in particular the design of two-dimensional garden layouts. In this paper, we present our work using GANs to generate optimal front- and backyard layouts. We are exploring various GAN engines, e.g., DCGAN, that have been successfully used in other design disciplines. We used supervised and unsupervised learning utilizing a massive dataset of about 100,000 images of front- and backyard layouts, with qualitative and quantitative attributes, e.g., idea and beauty scores, as well as functional and structural evaluation scores. We present the results of our work, i.e., the generation of garden layouts, and their evaluation, and speculate on how this approach may help landscape architects in developing their designs. The outcome of the study may also be relevant to other design disciplines.

Keywords: *deep learning, GANs, landscape architecture, artificial intelligence, outdoor design.*

ملخص. يعد استخدام محركات الذكاء الاصطناعي في تخصصات التصميم مجالًا بحثيًا ناشئًا، والذي أصبح شائعًا للغاية على مدار العقد الماضي. وقد أثبت كل من التعلم العميق وشبكات الخصومة التوليدية GAN على وجه الخصوص أنهما واعدان للغاية فى هذا الإطار. وبالرغم من وجود العديد من المشاريع البحثية التي تستكشف الذكاء الاصطناعي في الهندسة المعمارية والتخطيط الحضري، من أجل على سبيل المثال إنشاء تخطيطات مثالية للفراغات، والنماذج

الكتلية، وتقييم جودة الصورة، وما إلى ذلك، لا توجد العديد من المشاريع البحثية في مجال تنسيق المواقع وعلى وجه الخصوص تصميم مخططات الحدائق ثنائية الأبعاد. نقدم في هذه الورقة البحثية استخدام شبكات GAN لإنشاء مخططات أمامية وخلفية مثالية. نستكشف فى هذا الإطار محركات GAN المختلفة، منها على سبيل المثال، DCGAN، التي تم استخدامها بنجاح في مجالات تصميم أخرى. وقد تم استخدام التعلم الخاضع للإشراف وغير الخاضع للإشراف فى هذا البحث باستخدام مجموعة بيانات ضخمة من حوالي ١٠٠٠٠٠ صورة لمخططات الفناء الأمامي والخلفي، مع سمات نوعية وكمية، منها على سبيل المثال درجات للأفكار والجمال ، بالإضافة إلى درجات التقييم الوظيفي والإنشائى. فى النهاية نقدم نتائج البحث، أي إنشاء مخططات الحدائق وتقييمها، ونتوقع كيف يمكن لهذا النهج أن يساعد مصممى تنسيق المواقع في تطوير تصاميمهم. قد تكون نتائج الدراسة ذات صلة أيضًا بتخصصات التصميم الأخرى.

الكلمات المفتاحية: *التعلم العميق، شبكات الخصومة التوليدية، تنسيق المواقع، الذكاء الاصطناعى، تصميم الفراغات الخارجية.*

1. Introduction

In recent years, various design disciplines have become interested in utilizing artificial intelligence (AI) in their design deliberations, such as studies on deep learning (DL) systems to generate novel floor layouts, or answer other design questions (As et al. 2018; Chaillou 2021; Huang and Zheng, 2018; Nauata et al. 2020). Our study explores artificial neural networks' (ANN) ability to produce landscape designs for small scale residential front-, and backyards. We used a large dataset of design imagery, made them machine-readable and created a workflow that predicts various landscape layouts from simple sketches.

Landscape architecture works at different scales and it has to deal with complex environmental issues. Even though there is a difference at various scales, there are common and essential design deliberations, which we can learn and extrapolate from smaller residential landscape projects.

Generative Adversarial Networks (GANs) proved to be the most efficient and effective ANN to respond best to our research goals. There are many projects that deal with novel applications of AI in the field of architecture, but in landscape architecture it is somewhat limited, and there is a need for such research in this area (Newton, 2018). In this study, we used open-source data and software alternatives to answer our main research question: 'Can we develop a design tool from AI-generated mechanism for residential landscape design?' (Figure 1.).

2. Background

AI is becoming a popular tool among designers, for example, plugins and software tools such as Grasshopper are increasingly becoming more commonly used (Chaillou, 2022). The era of ours will be identified as 'Information Revolution' and AI-use will be more common in the future and will impact the life-cycle of an architectural project (Cai et al. 2018). Decision making with statistical and data driven optimization tools, i.e., AI, is a popular research topic (Cai et al., 2018). The ability of AI to generate design has the potential to open up new possibilities and allow us to explore a larger part of the design space, which we previously were not able to do with traditional means. Neil Leach, for example, is expecting AI to be used not only in architectural design but also in other design disciplines (Leach, 2018). Others claim that AI-design samples are not as developed as human-designed artifacts (Cutellic, 2019). There is however a vast interest to learn and use AI in the design space, which we can clearly see from the large amount of papers published in the field.

3. Methods and Tools

In this research, we tried to develop a mechanism that is helping landscape designers in their front and backyard garden designs. We used supervised deep learning processes and obtained a dataset from an extensive online repository, i.e., from Arcbazar.com, an online crowdsourcing platform for design projects. We selected designs that had beauty scores (given by platform users) that were higher than 5 (out of 10) (Dataset I). We then produced a twin dataset that was semantically separated (Dataset II). We used the existing Pix2Pix GAN, which uses the Dataset I and its semantic twin Dataset II, to develop a system that allows users to sketch some rough ideas (Garden Sketch) and is then able to generate novel garden designs.

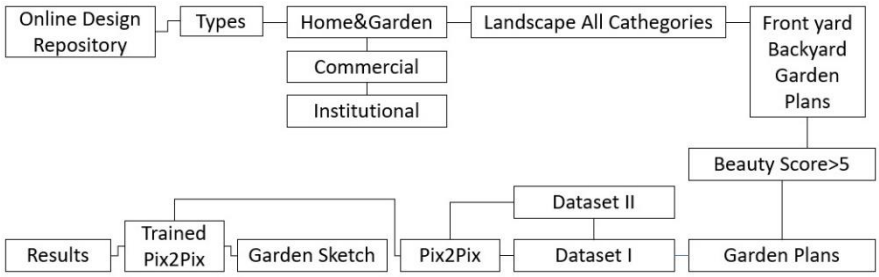

Figure 1. Workflow diagram of the study.

3.1 Data Preparation

The success of DL is dependent on the quality of training data, therefore we created our dataset from a large database management system (DBMS) of an online design repository. The DBMS has more than 300,000 design images such as plan drawings, section drawings, diagrams, and computer renderings. We picked high-quality projects from the DBMS, i.e., fully developed garden plans. All projects were evaluated by platform users on functional and aesthetic design criteria, i.e., 1 is worst, 10 is best, and we selected projects that were 5 and above.

3.2 Queries in DBMS

In order to filter relevant data from the DBMS, we used the following selection criteria:

- We only used top-view plan drawings, i.e., we did not use section drawings, perspective drawings or diagrams.
- We only picked front and backyard design projects.
- We selected projects that had more than 100 votes, i.e., were evaluated by more than 100 users.
- We filtered projects which were scored on average 5 or more (on a 1-10 scale).

(Figure 2).

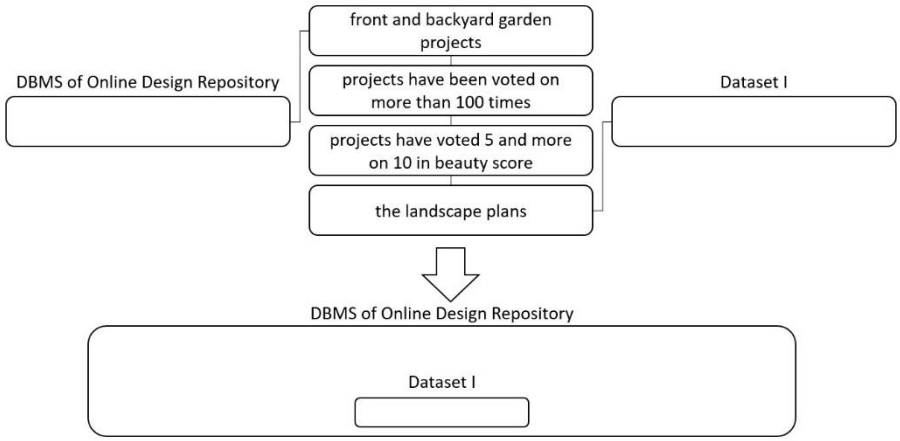

Figure 2. Queries in DBMS of Online Design Repository.

The dataset has an attribute table and contains different scores in terms of aesthetics, function, and other qualitative and quantitative aspects. After that we semantically segmented that data and created a twin dataset (Dataset II) (Figure 3, 4.). We used Dataset I and Dataset II to train the Pix2Pix GAN engine, with the aim to produce front and backyard designs from a rough

sketch. There are studies that try to relate architectural design with deep learning processes using a similar number of examples and similar algorithms (Huang and Zheng, 2018).

Figure 3. Dataset I – we used garden layout designs from an online design repository, i.e., landscape designs acquired from Arcbazar.com's online crowdsourcing platform.

The workflow process requires the semantic segmentation of Dataset I. We manually produced each project sample according to the following protocol: a.black: roads zones, b.grey: buildings zones, c.green: softscape zone, d.orange: hardscape zone, e.blue: water bodies. (Fig.4)

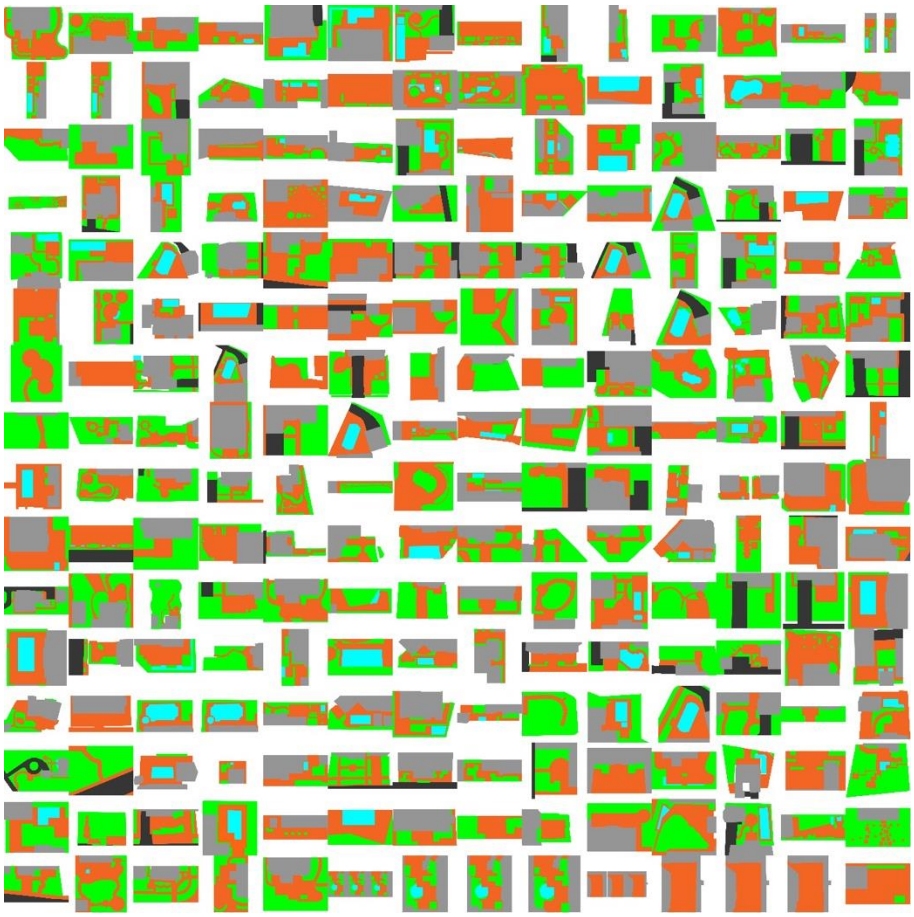

Figure 4. Dataset II – the semantic segmentation of the original landscape design samples.

3.3 Utilizing Pix2Pix GAN

Pix2Pix is a conditional GAN (cGAN), where the generation of the output image is dependent on an input image (Brownlee, 2019). The discriminator must decide if the target is a realistic transformation of the source image after being given both the source and target images. Through adversarial loss training, the generator is driven to produce believable images in the target domain. L1 loss is calculated between the manually created picture and the desired output image. This is method of updating the generator which encourages the generator model to provide accurate translations of the source image (Isola, et al., 2018). The Pix2Pix GAN has been explored on a variety of image-to-image translation tasks, including translating maps into satellite photos, black and white photos into color, and product drawings into actual product photos. The Pix2Pix model uses U-Net based architecture for the

generator, and PatchGAN classifier for the discriminator. U-Net is based on an encoder-decoder network architecture that consists of four encoder blocks and four decoder blocks – which are connected (Tomar, 2021). PatchGAN is a type of discriminator for GANs that penalizes structure at the scale of local image patches (Isola, et al., 2018). A deep convolutional neural network that conducts image categorization serves as the discriminator, especially conditional image-classification. It forecasts the chance that the target image is a true translation of the source image or a false one based on the input of both the source image and the target image. The model creates a target image from a source image. This is accomplished by first downsampling or encoding the input image to a bottleneck layer then upsampling or decoding the bottleneck representation to the size of the output picture (Isola, et al., 2018). According to the U-Net design, skip-connections are introduced to create a U-shaped pattern between the encoding levels and the appropriate decoding layers.

We initially trained the model with 224 images and with ReLU (rectified linear) activation function. If the input is positive, the ReLU will output the input directly; if it is negative, it will output zero. The images are resized into 512X512 pixels in order to be able to use them for training. After resizing images, we paired them for training. Initial data contained 224 garden images and 224 sketches that was generated based on the garden images.

4. Case Study

For this case study, we used residential garden designs, e.g., front and backyards that were gathered from an extensive online repository on Arcbazar.com, an online crowdsourcing platform for design projects. The projects were all part of residential landscape design competitions and were dealing with real-world residential landscape design challenges. The projects are all located within the United States.

There are many different uses for the DBMS content used in the study. A learning process has been developed, which is akin to traditional design approaches in landscape architecture. Similar to the human design learning process, we applied supervised deep learning and identified traditional landscape components, such as water bodies, green zones as softscape zone, and non-green uses as hardscape zone, buildings, and driveways, in the dataset.

Figure 5. Training pair of images. Semantic segmentation (left) and ground truth (right) of training data.

The results were promising. The system was able to construe various landscape designs based on entirely new sketches.

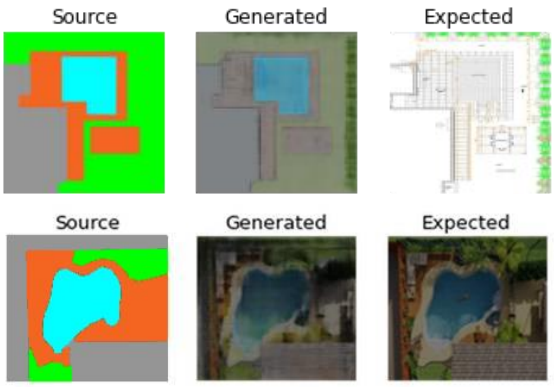

Figure 6. Training results of Pix2Pix model.

As can be seen from figure 6, the left side of the images are input images to the system and the right side are ground truth images -- after epoch 200, which is the final epoch of training. In the middle of the images, the generated results by the system according to input are given. The similarity between

expected images and generated images have shown that system can successfully generate landscape plans after training completed.

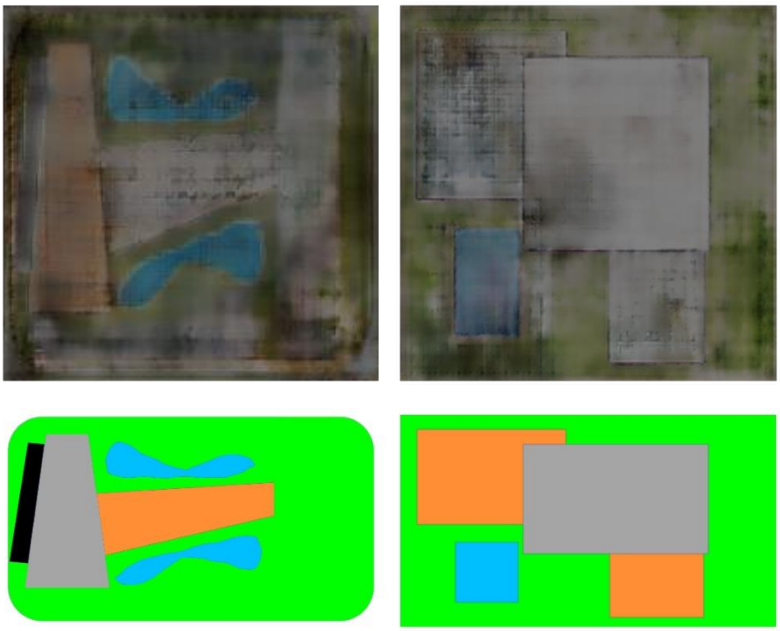

Figure 7. Generation of new images from new sketches.

The developed model with ReLU activation function is tested with new segmentation inputs as seen in figure 7. Images at the bottom of the figure 7 are input segmentation images and images at the top of the figure are newly generated landscape plans that are not included in training set.

After this first model, the pix2pix model was trained again with the mish activation function. Mish function is a novel self-regularized non-monotonic activation function, and it improves the performance of neural networks (Misra, 2019). We not only changed the activation function, but also skewd original images in order to increase the dataset. The final model was trained with 672 images.

4.1. RESULTS

Our latest results were improved and have higher resolution. The model is trained with 200 epochs to improve the output. The training results have shown that Mish function and the additional data improved the first model.

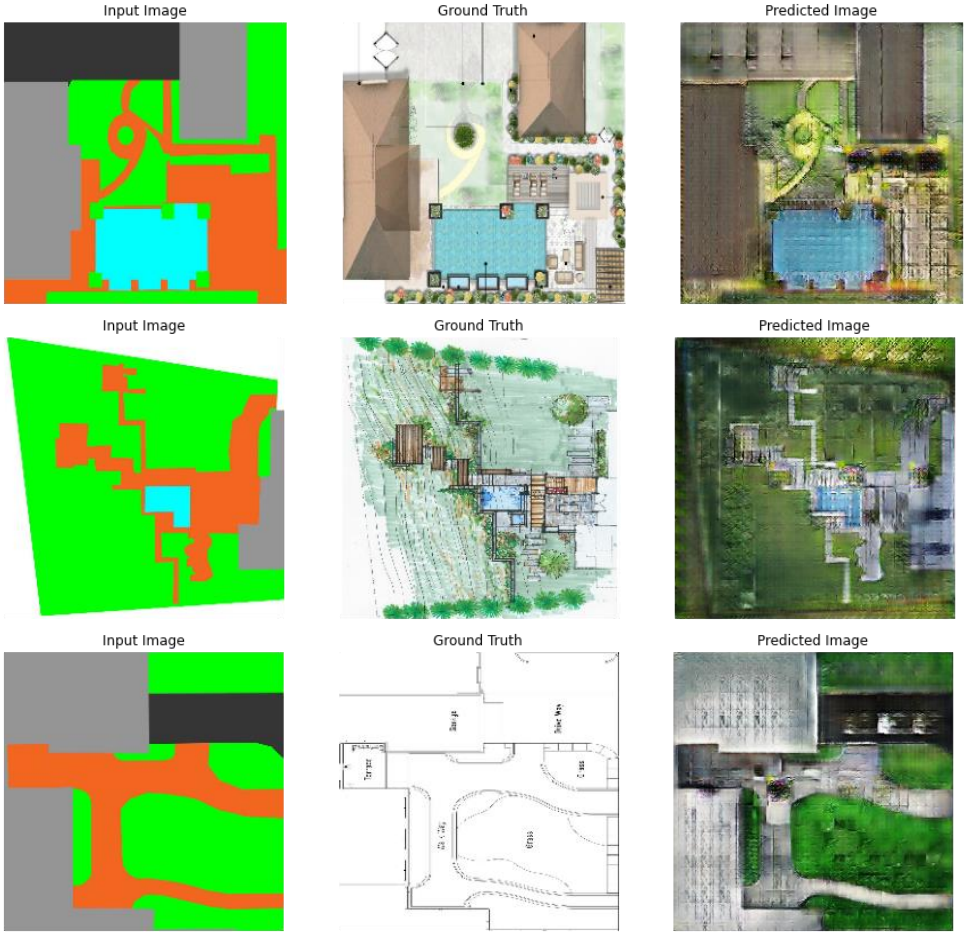

Figure 8. New training results.

Figure 8 illustrates some of the training results and one can notice the high accuracy in the predictions.

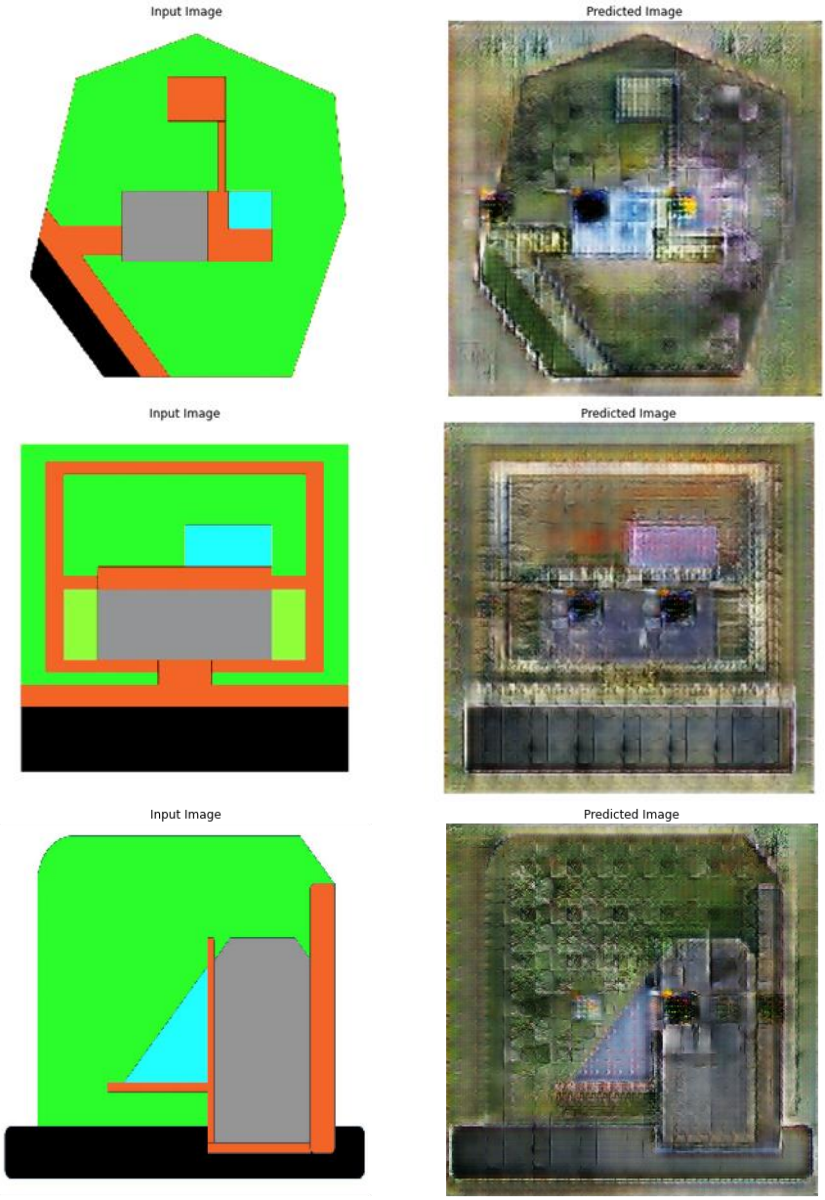

Figure 9. New generated results from new sketches.

The results demonstrated that our model is able to transform simple sketches into landscape plans. The design output can be obtained in seconds when a sketch is drawn.

4.2. LIMITATIONS

Firstly, the main limitation of this study is that the number of projects comprising our dataset is lower than it is usual to train such algorithms. Secondly, the image resolution of the output data is very low. We tried to overcome this limitation by increasing the image resolution from 256x256 to 512x512 pixels, adding a layer to the discriminator model and adding an addition to the decoder and encoder blocks.

However, our aim was to illustrate that machine learning can be used as a design tool in the field of landscape architecture, and one should consider our work as a work-in-progress, which we hope to develop in our future research. We will take steps to improve the results by experimenting with different generative models such as the diffusion model. We choose the pix2pix algorithm because of it was easy to implement (and thus can be easier adapted within the landscape discipline), and it proved successful in generating promising results.

5. Conclusion

Our paper explored the use of AI in landscape architecture, particularly smaller residential garden design. We examined the ability and potential of AI as a design tool. The study has two main parts, first, use the DBMS of an online design repository to obtain the dataset and its preparation to make the source data machine-readable. The second part of the study uses this dataset to train Pix2Pix, which generates unprecedented residential garden designs. Indeed, our model was able to generate front and backyard designs from a simple sketch.

We also encountered some limitations. The technical limitations of the dataset were about plans produced by different designers, for this reason, plans have different plan languages, textures, colors, and styles. This caused a problem, and the source data was not uniform. It took us some time to manually adjust some of the projects, and others we had to omit. The study offers a glimpse into using AI for landscape designs, however, in the future we think the data can be much larger and contain richer information.

The need for an AI-aided design tool that has emerged in recent years has become one of the researches and software development goals in the world of technology and design. This need, which is the driving motivation of the research, is important in terms of understanding the work of artificial intelligence within the scope of landscape architecture. Thanks to the understanding AI learning and production capabilities in the software to be developed, the results of the study are important for more comprehensive and

detailed research on this already new subject. This research deals with landscape architecture as the main focus, however we argue that this system can be also used in the planning process at other scales related to the built environment.

Past studies on AI to generate for example floor plans provided important background work for this research. It is important to notice that AI approaches to different design disciplines are similar. Artificial intelligence studies of different disciplines using similar datasets show that AI-aided design tools are suitable for multi-disciplinary use. The approach of different disciplines to machine learning with similar structures allows us to rethink the perception, learning, and production of human-made design by artificial intelligence and to seek answers to more comprehensive research questions by producing much more comprehensive data sets. Our approach presented in this study has shown that ML applications can become useful tools for designers. Being able to quickly produce landscape plans from simple sketches can save time in the design process, as well as enable different alternatives to be explored.

In this paper, we demonstrated whether artificial intelligence can make a contribution to the discipline of landscape architecture, landscape planning, and their design processes. Inspite of the limiting factors in the deep learning process, such as the difference in the graphic languages of various designers in the data set, the results are promising. In recent years, the European Union's turn to artificial intelligence-supported tools and research such as the Green Deal makes it essential for designers, experts, and researchers to develop this field of research. The abundance of publications investigating the relationship between design and AI, also show the importance and future popularity of this topic.

Furthermore, the scope of this research can be expanded from residential landscape design to larger scale ecological approaches in the future. One of the goals in our future research is to use artificial intelligence in city wide ecological designs. For example, one could train Ken Yeang's 'Ecodesign' approach, which puts ecological sustainability before human needs and makes 'Land use/Land Cover' (LU/LC) data the basic input of the design. One could gather an appropriate data set of Yeang’s work and use supervised artificial intelligence to automate designs that fit his criteria. Based on LU/LC data, which is real earth and ecosystem data in satellite images, we can develop ecologically designed AI structures that aim for ecological sustainability. Indeed, this paper presents the first steps toward this larger goal, and exploring the work of other tangent disciplines related to the field, will be the key to developing the AI-Aided Ecological Design tool.

In this paper, our main goal was to illustrate an AI approach for the conceptual design development of landscape architecture. Any design process consists of various subsequent phases, such as pre-design, conceptual design,

design development, construction drawings, project implementation and operations. Conceptual design is perhaps the most important first step in the design process, where all processes and scenarios are developed. We hope that this research sets a small milestone in the use of AI in landscape architecture and help landscape architects develop their conceptual design schemes in the future.

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GENERATING MASS HOUSING PLANS THROUGH GANS

A CASE IN TOKI, TURKEY

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Abstract. Nowadays, Machine Learning (ML) is frequently used in almost all disciplines having an intersection with technology. Recently, architects are using existing plan data sets in architecture through Deep Learning (DL) algorithms of big data to achieve generative and non-existent plan models by using ML. Especially, Generative Adversarial Neural Networks (GANs), one of the deep learning algorithms, have been in use in the creation of generative models for architectural studies. Within the scope of this paper, architectural drawings were generated by using GANs. This generation method allows for the training of spatial layout planning to networks and for the generation of plans that do not exist in the dataset. Architectural drawings of TOKI (Housing Development Administration of the Republic of Türkiye) mass housing projects were used as datasets. In line with studies already carried out, this study attempts to create a method for further processing of the research. In this study, the differences between the plan typologies generated with raster images and the reality relations in visual productions between graph-based plan layout productions were evaluated. In this context, 157 plan datasets were obtained by multiplying plans which were spatially correlated with the RGB settings of 21 plan typologies. As a result of this research, it has been determined that the spatial layout planning of the HouseGAN algorithm provides TOKİ's current plan typologies of generation together with bubble diagrams. HouseGAN was trained using its dataset and the outputs obtained were realistic background images.

Keywords: *Machine Learning, Generating Architectural Drawings, GANs*

ملخص. في الوقت الحاضر، يتم استخدام التعلم الآلي بشكل متكرر في جميع التخصصات تقريبًا التي لها تقاطع مع التكنولوجيا. في الآونة الأخيرة، يستخدم المعماريون مجموعات البيانات للمساقط الأفقية في مجال العمارة من خلال خوارزميات التعلم العميق للبيانات الضخمة لتحقيق نماذج لمخططات غير موجودة باستخدام التعلم الآلى. على وجه الخصوص، تم استخدام الشبكات العصبية التوليدية (GANs)، وهي إحدى خوارزميات التعلم العميق، في إنشاء نماذج توليدية للدراسات المعمارية. في نطاق هذه الورقة، تم إنشاء الرسومات المعمارية باستخدام شبكات GAN. تسمح طريقة التوليد هذه بالتدريب على

التخطيط الفراغى المكاني للشبكات ولإنشاء مساقط غير موجودة في مجموعة البيانات. تم استخدام الرسومات المعمارية لمشاريع الإسكان الجماعي TOKI (إدارة تطوير الإسكان في جمهورية تركيا) كمصدر لمجموعات البيانات. تمشيا مع الدراسات التي أجريت بالفعل، تحاول هذه الدراسة إنشاء طريقة لمزيد من معالجة البحث. في هذه الدراسة، تم تقييم الفروق بين أنماط المساقط الأفقية التي تم إنشاؤها باستخدام الصور النقطية وعلاقات الواقع في الإنتاج المرئي بين إنتاجات التخطيط القائمة على الرسم البياني. في هذا السياق، تم الحصول على ١٥٧ مجموعة بيانات للمساقط عن طريق مضاعفة المساقط التي ارتبطت مكانيًا بإعدادات RGB لـ٢١ نموذجًا للمسقط. نتيجة لهذا البحث، تم تحديد أن تخطيط المساقط المكاني لخوارزمية HouseGAN يوفر نماذج مساقط TOKİ الحالية للتوليد جنبًا إلى جنب مع المخططات الفقاعية. تم تدريب HouseGAN باستخدام مجموعة البيانات الخاصة به وكانت المخرجات التي تم الحصول عليها عبارة عن صور خلفية واقعية.

الكلمات المفتاحية: *التعلم الآلى، توليد رسومات معمارية، شبكات عصبية توليدية.*

1. Introduction

Plan layout generation methods have gained a different dimension thanks to machine learning. In addition to computational design techniques, by utilizing artificial intelligence algorithms, existing plans are used as a data set, processed, and tested with different algorithms for regeneration (Özerol and Selçuk, 2022). Some researchers trying to create an interface for users, also trying to use different algorithms and turn to the question of which of the plan layout generation methods provides clearer and more accurate generation (Chaillou, 2019; Nauata, 2020).

Plan generation methods are used together with algorithms developed according to the data sets used. Algorithms such as Pix2Pix (cGAN) are used to prepare the semantic segmentation and masking of a data set consisting of raster images. However, it is possible to see that in DCGAN algorithms used with the simplest architecture of GAN networks, data sets are used for training the network without pre-processing. These generation methods can give different results depending on the amount of the data set and its correct processing.

Architectural plan generation techniques have been developed from the past to the present by adding Graph Theory (March *et al.*, 2020). The mathematical basis of the algorithms used, turning them into rules and constraints in creating the plan layout, has been an essential point for processing the generation into computer-based information systems (Gross,1994). As a result, the reason why all the works are done is associated with Graph Layout Presentation plays a significant role in helping them to determine the proximity relations between the spaces and whether there are transitions between each other and to position them according to the north, south, east, and west orientations. While the room values are

considered 'nodes,' the distance relations between them or the 'yes' or 'no' relations between them are either determined by the matrix values, or the values are determined according to the side lengths and accessibility of the rooms. Positioning can be achieved by assigning these values to the 'edge' edges that provide the 'nodes' relations (March 1971; Gross, 1995).
When the previous studies we have carried out are evaluated, the realism of the results obtained when GANs algorithms trained with datasets converted from raster images to vector images are tested and the usability of the results by architects should be questioned and other GAN algorithms should be trained and compared in this context. In this process of the study, plan layout studies are generated with raster image data sets (DCGAN, Pix2Pix) and graph-based plan layout models containing GNN algorithms such as HouseGAN trained within the scope of the study. Testing and generation of different algorithms in these two different generation models resulted in the generation of a realistic and usable plan layout in plan generations.

2. Current Research Studies

A lot of work has been done at the intersection of architecture and machine learning, but recently GANs have emerged as the most used algorithm in plan generation methods or 3D model generation methods (Özerol and Selçuk, 2022). In addition to these studies, different algorithms (Wu *et al.*, 2019; Hu *et al.*, 2020). have been started to be developed in the preparation of plan layouts as data sets.

2.1. PLAN LAYOUTS GENERATION BY PROCESSING RASTER IMAGES

Liu *et al.* (2017) in their study (raster) first created the junctions from the intersections of the walls. The locations of doors and windows are determined. Afterward, post-processing, which creates a vector format, was obtained with the CNN algorithm. The important part of this process is the processing of the data from a raster image to a vector format.
Zeng *et al.* (2019) used the R2V dataset and the R3V dataset in their study. In this study, it is observed that an input consisting of colored, black, and white drawings is segmented according to the size and location of the rooms with the estimation of the network. This segmentation process has been tested and compared on more than one algorithm, including the algorithm in the previous study. Thanks to the open-source code in this study, the segmentation of our dataset was tried over Google Colab and the similarities were compared.

These stages carry out the plan layout generation, segmentation, and estimation processes tried with the CNN algorithm. However, many plan layout processes that provide a generation with GANs networks go through these processes, especially if they are carried out with data sets obtained from raster images. Because by determining the (boundary, edge) parts of the data sets, the proximity of the rooms with each other and their size relations enable the network to establish the plan layout hierarchically by detecting neighbourhood relations.

Chaillou, (2019, 2020) provided the segmentation of plan layouts over raster images by using the NVIDIA Pix2pix algorithm in their work, and both provided the generation of plan layouts and generated them together with parcels on an urban scale. However, in this study, like the training model of other raster images, the networks are trained on a pixel basis. In this way, different combinations in both the walls and the interior are regenerated.

TABLE 1. Recent Studies on Raster Image Generation

Authors	**Dataset**	**Algorithm**
Chaillou, 2019	LIFULL HOMES	ArchiGAN
Zeng et. al. (2019)	R2V	DeepLabV3+ PSPNet
Liu et. al (2017)	LIFULL HOMES	CNN

While examining the data sets, all the researchers try semantic segmentation methods if they are going to proceed over raster images. Although most of these methods are processed on ready-made data sets, different results can be developed in segmentation processes depending on the algorithm. The semantic segmentation methods obtained so far are listed as follows.

The pooling process is created by reducing the resolution pixels of an image to a smaller capacity (Akhtar & Ragavendran, 2020). In this different mapping process, the pooling phase may vary according to the maximum and average values. *U-net;* Its architecture is built for the segmentation of biomedical studies. However, it has been determined that the resolution of the result outputs is better than the old methods (Ronneberger, Fischer, & Brox, 2015). *Resnet;* Thanks to the multi-layer convolutional networks realized in its architecture, partitions such as U-net can be obtained (He, Zhang, Ren, & Sun, 2016). In recent studies, researchers have tried more than one c-GAN algorithm with their own data sets and compared them according to their production values, durations and Fréchet inception distance (FID) values (Rodrigues & Duarte 2022).

2.2. CURRENT STUDIES OF MACHINE LEARNING ALGORITHMS GENERATED USING GRAPH LAYOUT GENERATION OF PLANS

Graph Theory is a method used by mathematicians, physicists, chemists, electricians, computer engineers, architects, and planners for a very long time. One of the critical factors in using this method in all these scientific and professional groups is developing a more abstract linear expression method with systems, particles, and spaces that can establish close (binary) relations. According to the graph theory explained by the critical mathematical theorist Harary (1969), the matrix system also provided significant benefits in detecting and determining the variability of the states of the points and the edges connecting these points. While the relations between nodes can be directly or indirectly related, the closeness of these relations can be expressed with the adjacency matrix system, making it easier to change the length and weight of the connection edges (Harary, 1969). Architects first realize their way of thinking with various diagrams such as design sketches and bubble diagrams. Grason (1971) developed a graphical expression method according to the program infrastructures of spatial planning in the architectural design method. This expression method places spatial layout paradigms in the north, south, east, and west planes. A graphics-based presentation technique is developed that is positioned together with spatial orientations. March (1971) made his analysis based on the graph theory of the Swiss mathematician Euler[1] (1707-1782). March *et al.* (1971) analysed the transfer of the transition state and proximity relations between spaces. He discussed these transitions and neighbourhood relations together with the matrix system and the graphic plan layout expression method. It has been observed that the points placed in the rooms form a network pattern in line with the spatial relations, distance, and proximity relations. Considering the rooms as a zone, these proximity states can be connected to stripes according to the links of their dimensions and openings with each other.

Baybars (1982) developed a different perspective on the connections between plan and graph theory. The contribution of functions such as inner courtyard and circulation to the spatial, graphic plan layout change has been shown as a difference in the graph mapping technique of the spaces in the discussed plans through neighbourhood relations. This change has been possible by establishing a connection between the rooms through the relationship between 'there' and 'no.'

[1] In particular, the theorist expressed the Köningborg bridge problem graphically by creating edges between points and places that are connected to each other. Strings are not added in the graphical expression between areas that are not directly related to each other; that is, there are no bridges (Biggs, Lloyd, & Wilson, 1986).

Liao *et al.* (2015) developed software called VEGGIE (a Visual Environment of Graph Grammar Induction Engineering) to consider the semantic relations of shape grammars and spaces together in their study. They tried to create spatial, graphic grammar traditionally (Liao, de Vries, Kong & Zhang, 2015). Along with these semantic approaches, settlement studies on topography have also been developed. Ślusarczyk (2018) approached the graph presentation layout system from a hierarchical point of view and created the "hierarchical layout hypergraphs (HL-graphs)" method with the software he developed for local architectural plan layout. After these studies, many researchers deemed RFP (Rectangular Floor Plan). layout formations from the block plan layout system are more appropriate for creating a productive plan model. Progress was made in this regard. Shekhawat (2018) continued to work on RFP. They tried to combine various theorems with RFP, combined them with graph layout systems, and followed a comparative method.

It has been determined that Graph Presentation of Plan Layout methods provide benefits both in the use of the network and in the realistic plan generation systems produced for the users, in the process of producing the plans (Nauata, Chang, Cheng, Mori, & Furukawa, 2020; Shekhawat, Upasani, Bisht, & Jain, 2020) studies with the GAN networks. It has been evaluated that both the realistic plan generation systems produced for the users are beneficial. However, the diversity of recent studies proves that Graph Layout Generation of Plans algorithms is more diversified. Recently, the most used algorithms of machine learning in plan generation techniques have been GANs and CNN algorithms, respectively (Özerol & Arslan Selçuk, 2022). These algorithms have been tried to be used in the most accurate way to shape the spatial layout planning process.

In Table 2, the data sets used in recent studies and the algorithms they used are included. It is understood that, while developing these algorithms, researchers tried more than one algorithm and discovered their own algorithms. Shekhawat *et al.* (2020) dealt with this situation by associating the RFP layout plan generation methods with the graph layout system with the minimum and maximum values that the rooms can take, giving quantitative weight to the lines between the points. Hu *et al.*, (2020) used the RPLAN dataset while developing the Graph2Plan algorithm in their study. Afterward, they created the user interface with the graph plan layout combination of this data set, which they processed by combining them with the GNN algorithm in Phycharm.

TABLE 2. Recent Studies on Graph Based Plan Layout Generation

Authors	**Dataset**	**Algorithm**
Nauata *et al.*, (2020)	LIFULL HOMES	HouseGAN
Hu *et al.*, (2020)	RPLAN	Graph2Plan
Shekhawat *et al.* (2020)	-	GPLAN

Nauata *et al.* (2020) used the LIFULL HOMES DATASET in the HouseGAN study. First, boundary detections were created on the floor plan images, which are raster images obtained here, and then Conv-MPN and GCN algorithms were tried with Graph Layout Based generation and correct models were tried to be revealed by comparing these algorithms.
Pixels gain importance as both masking and segmentation are done in raster image data sets. Recently, separating these images with clearer lines has enabled the results to obtain more realistic and clearer images. Therefore, boundary detection parts also gain importance in new algorithms developed for segmentation. When this segmentation process is supported with the Graph neural network in plan layout generations, the neighborhood relations of the room volumes with each other and their alignment to each other's borders are provided more clearly.

3. Methodology

Considering literature review we concluded that the generation methods of the Architectural Plan Layouts, which are with the raster image-based data set (Uzun et. al,2020), and the methods that change according to their pre-processing datasets status. The generation methods of the Architectural Plan Layouts, in which dual working algorithms (such as GNN and GPN) are used with the support of the graph layout presentation method (Nauata et. al,2020). It is important that these GANs algorithms, which are one of the fast generation methods, produce results that are realistic and close to the given input values (Figure 3.1).

Figure 1. Methodology

The creation and use of the dataset during the final implementation depends on whether the network is working with the Unsupervised Learning method, or the Supervised method developed by Lee *et al.*, (2019) (Figure 3.2). While DCGAN, one of the methods used, works with the unsupervised learning method, HouseGAN works with the supervised learning method.

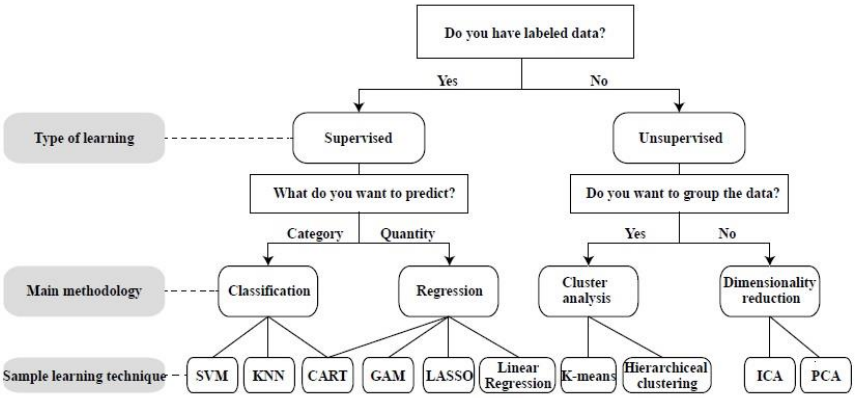


Figure 2. The Elements of Statistical Learning (Lee et al., 2019)

4. Implementations with GANs

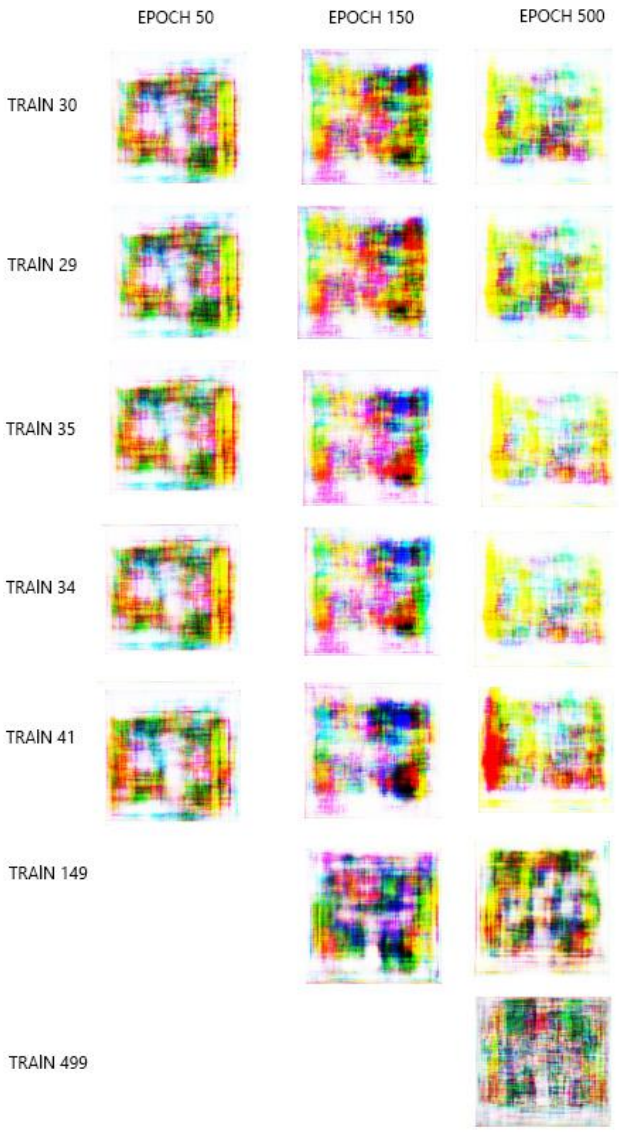
DCGAN

This algorithm is provided by establishing a TensorFlow link (URL-1) Relu activation function is used and the Convolutional 2D padding method is used (URL-1). These operations have two modules that distinguish GAN algorithms from other deep neural networks, discriminator, and generator. The generator replicates the dataset after training the network, while the discriminator detects the difference in the replicated dataset. These detection values are important. The training cycle of this basic algorithm was formulated by Goodfellow in 2014(1).

"min G max D V (D, G) = Ex∼pdata(x) [log D(x)] + Ez∼pz(z) [log(1 − D(G(z)))]
(Goodfellow et al., 2014)" *(1)*

TOKİ Plan typologies have been prepared by giving different colors to each room by using the Numpy Array Anaconda-Jupyter Notebook. Then, this smallest dataset, consisting of 21 typologies, was replicated to 157 plan datasets by rotating and mirroring with the data augmentation method. These

generated data sets were tested for high epoch values by retraining the network (Figure 4.1).
However, results up to an epoch value of 500 could not make the images generated can detect real or fake. Because the raster image images of the generated plan layout images were blurred noise images.



Epoch 500, gen loss=0.432994544506073,disc loss=2.256586790084839, time=0.019072771072387695

Figure 3. Images obtained in line with the epoch cycles tried with the augmented data set

HOUSEGAN

In light of the data determined later and in parallel with a recent study suitable for spatial settlement planning, the data and open-source licensed codes were used with the HouseGAN algorithm. The code, obtained via Github open-source code sharing, was cloned, and pulled from Google Colab. Major problems were encountered in the Windows operating system and Phyton coding platforms such as Pycharm and Jupyter. The dataset was then changed, and the initial dataset was tried, but positive results could not be obtained. Using 117,587 plan datasets, this algorithm worked in conjunction with graphical diagrams. In addition to the generated plans by the authors, simultaneous graphical charts were generated (Figure 4.2). This pilot study provides an essential method for the further process of the study. The graphical user interface makes it possible to create a plan generation interface that can give easy generation to users or architects. This algorithm was implemented via Google Colab using open-source code shared by Nauata et. al., (2020). Its own dataset, Lifefull Home, defined by the code, is used.

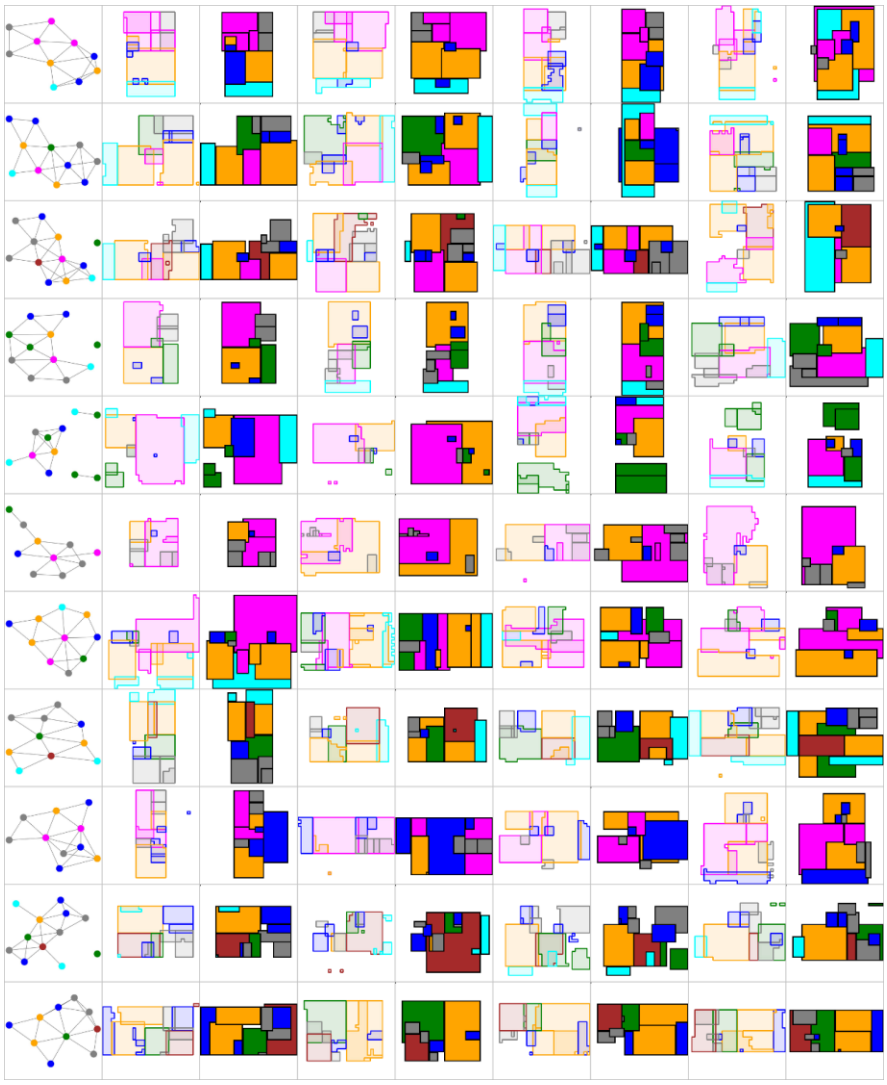


Figure 4. HouseGAN with LIFULL HOMES Datasets, images generated by authors

5. Conclusions

In the first study, the plans created with the DCGAN algorithm were created with our own data set (TOKI plan typologies). However, in raster image-based generation, the resolution quality and numbers of datasets images gain importance as well as the algorithms used. The HouseGAN algorithm was used with its own dataset, the LIFEFULL dataset. Considering these methods carried out within the scope of this paper, despite the multiplication

of TOKI plan data sets, raster image data sets with colored rooms used for training the DCGAN network could not provide generation close to the given input values of the network. The reason for this is thought to be due to the insufficient number of data sets and the incomplete handling of the data set (supervised learning) in the working logic of the algorithm (supervised learning).

Secondly, the HouseGAN algorithm has been tried by using its LIFULL dataset. In addition to Conv-MPN and GCN and CNN algorithms, which are used in addition to the working process of the supervised learning algorithm in the working logic of the network, different Architectural Plan Layouts generated by the method in which they create their own GAN algorithms by using them together can be given with Graph-Based Plan Layouts.

It is concluded that the generated plans can be used more realistically and, in a way, that architects can use them systematically and more functionally. In the further process of the study, comparisons can be made with our own data set according to FID values by using the techniques and pix2pix algorithms. In addition, Graph based plan layout generation algorithms can also be tested within themselves and all of these values can be compared.

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[URL-1] https://www.tensorflow.org/tutorials/generative/dcgan

GESTURAL DESIGN

Hand Tracking for Digital Drawing

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Abstract. Computational design is increasingly interested in the active feedback between the user/designer and the digital space. Often, our initial instinct as designers comes from a gesture, a movement of the hands that gets translated into sketches and 3D models via the tools available to us. While the physical realm allows for muscle memory, tactile feedback, and creative output via movement, digital design often negates the body of the designer as it sequesters us into a screen-mouse-hand relationship. Moreover, current CAD software tools often reinforce this standardization, further limiting the potential of physical bodily gestures as a vehicle for architectural form-making. Seeking new opportunities for a gestural interface, this research explores how Machine Learning and parametric design tools can be used to translate active movements and gestural actions into rich and complex digital models without the need of specialized equipment. In this paper, we present an open-source and economically accessible methodology for designers to translate hand movements into the digital world, implementing the MediaPipe Hands tracking library. In developing this workflow, this research explores opportunities to create more direct, vital links between expressive gesture and architectural form, with an emphasis on creating platforms that are accessible not only to design experts, but also the broader public.

Keywords: *Machine Learning, Hand-Tracking, Gestural Drawing, 3D Printing, Agent-Based Modelling.*

ملخص. يهتم التصميم الحوسبى بشكل متزايد بالتغذية المرتجعة النشطة بين المستخدم أو المصمم والفراغ الرقمي. غالبًا ما تأتي غريزتنا الأولية كمصممين من خلال لفتة، وهي حركة للأيدي تترجم إلى رسومات ونماذج ثلاثية الأبعاد عبر الأدوات المتاحة لنا. بينما يسمح الواقع المادى بذاكرة العضلات وردود الفعل اللمسية والإخراج الإبداعي عبر

الحركة، فإن التصميم الرقمي غالبًا ما ينفي جسد المصمم لأنه يعزلنا في علاقة بين الشاشة والماوس. علاوة على ذلك، فإنه غالبًا ما تعزز أدوات برامج CAD الحالية هذا التوحيد القياسي، مما يحد من إمكانات الإيماءات الجسدية كأداة لصنع النماذج المعمارية. فى إطار البحث عن فرص جديدة لواجهة إيمائية، يستكشف هذا البحث كيف يمكن استخدام التعلم الآلي وأدوات التصميم البارامترى لترجمة الحركات النشطة والإجراءات الإيمائية إلى نماذج رقمية غنية ومعقدة دون الحاجة إلى معدات متخصصة. نقدم في هذا البحث منهجية مفتوحة المصدر ويمكن الوصول إليها اقتصاديًا للمصممين لترجمة حركات اليد إلى العالم الرقمي، عن طريق المكتبة التتبعية لـMediaPipe Hands . وفي إطار تطوير سير العمل هذا، يستكشف هذا البحث فرصًا لإنشاء روابط حيوية ومباشرة أكثر بين الإيماءة التعبيرية والشكل المعماري، مع التركيز على إنشاء منصات يمكن الوصول إليها ليس فقط لخبراء التصميم ولكن أيضًا للجمهور الأوسع.

الكلمات المفتاحية: *التعلم الآلى، تقنية تتبع الأيدى، الرسم عن طريق اللفتة، الطباعة ثلاثية الأبعاد، النمذجة المبنية على الوكيل.*

1. Introduction

From the inception of architectural drawing, architects have relied on tools to generate exacting drawings that are later used as a communication tool for construction. The craft of architectural drawing grew out of the drafter's capabilities to translate intuitive physical gestures into coherent and legible inscriptions. The "human error" or "makers marks" inherent in this project provides a method of individualization for the final product (Jenny et al., 2018). The introduction of computer aided drafting and digital design has abstracted this process and progressively introduced a distance between the hand and the surface of representation. (Sunshine, 2021). While there have been extensive developments of a plethora of algorithmic approaches aimed at introducing variation or indeterminacy in the drawing process, for the most part, these do not originate in the hand or the gestural expression of the human body.

The process of translating gesture into design is often frustrating, especially as we consider the multi-sensory essence of gestures and the current limitations of the tools for interfacing with digital design platforms. While digital design initially developed as an analogue to hand-drawing, in recent decades, it has been able to explore new realms of digital expression. However, digital tools exist within the limited range of human-computer control devices, such as the mouse and keyboard, which tend to reinforce the visual regime of representation and design thinking, at the exclusion of more tactile engagement with form (Oliveira, Nedel and Maciel 2018). This Human-computer interaction, thus, becomes a critical element of creative output (Yasen and Jusoh, 2019). This research seeks to explore dynamic methods of interaction with virtual environments for the purpose of architectural design, improving upon the current tools of digital design by leveraging the power of Machine Learning and data organization in Grasshopper for Rhino.

The development of human-computer interaction via hand gestures rather than keyboards and mice has allowed for a more fluid and flexible interaction with 3D virtual environments, laying out the foundation for Virtual Reality Aided Design (VRAD). While in VRAD hand gestures continue to be understood as controlling gestures, in architectural design gestures are often communicative, borne out of an initial instinct to design with our hands, a movement that is later translated into sketches and 3D models via the tools available to us. Virtual Reality (VR) is a human-computer interface in which the computer creates an immersive environment that is controlled by the behaviour of the user (Abdelhameed, 2012). The most common system for VR is that of Head Mounted Displays (HMDs), where the user wears a set of goggles that provide deep immersion and a set of hand-held controllers to interact with the digital space (Balzerkiewitz & Stechert, 2020). VRAD has a great deal of potential for a more direct connection between bodily gestures and digital form making and presents an important avenue for future exploration in this area. However, in terms of the current and near-term future technology, VRAD has a few notable limitations. First, it remains a fairly computationally intensive and expensive technology, and thus accessible to a limited number of people; second, the ability of VR interfaces to capture fine motor gestures in the fingers, hands and wrists is somewhat limited in typical handheld controllers; and third, entry into "virtual space" inherently involves a kind of disembodiment that detached the user from concrete physical space, materiality, and experience.

In the search of a less mediated gestural interface, this research engaged the development of hand-gesture recognition in the field of computer vision. The evolution of user interaction is a well explored topic in computer vision, where alternatives to keyboards and mice in 3D virtual environments have been sought in areas such as Human Computer Intelligent Interaction and Perceptual User Interfaces (Mohamed, Mustafa, and Jomhari 2021; Wu and Huang, 1999b). Visual-based gesture recognition techniques first endeavoured to understand gestures, classifying them into conversational, controlling, manipulative, and communicative gestures (Wu & Huang, 1999a). For the purposes of computer-vision, hand gestures are used to activate a virtual environment thus falling into the classification of controlling gestures. As such, hand motions are translated into actions within the digital space.

This field has developed a number of algorithmic approaches to analyse hand positions, segmenting hands into features such as fingertips, finger directions and hand contours (Wu & Huang, 1999b). These segmentations provided a basis for commonly found landmarks, such as fingertips, knuckles, and particular areas in the palm. However, it was recognized that a temporal dimension, one that could capture the stroke and movement of a gesture, was needed. An approach to capturing the temporal dimension is by generating a wireframe model of a hand based on landmarks. The wireframe model, connecting the landmarks via primitive components such as spheres

and cylinders, becomes a digital proxy that is then controlled by the user via gestural commands. This approach, however, is computationally expensive as it relies on a redundant method of landmark finding (to first generate the digital proxy) and landmark controlling (using landmark recognition to activate the digital proxy) (Jaimes & Sebe, 2005).

An emerging alternate approach relies on Machine Learning. Machine Learning is a probabilistic approach for pattern finding via the training of a neural network. The neural network is trained using a large and as varied as possible dataset. Once the neural network is trained, it can accurately approximate the patterns it has learned. For hand-tracking, a neural network would be trained on static hand positions with their related marked landmarks. Once trained, the model can be used to recognize landmarks in real time using very little computational power. By using Machine Learning, the potential of a light-weight real-time feedback without the need of external tools is possible. (Cheok, Omar, Jaward 2017; Pavlovic et al., 1997).

In search of a more flexible, accessible, and computationally light approach this project opted for an open-sourced, thus free, Machine Learning model. The MediaPipe Hands library, developed in 2020 by Google Research, is a real-time hand tracking solution that predicts a hand skeleton of a human from a single RGB camera input (Zhang et al., 2020). The hand tracking consists of two models, a palm detector, and a hand landmark. The palm detector is enacted on the input image from the RGB camera, where the palm is segmented and cropped from the background. The palm is then transformed into a bounding box with a direction, which reduces the area of probability of where to find the fingers. The palm detector is only enacted at the start of the model, or if the palm is lost in the subsequent image. This means that the palm detector model is only used as needed, lowering the required computational power. The hand landmark model performs precise landmark localization of 21-point coordinates in a 2.5D space (see figure 1), which is done through a regression neural network. The hand landmark model provides an x, y, and relative depth, as well as the possibility to discern left from right. The goal of the MediaPipe Hands library is to become so lean that it can achieve hand-gesture recognition on mobile devices in the future (Zhang et al., 2020). With such a computationally light model that requires nothing more than an RGB camera, and that can capture the movement of the knuckles of each finger, this project began to explore the translation of active movements and gestural actions into rich and complex digital models without the need for specialized equipment.

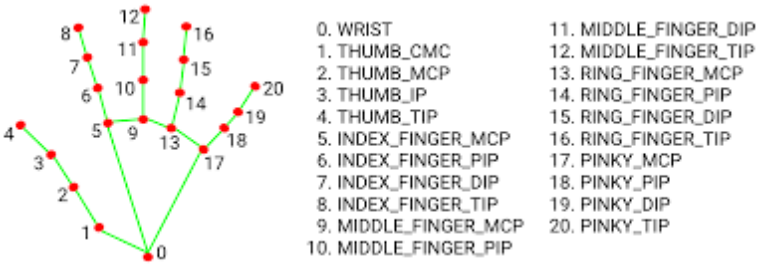

Figure 1. Hand landmarks for MediaPipe Hands Library.

Introducing the MediaPipe Hands library frees the user from the limits of keyboard and mouse interface and allows for an enriched exploration of the virtual environment. In this research, we tested a workflow for translating from physical hand gestures to a digital point-cloud model using the MediaPipe Hands library and a computer webcam. We then developed one possible process for translation that point-cloud into a robust geometry, and finally, to translate that resulting digital geometry into a physical form via 3D printing. By closing the circle from physical gesture to digital form to physical form, this research sought to initiate a feedback loop that could allow for an iterative exploration of the design possibilities in the intersections of physical gesture and digital geometry. Ultimately, this research sought new ways to introduce “makers mark” and gestural expressiveness back into the digital design process.

2. Methodology

2.1. FROM PHYSICAL TO DIGITAL: MAPPING GESTURE COORDINATES

Making use of the MediaPipe Hands library, a python script was developed to track five landmarks, one for each fingertip. The MediaPipe Hands utilizes the ML Pipeline to detect and track hand motion, identifying the palm, cropping the image, and identifying hand and finger landmarks on each image frame of the video.

The Hands model operates in two modes - detection and tracking. Detection is more computational intensive and relies more on image detection to formulate the hand model; tracking relies on prediction based on previous states of the model. If the tracking confidence of a model falls below a certain threshold, then the model will switch to detection mode (MediaPipe Hands). In our experience, this switch occurred during rapid changes in hand position or movement during a gesture, and would result in a significant decrease in the frame rate at which the model ran. In order to create a consistent sampling of the hand landmarks through the gesture, our implementation of the Hands model recorded the coordinates of the tracked landmarks at a regular time interval. The resulting series of sets of

coordinates (one set for each tracked finger landmark, one series for each recorded frame) were then exported into a CSV file, whose length is a changeable variable and can be adjusted according to the desired outcome. For the purposes of this paper, the length of the CSV file varied between 80 and 200 captured frames. This meant that we were able to collect five landmarks, each with an x, y, and relative z, for each frame, depending on the length of the gesture.

The python script, when activated, uses an RGB camera, for example a laptop webcam, and begins capturing landmarks as soon as a palm is detected. Upon this detection, the user can move their hands in space, expressing a particular gesture or design motion, which is then captured as coordinates in space. The series of coordinates begins to capture the stroke of gesture over time, rather than a static hand motion. Once the recording was complete, the coordinates were imported into Rhinoceros 3D and converted into point geometry with the scaling factors applied to create an accurate digital map of landmark locations over the time of the recorded gesture.

To convert the results of the model recording from a pixel based unit system to one that corresponded to the spatial measurements of the hand gesture, a series of validation recordings were made before the gesture recordings. These validation recordings consisted of simple hand movements of known distances and directions, which were then used to calculate scaling factors for x- (right to left), y- (up and down), and z- (distance to camera) coordinates. These scaling factors were then applied to the coordinates of each recorded point, to ensure that the digital model accurately represented the physical space of the gesture. The z-coordinate values, in particular, deviated from the x- and y- coordinate values because the Hands model used the image depth map to calculate these values, and therefore required a much larger scaling value.

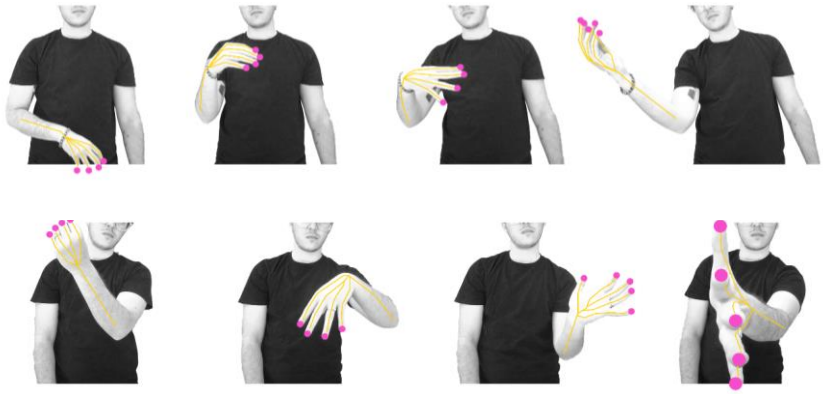

Figure 2. Collecting coordinates of hand landmarks with MediaPipe Hands.

2.2. TRANSFORMING THE POINTS INTO SURFACES

With the points in space inside the Grasshopper environment, the user/designer can make decisions based on their desired outcome. There are several ways these points in space could be translated into volumetric geometry (lofting, isosurfacing, etc.). In this research we focused on the motion of hands in space and time; therefore, the decision was to make lofted surfaces that follow the order in which the landmarks were captured. Each fingertip motion was traced by a line and after these lines were lofted with each other. The results are complex and organic surfaces that capture motion, not hands. At times, these surfaces overlap creating knotted looking meshes, and other times the surfaces are elegant ribbons in the virtual 3D space. The lofted surfaces have an ethereal lightness and can be argued to capture the emotive quality of the gesture in some form (see figure 3).
The hand gestures tried for this project ranged from fast motions and complex pirouettes to simple and slow directional movements. However, the steps followed to generate lofted surfaces had yet to translate the intensity of the hand gestures. The resulting geometry represents an index of the gestures intensity, variation, finger movement, etc.

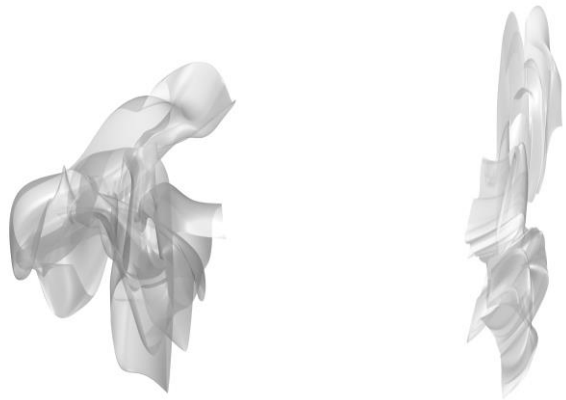

Figure 3. Lofted surfaces in Ghosted view to showcase overlapping.

2.3. IMPLEMENTATION OF AGENTS ON SURFACE

In order to further explore the geometric potential of these meshes, and to reconstitute the sense of movement in the original gesture, a system of agent-based modeling was implemented. Agents are components that provide multi-object behaviours, thus creating dynamic interactions. Luis Quinones developed Culebra.NET, a grasshopper plug-in developed in C#, where the user can enact agents upon a surface and establish behaviours such as flocking, wandering, mesh crawling, etc. The user can specify how many generations of agents are to be summoned, at which locations, if they are to

have one or multiple generations, and how they will behave. Although there are many agent-based plug-ins for Grasshopper, Culebra was chosen because it offers a "graphics-only" exploration of agent behaviours before transforming them into geometries. This graphics-based approach makes it so computers with limited GPU power can perform complex behavioural iterations in a short period of time. For this research, the number of agents was relative to the speed of movement based on the distance between points at each framerate. If the distance values were constant between points, then a single point for agent spawning was generated and a simple mesh crawl behaviour selected. However, if the distance became greater, then a second point of agent spawning was generated this time with a flocking behaviour, following the first generation of agents as they proceeded with their mesh crawl (see figure 4). In this way, the agents responded both to the surface geometry and the velocity of the original gesture at any given point in its duration. Though clearly abstract, this was intended to enhance the connection between the original gesture and the final geometry.

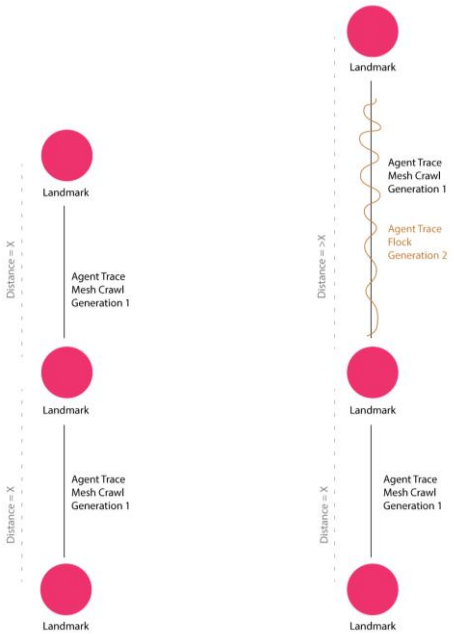

Figure 4. Agent spawning behavior

The implementation of agents resulted in rich and complex models, where the tracing of motion through space became enhanced by the beauty of the models. The varied densities and spawn locations of the agents help reconstitute the original hand gesture through their interactions with the lofted geometry. The agents, thus, highlight the motion of the fingertips

creating not just one line per fingertip landmark but rather multiplying the impact of the hand motion.

2.4. FROM DIGITAL TO PHYSICAL: 3D PRINTING

As a method to close the loop between physical gesture to physical form, the resulting digital gestural models were prototyped through 3D printing. To do this, the traces generated by the movement of the agents had to be optimized and interconnected so they could support one another. While the agent traces in the digital space could exist without concern for gravity or material thicknesses, once we began 3D printing the traces had to be converted into pipes, and these pipes had to connect to one another so that the model could self-sustain. Once again, the use of distances was selected as a factor for decision making. By subdividing the agent traces into evenly spaced segments, we could then measure the distance between these newly identified segment points. If the segment points were close enough to one another, such that the pipes intersected, then no additional geometry was added. If the points were beyond this intersection threshold (i.e. the diameter of the pipe), then a line was generated connecting the two segment points. This line was then piped as well, to create a supporting "strut" between the various agent pathways. The threshold for when to place a connecting line was also based on the scale of the model, where the physical characteristics of the 3D printing material had to be taken into consideration. These small connectors allowed us to generate digital models that would be self-supporting. Three small scale prototypes were printed, showing that generally the connecting lines were only needed when the hand gesture was slower, resulting in fewer agents and therefore fewer interconnecting pipes.

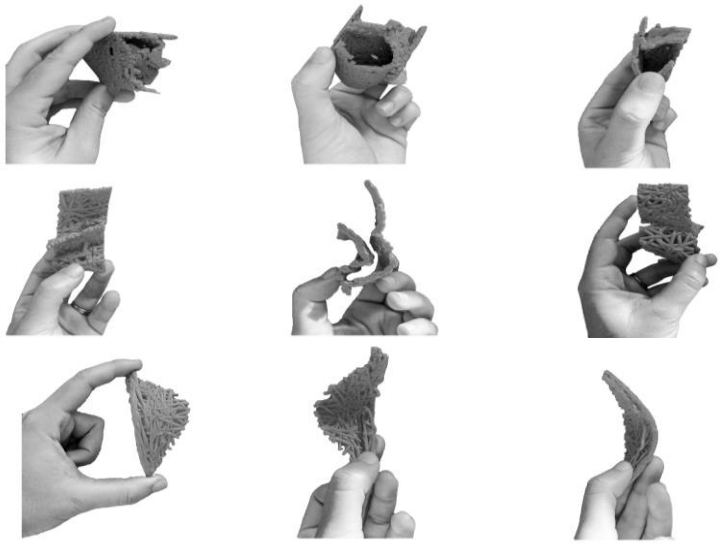

Figure 5. Sample 3D Prints.

3. Results

The result of this research is the development of a workflow that translates hand gestures into digital geometry and then back to physical form through 3D printing. This research explored the potential for the use of Machine Learning platforms to record and create robust digital models of hand gestures using a laptop and webcam only. This presents a new avenue for reintroducing the intricacies, individuation, intimacy, and expressiveness of hand gestures into the digital modeling process and explores a workflow to close the loop in the translation from physical gesture to digital model to physical form.

In terms of the translation from physical gesture to a digital point array, the research further validated the capacity of the ML Pipeline to accurately capture a variety of gestures without requiring intensive or specialized computer hardware (GPU, VR headsets, etc.). The scaling validation process implemented in this workflow ensured that the 3d model was accurately scaled to physical space. The decision to sample landmark positions at a regular time interval allowed for the resulting point geometry to reflect the velocity of the hand gesture at any given moment - as determined by the distance between any two points from one landmark in sequence divided by the regular time. This fact was taken advantage of in the subsequent agent modeling process, as the agent behavior responded to the variation in velocity. An alternate approach would be to sample the landmark positions at a regular frame (i.e. every 10 frames, etc.). This would have resulted in a sampling that would adjust the “resolution” of the recording relative to the complexity of the gesture. For example, when a more complex sequence of movements occurs, and the Hand model switches to detection mode, reducing the framerate of the model, the rate of recordings per second would go up. This would result in a point cloud composed of more samplings when the gestures are more complex, and less samplings when it is less complex or more predictable. More research is needed to explore which approach produces a better representation of the gesture, and in what contexts one or the other works better.

The process of translating the digital point array into surface and pipe geometry represents one possible approach among many. The degree to which this workflow captured the “essence” of the gesture is open to interpretation. However, the development of a closed-loop design process that translates from physical gesture to digital model back to physical form opens the possibility of an iterative design process where these instances of translation can be further experimented with, tested, and refined. While the use of lofting, agent-modeling, piping, and 3d printing were not novel to this research, they did provide invaluable points of reference in creating tighter feedback between gestures and design.

There is room to further a multi-sensory interaction via haptic feedback by generating physical objects from the gesture-generated virtual objects.

Haptic feedback is concerned with the sense of touch, often achieved by creating physical artifacts that express some aspect of architectural design. However, physical modelling of complex digital massing had been difficult to achieve before the widespread access to 3D printing. By creating a physical artifact, we shift from a visually dominated interaction and attempt to incorporate multiple senses. Introducing 3D printing as part of the muti-sensory feedback loop builds on the idea of communicating with virtual environments through our bodies, and thus accessing otherwise sequestered means of creation.

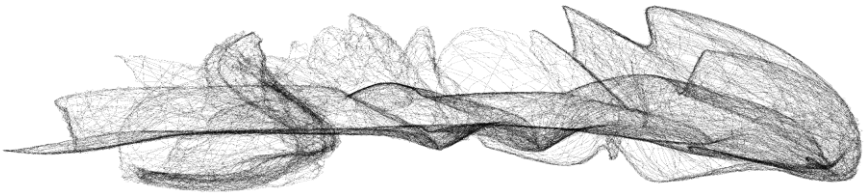

Figure 6. Finished Model B with two generations of agents. Plan view.

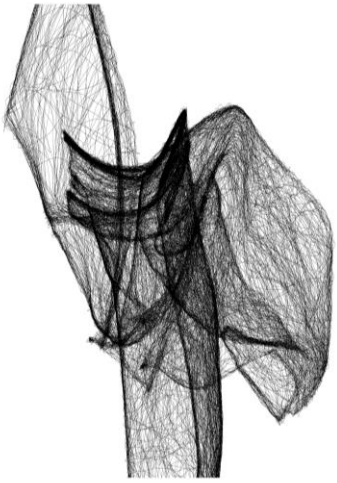

Figure 7. Finished Model C with two generations of agents. Plan view.

4. Discussion

This research project began by asking how users and designers could interact with the 3D digital space without negating their corporality, and by

accessing the initial instincts of design through gestural movements, without the need of specialized equipment or high-performance computer hardware. Focusing on hand gestures, the use of the MediaPipe Hands library, provided a computationally light and straightforward approach using landmarks at the fingertips of the user. This workflow was then extended into a process of digital parametric modeling and 3d printing. The project illustrates that the use of specialized equipment for interacting with 3D virtual environments is no longer an unavoidable necessity, and that other kinds of interfaces can be both technically and economically accessible to a broad base of potential users and designers.

This workflow suggests a more inclusive approach to design and digital form making. It opens the possibility of leveraging the universal language of hand gestures as a direct driver of design processes and form making. This has the potential to liberate the designer or design expert from the limitations of conventional user-interface tools, such as the keyboard and mouse, and to create a much more embodied, less mediated user interface experience. It also suggests the potential for non-experts to engage in the design process in a more direct way, allowing their expressive gestures to be translated into digital and physical form. By tying this workflow into the broader network of DIY makers, artists and designers will only expand the possibilities for form making in the future.

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ARCHITECTURAL HYBRID (PHYSICAL-DIGITAL) PROTOTYPING IN DESIGN PROCESSES WITH DIGITAL TWIN TECHNOLOGIES

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Abstract. A digital twin is a simultaneous digital reflection of object processes and states. Digital twins are usually made of objects that exist in reality or which are very near completion in a design and production process. In our research, we investigate the potential of digital twin technology for early design. Key to the early application of digital twin in design is the role of information and simulation. Since design information is valuable for predicting the future of design, we assume that design will begin to change as digital twin technologies become more and more adaptable, as designers simultaneously have digital twins of the past, present, and future. Digital twin technologies have many capabilities to support the design process at various stages from concept design to the final design. Throughout this process, architects use digital and physical models. Combined with digital twin technology, these models form what we call hybrid prototypes. Estimating that simulation has a vital impact on the design process, we raised the question of what the potential of architectural hybrid prototyping in design processes with digital twin technologies is. Similar to the development of the design through increasingly informed and detailed models, we think that the closest thing to the design process with the digital twin is the so-called foetal, child, and adult digital twin. Based on this classification, we approach the concept of hybrid prototyping and digital twin.

Keywords: *Digital Twin, Technology, Design, Design Process, Prototyping, Hybrid Prototyping.*

ملخص. التوأم الرقمي هو انعكاس رقمي متزامن لعمليات وحالات أى شئ أو كائن. عادة ما تصنع التوائم الرقمية من أشياء موجودة في الواقع أو على وشك الاكتمال في عملية التصميم والإنتاج. ندرس في هذا بحث إمكانات تكنولوجيا التوائم الرقمية لمراحل التصميم المبكرة. ودائما ما تكون المعلومات والمحاكاة مفتاح التطبيق المبكر للتوائم الرقمية في التصميم. نظرًا لأن معلومات التصميم ذات قيمة للتنبؤ بمستقبل التصميم، فإننا نفترض أن التصميم سيبدأ في التغيير حيث تصبح تكنولوجيا التوائم الرقمية أكثر قابلية للتكيف، حيث أن المصممين لديهم في الوقت نفسه توائم رقمية من الماضي والحاضر والمستقبل. تتمتع تقنيات التوأم الرقمي

بالعديد من القدرات لدعم عملية التصميم في مراحل مختلفة من التصميم الأولى إلى التصميم النهائي. خلال هذه العملية، يستخدم المعماريون النماذج الرقمية والفيزيائية. إلى جانب تكنولوجيا التوائم الرقمية، تشكل هذه النماذج ما نسميه النماذج الأولية الهجينة. بتقدير أن للمحاكاة تأثيرًا حيويًا على عملية التصميم، فقد طرحنا السؤال حول ماهية إمكانات النماذج الأولية الهجينة المعمارية في عمليات التصميم باستخدام تكنولوجيا التوائم الرقمية. على غرار تطوير التصميم من خلال نماذج مستنيرة ومفصلة بشكل متزايد، نعتقد أن أقرب شيء إلى عملية التصميم مع التوأم الرقمي هو ما يسمى بالتوأم الرقمي الجنين والطفل والبالغ. بناءً على هذا التصنيف، نقترب من مفهوم النماذج الأولية الهجينة والتوأم الرقمي.

الكلمات المفتاحية: التوائم الرقمية، التكنولوجيا، العملية التصميمية، النمذجة الأولية، النمذجة الهجينة.

1. Introduction

Digital twin (DT), is a simultaneous mirroring of physical and digital processes (Glaessgen and Stargel, 2012, p. 7). Currently, DT is not used in the design process (Roozenburg and Eekels, 1995, p. 118) since there is no counterpart to sense or monitor. However, DT can work with design information, which is valuable for predicting the future of design. Digital twin technology exists with knowledge of the past, present, and possible future scenarios with the help of intelligence (Rios *et al.*, 2015, p. 657).

In previous research (Emir Isik and Achten, 2022), we focused on evaluating the digital twin theoretical framework in the design process (mapping between the Basic Design Cycle (Roozenburg and Eekels, 1995, p. 88) and Digital Twin Technology Development Layers (Lu *et al*., 2020, p. 5)) to comprehend how digital twin technology can be used in the design process. The digital twin layers are classified subsequently as the data acquisition layer, transmission layer, digital modeling layer, data-model integration layer, and service layer. These stages are meant for determining what data can be obtained, for getting data to the system, making all required models, combining the intelligence with layers (2 and 3), and for management and decisions. This can help designers achieve superior designs with the digital twin. We identified activities (analysis, synthesis, simulation, evaluation, and decision) and products (function, criteria, provisional design, expected properties, the value of the design, and approved design) that can have the highest impact on the design process. One of the most prominent activities is a simulation (Roozenburg and Eekels, 1995, p. 235), the first system model to mimic other system behaviours, called an imitated prototype in some fields of science. Simulations can vary from digital simulation in a computer program up to a full-scale realization of a physical prototype (Achten and Kopřiva, 2010, p. 174).

In the means of generation of the digital twin in the design, the designers can integrate data with the model through more detailed simulations. Only

simulation can provide factual information to designers with the expected properties of the design (Roozenburg and Eekels, 1995, pp. 235-236). Designers can simulate applying tests to the prototypes for real performance prediction on physical artefacts. The simulations can be determined by the intended use such as energy; availability of daylight; comfort levels; load profile; occupation; room layouts; temperature; acoustic; fire safety; fire escape scenarios; user activities (Emir Isik and Achten, 2022, p. 52) and also VR hardware devices can be used for digital twin for simulation purposes (Tao *et al*., 2019, pp. 7-14). Thus, in parallel with simulations, there may be several prototypes for testing according to the design purposes. Achten (2009, pp. 523-524) distinguishes the simulation in several roles; in particular, we focus on the fabrication (prototyping (physical realization of the design)) and 4D (digital realization of the design). At the design stage, you can simulate digital twins to ensure that the prototype is functional (Semeraro *et al*., 2021, p. 12). The summary of general approach design with prototyping is testing, timing, idea, fixation, feedback, usability, and fidelity (Camburn *et al*., 2017, p. 5).

When we combine physical prototypes with DT technologies, we propose to call the resulting model a “hybrid prototype.” Simulations can guide hybrid prototyping techniques in determining the performance of the design with a digital twin. Feedback from these prototypes will determine the digital twin design process. Thus, this can help add value to the built environment requirements in the design situation.

Interest in digital twins is growing, but to date, little has been done on their implementation during the design phases before achieving design (Jones *et al*., 2019, p. 2558). Sacks *et al*. (2020, p. 16), define progressive states of digital twins in the form of so-called foetal, child, and adult digital twins. We see this as closely related to the progressive states in the design process (Figure 1).

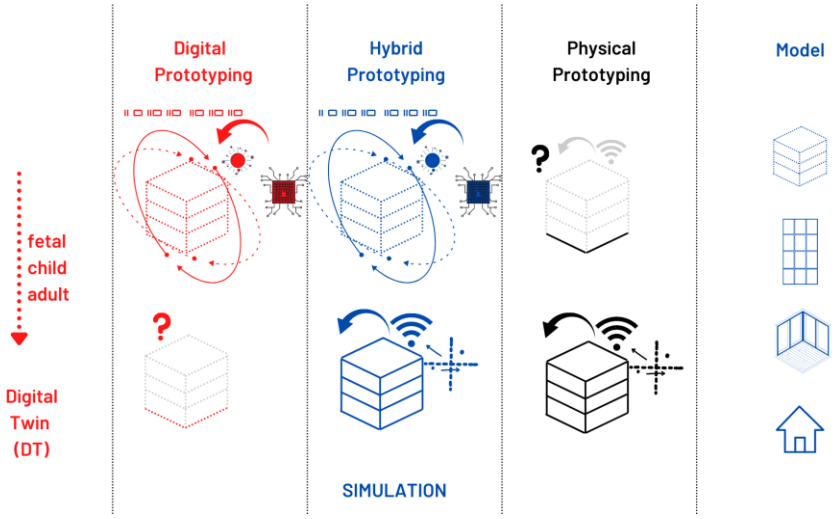


Figure 1. Prototyping with a digital twin (DT).

This paper is organized as follows: we present the relevant (2) background, which includes digital twin technologies and hybrid prototyping; (3) the case for the digital twin as connected to prototypes; (4) an explanation of hybrid prototyping; and the conclusion.

2. Background

This section outlines (2.1.) the traditional understanding of the digital twin and (2.2.) the hybrid prototyping and the digital twin approach, which includes subtopics (2.2.1.) the traditional prototyping and (2.2.2.) the hybrid prototyping.

2.1. TRADITIONAL UNDERSTANDING OF DIGITAL TWIN

The implementation of the digital twin is rapidly growing with the evolution of information technology (Liu, Zhang, and Wang, 2020, p. 1) in several scientific disciplines, from formal science (computer, statistics, etc.) to empirical science (economics, engineering, earth sciences, etc.). The origins of the digital twin concept date back to the 1960s National Aeronautics and Space Administration (NASA) studies. The Apollo 13 program by NASA devised a spacecraft model, which has the same approach as the digital twin, including designing a mirrored system (digital and physical identical vehicles) (Rosen *et al*., 2015, p. 568). Then, NASA scientists defined the

digital twin as an integrated simulation of the process that mirrors (mocks) the life of its flying twin (Glaessgen and Stargel, 2012, p. 7).

Gelernter (1991), in the book Mirror Worlds, narrated an imagination of a digital world that mimics real-world situations simultaneously, which had a similar idea to the digital twin. The origins of the digital twin concept were accredited to John Vickers of NASA and Michael Grieves when Grieves put this concept, as a tryadic system (physical-virtual-link) in a product life cycle management lecture in 2003 (Grieves, 2014, p. 1; Grieves and Vickers, 2017, p. 92) (Figure 2). El Saddik (2018, p. 87) states that the digital twin is a digital replication of the entity that transmits data between physical and virtual worlds, and it eases monitoring, understanding, and optimizing the functionality of the physical entities with feedback between these worlds to improve life quality. The digital twin revolves around guiding a physical artefact into the desired situation through feedback and feedforward information. Although in all cases the digital twin is structured as a physical artefact, a virtual artefact, and their links, there is not one unified terminology underlying the digital twin, but there is a lot of diversity (Korenhof, Blok, and Kloppenburg, 2021, pp. 1753-1765).

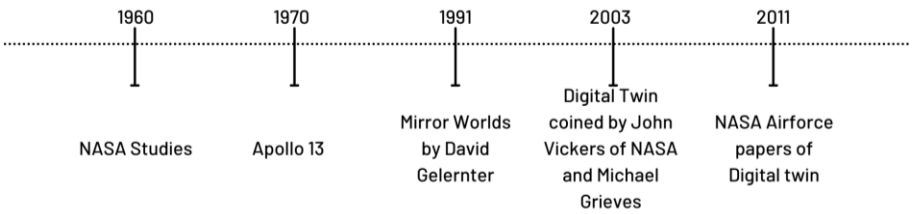


Figure 2. The basic timeline of the digital twin.

Grieves and Vickers (2017, pp. 94-95) classified digital twins into types in Digital Twin Environment (*DTE*, an integrated physics application area for working on DTs for various purposes such as prediction or interrogation): (1) Digital Twin Prototype (*DTP*, including information to define a physical artefact that mirrors the virtual artefact), (2) Digital Twin Instance (*DTI*, matching the physical artefact which a DT remains attached to it), and (3) Digital Twin Aggregate (*DTA*, combining all DTIs) (Figure 3).

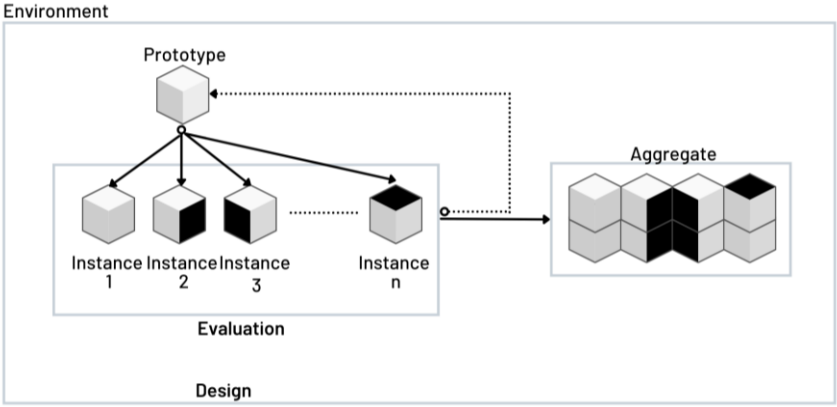


Figure 3. Prototyping of digital twin through design (adapted and modified from Grieves and Vickers, 2017, pp. 94-95; Grieves, 2021).

Digital twin technologies have many abilities such as for the physical part to *sense* (real-time observation via sensors, etc.), *monitor* (tracking and informing on relative changes), *actuate* (changing physical things based on virtual decisions); for the data to *integrate* Building Information Modeling (BIM) (combining data), Internet of Things (IoT) (combining and sharing the data linked with related devices), *data linking* (combining and sharing data with semantic Web protocols such as common data environment, industry foundation classes, resource description framework, etc.*)*, and *store knowledge* (storing the knowledge of the system). For the virtual part, DT technologies have the ability to *simulate* (creating simulation models*)*, *predict* (foreseeing the physical things with simulations and observations with digital things), *optimize* (applying effective solutions simultaneously), and *agency* (empowering artificial intelligence agents for managing the physical data based on digital data) (Boje *et al*., 2020, p. 10) (Figure 4). The design process can contain these abilities in several stages, from concept design to final design.

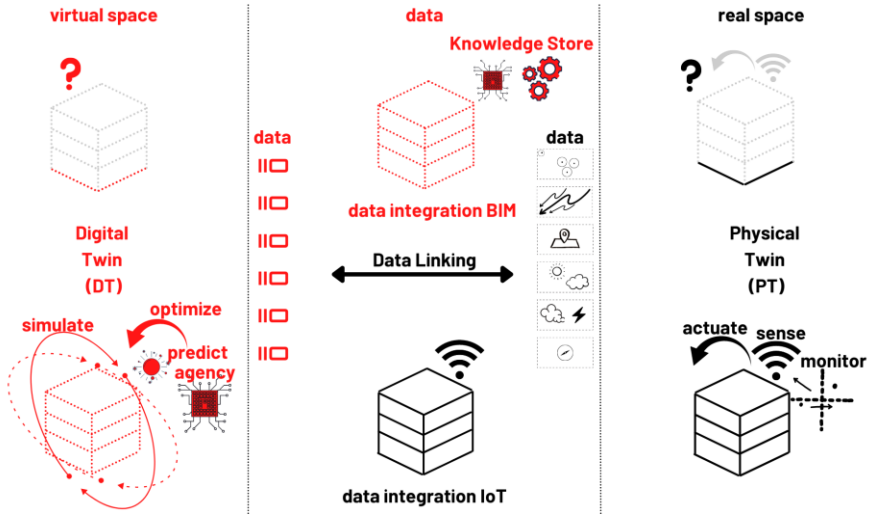


Figure 4. The abilities of digital twin technologies (adopted from Boje *et al*., 2020).

Although it is possible to build custom DT models, we feel that ultimately the base of such models will be BIM models. BIM is a coordinated, information-rich model that allows virtual prototypes, analyses, and virtual projects to be created (Eastman *et al*., 2008, p. 94). When we consider a digital twin and BIM technology, they have common capabilities. BIM has seemed like a central technology for the lifecycle, which also includes the design process, a tool of digital twin by many professionals. However, while BIM reflects the physical model, the digital twin is linked to its physical twin also by intelligence, so it can update simultaneously with physical changes (Boje *et al*., 2020, p. 13; Sacks *et al*., 2020, p. 4).

2.2. HYBRID PROTOTYPING AND DIGITAL TWIN APPROACH

In this section, we introduce first the general descriptions and definitions of *traditional prototyping* (physical prototypes) and then as an innovative approach, *hybrid prototyping* (combination of physical prototypes with DT technologies). As a manifestation of data, the prototype needs to have ample time to occur during the design process from the early phases of the design to the final design to achieve a good design.

2.2.1. Traditional Prototyping

Prototyping is an activity in which representative and manifest prototypes are created and used for the design (Lim, Stolterman and Tenenberg, 2008, p. 10). So, prototyping and prototype differ from each other; prototype definitions are formerly referred to as the beginning of the design process to

comprehend prototyping (Kim, 2019, p. 1). Inspired by Burry and Burry (2016) prototyping is classified into four types in this paper: (a) model; (b) prototype; (c) mock-up; and (d) prefabrication. According to Oxford Dictionary (2022), (a) model can be defined as a copy of the design, usually proportionally and intentionally smaller than a realized or imagined design; (b) prototype is denoted as a copy or originated from prototupos 16th century, as a first or primary type of anything; (c) mock-up is a model or a copy of a design, mostly a 1-1 scale of the related design to test and display to the customers; and (d) prefabrication is a part of a design that is produced in a factory so that the structure consists of assembling and unifying standardized parts.

Earlier work on the architectural design process for physical prototyping is Filippo Brunelleschi's wooden model of the Duomo in Florence. His prototypes are based on testing and exploration, intended to build with an unusual methodology, due to construction being hard to do by traditional construction methods (Kim, 2019, pp. 2-3). Michelangelo and Palladio also used physical prototyping tools in their designs, from designing to marketing challenges (Sass and Oxman, 2006, p. 325). Further, the use of 1-10-scale models by Gaudi on Colonia Guell Church is a clear sign of the architect's interest in understanding the performance aspects of design. As Burry and Burry (2016, p. 27) pointed out, mock-ups are a test method used late in the design process before construction to see the potential of the design. The mock-ups offer an opportunity to upgrade the design at the last minute. As we can see in Gaudi's Sagrada Família, the prototypes help to build the real design. Camburn *et al*. (2017, pp. 3-4) offer a comprehensive overview of design prototyping goals such as design clarification, communication between designers, exploration of the design process, and knowledge acquisition. Lim, Stolterman and Tenenberg (2008, p. 11) proposed several dimensions *(appearance, data, functionality, interactivity,* and *spatial structure)* for prototypes. They reflect the different aspects of the design ideas that the designer is trying to represent in their prototypes (Figure 5).

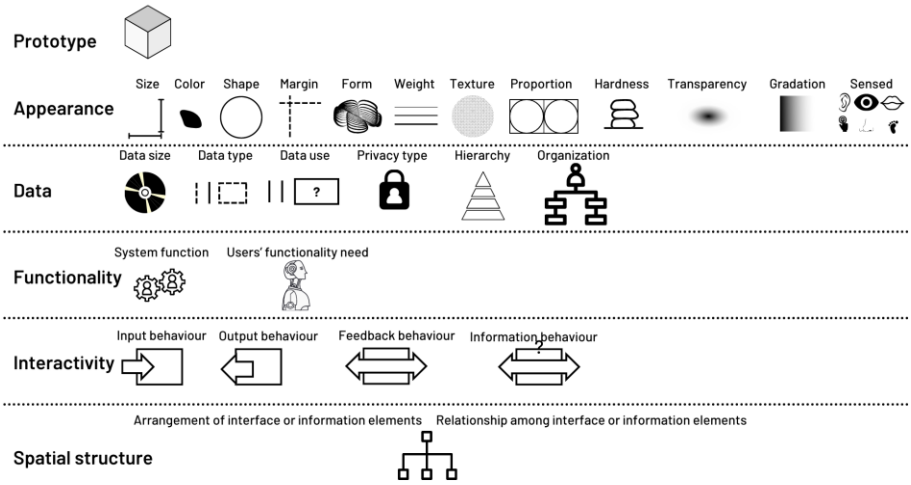


Figure 5. Prototyping variables adopted from Lim, Stolterman and Tenenberg (2008, p. 7).

Depending on the prototyping ideas of the designers, we can summarize prototyping as; *representing* the intention; *testing* the design, abstraction, things (hard to calculate or simulate in a digital environment such as gravity, inertia, wind loads, strength, etc.), ideas, emotions, material, assembly, fabrication techniques, technology, and the performance of environmental factors with design; *integrating* passive and active technologies; *responding* to different conditions; *informing* designers about the design process and *relaxing* the project owner (Burry and Burry, 2016).

In this section, Burry and Burry's (2016) book 'Prototyping for Architects' there are given examples from architectural practice. Regarding architectural applications, many designers work with models, prototypes, mock-ups, or prefabrications (Figure 6). Moreover, Bollinger+Grohmann only engages with projects if there is prototyping; Snohetta usually works with several scale prototypes on projects for both the field and lab; Blumer Lehmann works with full-scale mock-ups for timber projects; Zaha Hadid explores material, curves, and finishes with the full-scale physical mock-ups such as facades or assembly details combined with the digital prototypes. Attested by Alan Dempsey, the prototype can be considered an instrument to re-contextualize for other similar projects. Within this scope of approach, we can make a point of using prototypes of digital and physical twins, which evolve sustainably in the design process. Today the technology helps to create digital simulations to achieve real-time feedback about designs with digital twin to support decision-making.

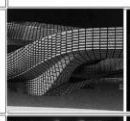
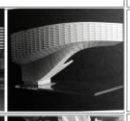
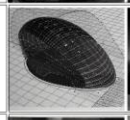
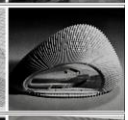
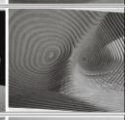
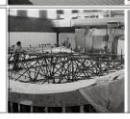
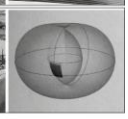
Practices	Information	Project Pictures		Practices	Information	Project Pictures	
SHoP	*Barclays Center, Brooklyn, New York*			MAD Architects	*Harbin Cultural Center, China*		
ARUP	High Roller, Las Vegas			Nex	DRL10 Pavillion, London		
Hopkins Architects	Velodrome Olympic Park, London			dECOi Architects	Miran Gallery, Paris		
Studio Gang	Writers Theater, Glencoe Illinois			Kreysler & Associates	Big Concert Hall, Stanford		

Figure 6. The architectural practice of prototyping (inspired by Burry and Burry, 2016).

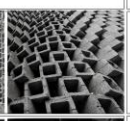
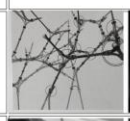
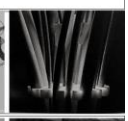
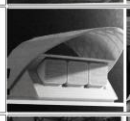
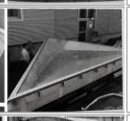
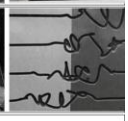
Practices	Information	Project Pictures		Practices	Information	Project Pictures	
Archi-Union	*J-Office, Shanghai, China*			CITA	*The Rise, Paris, France*		
GAP Architects	Sky Soho Leasing Showroom, Beijing			Eva Jiricna Architects	Somerset House, London		
Foster & Partners	Canary Wharf Cross rail Project, London			Franken/Architekten	Kleine Rittergasse, Frankfurt		
3XN	Louisiana Museum of Art, Denmark						

Figure 6. (continued). The architectural practice of prototyping (inspired by Burry and Burry, 2016).

2.2.2. Hybrid (Physical-Digital) Prototyping

Prototyping needs a unique strategic approach for solving each design objective in the design process (Camburn *et al*., 2017, p. 2). As seen from practice, physical prototyping offers tremendous detail, while digital prototyping supports design with many capabilities (Burry and Burry, 2016).

Digital twin technology is devised as a simultaneous dashboard, which one can use to get information about the status of things or revise or search for any missing points (Gelernter, 1991). When a digital twin is used for

design, it is important to have an architectural hybrid prototyping process that enables the design to be tested and updated based on feedback. The digital twin design process will include data to test and update the parameters of the digital twin prototype (Wright and Davidson, 2020, p. 3). When this data is used to feed the digital twin, a digital twin can tell the story (such as history and experiences) of its physical artefact (Madni *et al*., 2019, p. 4).

Since the physical object must exist, digital twins in the design process only make sense once the prototyping stage has been reached (Wright and Davidson, 2020, p. 13). Prototypes evolve with the design process. The incompleteness of a prototype contributes to the evaluation of a design concept, which also makes it powerful. Prototypes are exploration tools to determine the quality of the idea before building the final design. They are used for exploring problems or new solutions in the design process (Lim, Stolterman and Tenenberg, 2008, p. 7).

We define a "hybrid prototype" as a prototype enriched with Digital Twin technology and capabilities. That means, that the prototype is equipped with sensors, the state of which are fed live to the digital design model. Depending on the purpose of the prototype, and state in the design process, the hybrid model plays a role in the simulation and evaluation of the design. In this way, hybrid prototyping techniques can help to tackle the challenges of the digital twin in the early stage (Jones *et al*., 2019, p. 2566).

Hybrid prototyping will allow designers to test conditions and simultaneously get feedback in real-time. It is further divided into levels *of digital prototypes* (representation, production, operation, and interaction) and *physical prototypes* (representation, production, and operation). As seen from this classification level, one of the important common parts of hybrid prototyping is the operation, which can be associated with the idea of a digital twin with supported tools such as *sensors* (used for sensing the behaviors), *actuators* (used for running functions), and *processors* (used for transforming the outputs into meaningful information), etc. (Kim, 2019, pp. 7-10) (Figure 7).

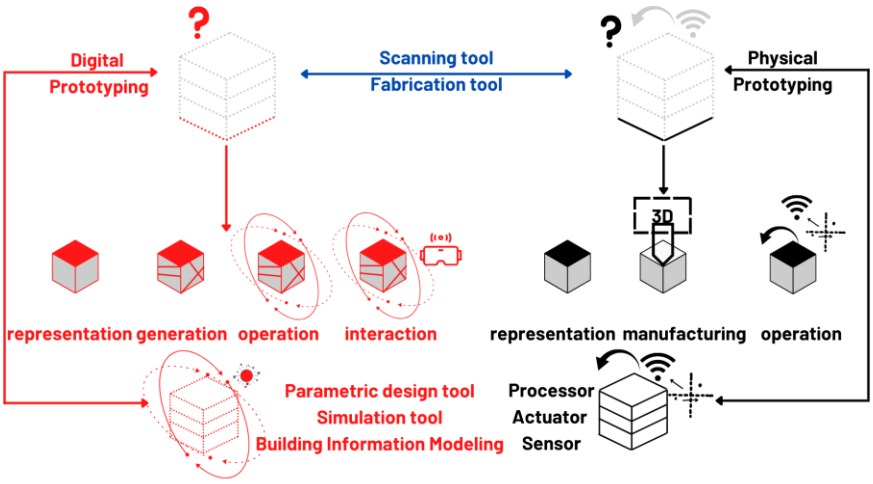


Figure 7. Hybrid prototyping is adopted from Kim (2019, p. 7).

To some extent, we can see the close linkage between prototype and digital model (but not to the degree of digital twin application) in for example Gehry Partners. They work with physical models in their designs and create complex forms, which eventually, like many designers, are further refined using digital modeling tools (Sass and Oxman, 2006, p. 327). Eekhout and van Swie (2004, pp. 4-7) believe both digital and physical prototyping as hybrid prototyping is complementary and used in a design process simultaneously. They also emphasize prototyping for designing, performance, and marketing.

3. The Case for Digital Twin as Connected to Prototypes

Designers can use prototyping tools to test whether designs are responsive to intended performance criteria such as energy efficiency, temperature, humidity, and aesthetics according to the design intentions (Kim, 2019, p. 2). De Jong and van der Voordt (2002, p. 169) highlight that prototype design has two evaluations: *ex-ante evaluation* which is before building the design, and *ex-post evaluation* which is after building the design. Both can help to enhance the design with simultaneous testing, in which digital twin prototypes are effectively involved. Using physical and digital prototyping in parallel for the design process leads to some issues, such as a lack of control over the review of physical prototypes and manually analyzing, measuring, and interpreting hybrid prototypes (physical and digital) changes to update later by designers. Digital twin processes can be carried out by realization

and metrology by the Internet of Things (IoT) sensors from physical to digital and from digital to physical by actuators (Jones *et al*., 2019, pp. 2558-2559) (Figure 8).

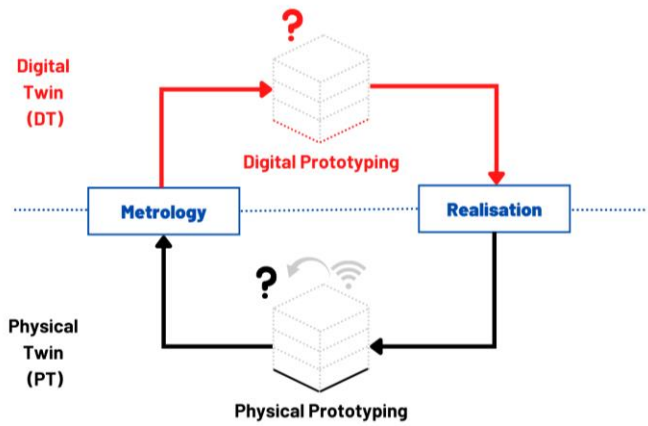


Figure 8. Twinning Cycle adopted from (Jones *et al*., 2019, p. 2559).

Delgado and Oyedele (2021, pp. 10 - 11) provide detailed information on the prototypical digital twin in the built environment, as shown in Figure 9. Digital prototypes facilitate the achievement of complex forms that are physically hard with the help of technologies in some functions such as parametric design, simulation, BIM, digital fabrication, etc. (Kim, 2019, pp. 4-10).

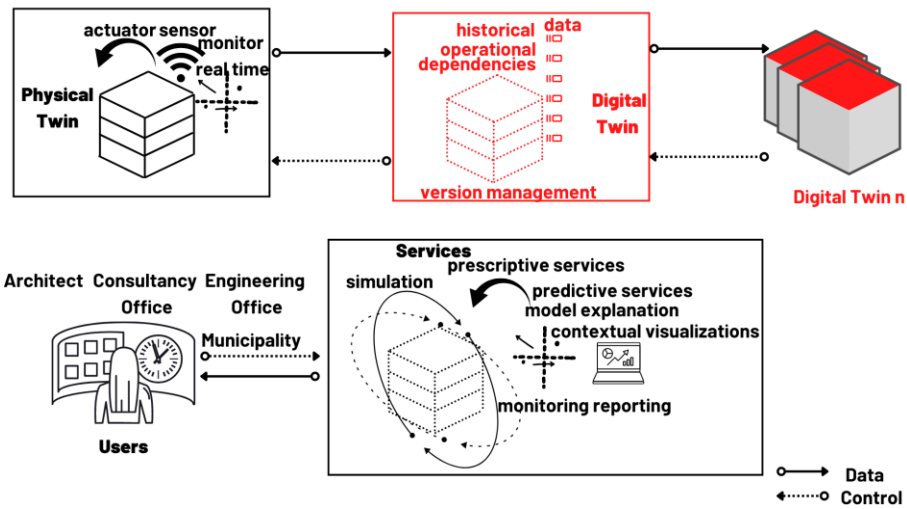


Figure 9. Prototypical digital twin adopted from (Delgado and Oyedele, 2021, p. 11).

In research by Kalantari *et al*. (2022), Ph2D, a physical/digital prototyping tool, focuses on the design process, with the digital twin implementing several demonstrations related to office and hospital design scenarios. They developed a physical prototype tool that could transfer detailed architectural layout information to the CAD software.

4. Hybrid Prototyping

Hybrid prototypes combine physical and digital models through live linkage using Digital Twin technology. Usually, physical, and digital models are conceived as two separate categories. For example, Burry and Burry (2016, pp. 12-15) argue that digital and physical prototyping have different approaches to their purposes. As we stated earlier, we believe that Sacks *et al*. (2020) make an important distinction in the developmental phases of digital twins through the notion of foetal, child, and adult digital twin. Prototyping can be considered as an implementation of ideas, concepts, and relationships as physical or digital artefacts for architects as part of their repertoire. Throughout the design process, as ideas evolve, the prototypes evolve as well – very much in the same way as foetal, child, and adult digital twins. The foetal and child digital twin is a type of incomplete model or working process digital twin, while the adult digital twin is a complete model or a constructed process of the digital twin. In the concept design, the digital twin comes to life with the foetal digital and physical twin. In the preliminary design, the digital twin starts to grow as a child digital twin, with its child digital twins supported by child physical twins as its physical twin. Through the detailed design or final design, both digital and physical prototyping helps foetal to turn into child, and child to turn into adult twins. The prototyping through the design process of the digital twin and the physical twin is shown in Figure 10. The scale of the physical prototyping can differ according to the intention of the design objectives, such as a 1-1 or 1-5, etc.

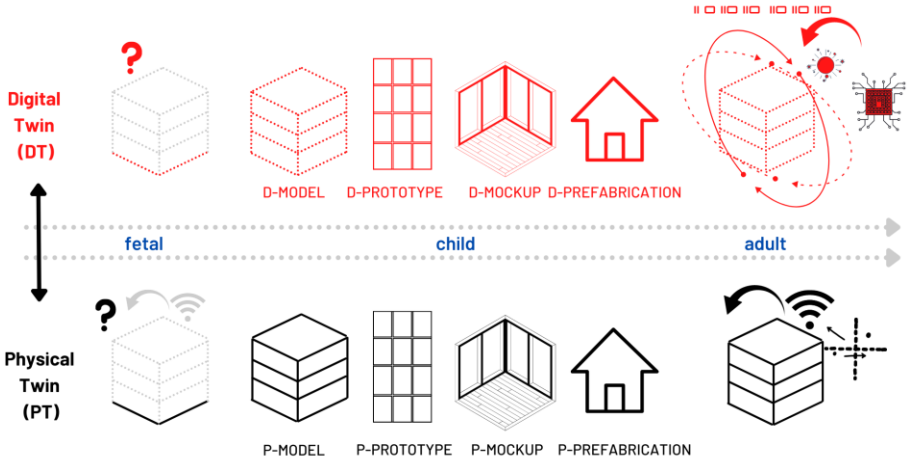


Figure 10. Prototyping with digital twin (DT) and physical twin (PT) through the design phases.

Hybrid prototyping takes advantage of the rich repertoire that architects have developed in the use of physical modeling and adds to this the potential of digital twin technology. This shifts the emphasis in physical models from verisimilitude or likeness to real-time sensor data reading, simulation, and live feeding of the digital design model.

5. Conclusion

This article primarily provides definitions and explanations of the traditional understanding of digital twin technologies and prototyping. Then, the potentials and problems of the digital twin added to the prototypes were discussed, and the definition of hybrid prototyping related to the digital twin approach was concluded. What if we already started to use foetal and child physical and digital twins through prototyping? Realizing the potential of architectural prototypes for design processes with the digital twin is vital here. In practice, many prototypes are produced during the design process, but what if adding more sensors makes it smarter? Therefore, hybrid prototyping tools such as models, prototypes, mock-ups, or prefabrication can increase the connectivity of the digital twin. Ultimately, designers can achieve better designs by using the digital twin when prototyping. For these purposes, we can assume that we have a digital twin data system to feed into subsequent designs. Thus, hybrid prototyping can inform designers during the design process.

Acknowledgments

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COMPUTER VISION AIDED HOTSPOT CREATION IN VIRTUAL ENVIRONMENTS

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Abstract. Hotspot creation is one of the most important modules within virtual environments which helps show the navigators of these environments some information about semantic elements within it and facilitate the navigation between the virtual spaces. In this paper, a system for automatic hotspot proposals and creation in virtual environments is proposed. The system uses computer vision modules to automatically propose hotspot locations in addition to identifying and creating these hotspots with candidate labels. Two main modules used in the system are object detection and scene segmentation. The scene segmentation helps give candidate hotspot areas and provides an overall understanding of the semantics of the virtual environment. The object detection module also uses pretrained deep networks for automatic hotspot creation over these objects. The system helps speed up the hotspot creation process and offers a tool for virtual environment users and creators.

Keywords: *hybrid metaverse, virtual environments, object detection, deep learning, computer vision*

ملخص. يعد إنشاء النقاط الفعالة أحد أهم الوحدات النمطية في البيئات الافتراضية والتي تساعد في إظهار ملاحي هذه البيئات بعض المعلومات حول العناصر الدلالية بداخلها وتسهيل التنقل بين المساحات الافتراضية. في هذه الورقة البحثية، تم تقديم نظام لاقتراح وإنشاء النقاط الفعالة التلقائية في بيئات افتراضية. يستخدم النظام تقنية رؤية الكمبيوتر لاقتراح مواقع النقاط الفعالة تلقائيًا بالإضافة إلى تحديد وإنشاء هذه النقاط الفعالة باستخدام الملصقات المرشحة. هناك وحدتان أساسيتان مستخدمتان في النظام هما كشف الأشياء وتجزئة المشهد. يساعد تقسيم المشهد في إعطاء مناطق النقاط الفعالة المرشحة ويوفر فهمًا شاملاً لدلالات البيئة الافتراضية. تستخدم وحدة كشف الأشياء أيضًا شبكات عميقة مُدرَّبة مسبقًا لإنشاء نقطة اتصال تلقائية فوق هذه الأشياء. يساعد النظام في تسريع عملية إنشاء النقاط الفعالة ويوفر أداة لمستخدمي البيئة الافتراضية ومنشئيها.

الكلمات المفتاحية: *الميتافرس المختلط، البيئات الافتراضية، كشف الأشياء، التعلم العميق، تقنيات رؤية الكمبيوتر.*

1. Introduction

The metaverse is a new era in technology and social communication which offers a parallel universe and provides access to multitudes of 3D virtual spaces and environments created by users. In fact, virtual environments are vital components in the metaverse, with an effect over various aspects ranging from environment architectures to personal interactions.

The latest advancements in Virtual Reality tools are convincing users to increasingly be immersed in virtual worlds. It takes control of their vision and provides them with hotspots to interact with virtual objects or to navigate in the virtual environment. The hotspots can also ruin the visual display or cause some distraction when not implemented correctly.

Accordingly, one of the most important modules within virtual environments development is hotspot creation. Among this process, the creator of the virtual environment can set interactive mediums for visitors to interact with the virtual environment and launch predefined events and actions. These hotspots attract the navigators of these environments and show them some information and definitions about semantic elements within it and facilitate their navigation between the virtual spaces. (Napolitano, Blyth and Glisic, 2018; Eiris, Wen and Gheisari, 2020).

Current techniques for hotspot creation are implemented using manual localization by the users during the creation of the environment and are updated upon need. This can be considered a highly hectic process for the users and might even result in missing some important hotspots.

Certain virtual spaces within virtual environments contain similar hotspots which the virtual environment creator must separately define. For example, when the virtual environment creator is working on a 360° virtual classroom that contains 20 chairs, 20 hotspots must be localized and defined by the user. However, the virtual environment creator could miss defining some hotspots on some objects in the environment which might cause visitors to wonder, such as a certain class chair in the virtual classroom we mentioned, or any other object (i.e. door) in a virtual room.

In this paper, a fully automatic hotspot creation tool is proposed. The virtual spaces in the virtual environments are represented by 360° panoramic images. This tool scans these images when the virtual environment creator is building the virtual environment so that required hotspots can be automatically localized and set, or at least proposed. This will facilitate the development phase of the virtual environment, and aid in mitigating the negative impact or unintended consequences from missing essential hotspots. However, architects can then be immersed in these environments and benefit from this tool to design and manage the assets in their intended virtual spaces (Zhang *et al.*, 2011; Schnabel and Kvan, 2003).

Most of the Integrated Development Environments (IDE) that are used to build VR scenes provide the feature of manually adding interactive hotspots. The focus in our work is to propose such automated hotspots creation and proposition tool that could be integrated in any of the interesting VR-IDEs.

The rest of the paper is organized as follows. In section 2, the work related to the hotspot creation system is summarized. The pipeline used is then explained in section 3 where details about each component used are shown. Experimental results follow in section 3 where the dataset used to verify the hotspot creation approach is discussed and sample results are shown. Finally, the conclusion and future work are included in section 4.

2. Related Work

The virtual environment is composed of a set of scenes having defined entities. The creator of this environment works then on connecting these scenes and enabling interactions on these entities through hotspots (Cantatore, Lasorella and Fatiguso, 2020; Lanzieri *et al.*, 2021; Shah *et al.*, 2021). Additional techniques are currently being used for adding hotspots, like in https://kuula.co/. They provide creators of virtual environments with some tools that allow them to select multiple hotspots for updating or duplication abilities.

One of the modules used in the hotspot creation is object detection. In general object detection is a widely studied area in computer vision and it started with basic hand-crafted image features such as HOG (Wang, Han and Yan, 2009) coupled with supervised learning and basic classifiers. Advances in deep learning and convolutional neural networks (Girshick, 2015; He et al., 2017; Huang et al., 2018) in specific gave rise to a leap in object detection where more advanced detectors are able now to give state of the art performance and succeed at identifying a huge range of objects. Recently, object detection in 360° images i.e. panoramic object detection is now being studied where Deng, Zhu and Ren (2017) use a convolutional neural networks on panoramic images. In addition, another relevant work by Zhang et al. (2014) includes geometric understanding of the scene to allow object detection in such images.

In general, object detection performance is highly affected by the training data. Datasets (Deng, 2009; Everingham, 2010; Veit, 2016) found in the computer vision community are based on two dimensional images and most object detection frameworks are built on such images. The Sun360 dataset (Xiao, 2012) handles this issue and offers a collection of panoramic images with ground truth object detection labels which would be most relevant to the meta verse environment. An extension to this dataset, which is considered highly relevant to hotspot creation, was also proposed in

(Guerrero-Viu, 2020) where scene segmentations are added including tight outlines of objects and scene background such as floor and wall.

Another main module in the hotspot creation pipeline is image segmentation. Early methods in image segmentation use basic image processing techniques such as thresholding (Otsu, 1979), region growing (Nock and Nielson, 2004), k-means clustering (Dhanachandra, Manglem, and Chanu, 2015). More advanced techniques such as graph cuts (Vicente, Kolmogorov, and Rother, 2008) were also used in the liteature. Recent advances in image segmentation used deep learning models (Chen et al., 2017; Long, Shelhamer and Darrell, 2015; Noh, Hong and Han, 2015) which resulted in remarkable performance improvements. A recent survey on deep learning methods for image segmentation by Minaee et al. (2021) gives a detailed summary of these methods.

3. Hotspot Creation Approach

The approach that is used for the creation and localization of hotspots can be summarized in Figure 1. As can be shown in the image, the input to the pipeline is a 360º image panorama taken at a specific location within the virtual environment. The panoramic image is first projected into perspective view. Each view is then input into a deep network for object detection where various semantic elements are localized. In addition, the panoramic image is segmented. Finally, the candidate objects and segmentation map are combined to localize and create hotspots in the panoramic 360 image. These hotspots can thus be integrated into the virtual environment. The following sections describe in more details the various components used within the pipeline.

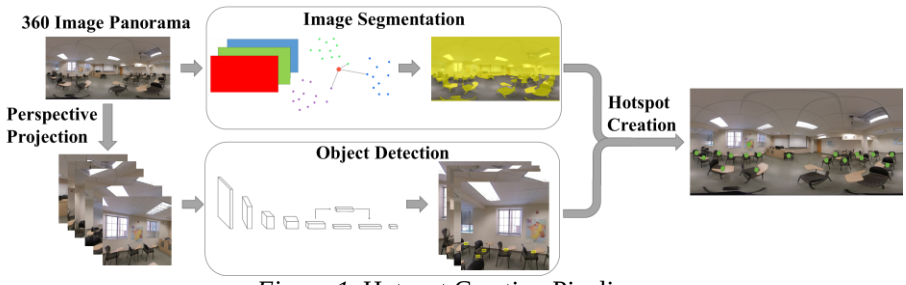

Figure 1. Hotspot Creation Pipeline

3.2. PERSPECTIVE PROJECTION

The initial step in the hotspot creation is perspective projection of the input 360 image panoramas. Most generic object detection approaches apply

object detection on images taken by a normal camera. Thus, one critical step to be implemented is applying equirectangular projection on these images to obtain the perspective view. The equirectangular projection is applied as a transformation that warps the input panorama by identifying specific tilt, roll and pan angles in addition to field of view. The transformation is produced by computing the camera calibration matrix K and the rotation matrices referring to the pan θ and tilt φ respectively (roll is ignored here since it's constant for panoramic images).

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = K^{-1} R_\theta R_\phi \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

The above equation shows how each pixel (x, y, z) is transformed into perspective view as a multiplication of the calibration and the rotation matrices. Finally, the longitude and latitude are calculated from the projected homogeneous coordinates. For each panoramic image, $P+T$ perspective images are created referring to P different pan angles and T different tilt angles. Each of these images are input into the object detection step described in the next section.

3.3. OBJECT DETECTION

The object detection step in the hotspot creation pipeline is applied on the perspective view images extracted from the panoramas. Each perspective image is input to a pre-trained deep network that allows the detection and localization of various semantic elements such as chairs, sofas, people, etc... The object detection framework used is the YOLO (You Look Only Once) detector (Redmon and Farhadi, 2017) which is considered the current state-of-the-art object detector.

The YOLO object detector applies a single deep network to an input image by dividing the image into regions. It uses a convolution neural network consisting of a total of 24 convolutional layers with different functionalities and followed by 2 fully connected layers. The first 20 layer are used for pre-training and the last 4 layers are specified for object detection. The final layer predicts bounding boxes that are weighted by predicted probabilities.

Figure 2 below shows example object detection output on two perspective images. The above images produce (x', y') locations of detected objects which are mapped to their corresponding locations in the panoramic 360 image for further processing in the hotspot creation step. In addition to the object locations, a confidence score is also given which gives a probability value for the certainty of the identified object.

Figure 2. Object detection on two perspective images. Left image shows the detected chair and sofa objects. Right image shows the detected TV monitor.

3.4. IMAGE SEGMENTATION

The image segmentation step gives an overall understanding of the scene within the virtual environment. It basically divides the input image into a set of segments which gives a simple representation of the main areas that have similar color and texture within the image. Thus, the whole panorama is input into the segmentation algorithm and a mask that maps each pixel to a segment is produced. The image segmentation technique chosen is the k-means clustering technique due to its simplicity and speed. The *k* in this technique refers to the number of segments to be formed. K-means clustering is an iterative approach for image segmentation that takes the R-G-B values of each pixel in the image and assigns them to cluster centers. The segmentation is done in two main steps which are formed of cluster assignment and cluster center update steps. Once the pixels are mapped to the cluster centers a segmentation mask is created.

The segmentation of the scene gives rise to identifying various segments within the panoramic image and thus allows the identification of semantic regions referring to the floor, ceiling and walls in the scene. These regions are considered vital for adding navigation hotspots in panoramic images especially at location with doors and entrances are located.

Figure 3 below shows an example panoramic image with the corresponding segmentation. As shown in the figure the panoramic scene is divided into 4 segments. These segments can be identified from the scene as wall, floor, chairs and ceiling. It is important to note here that the floor part is in general located in the bottom part of the image assuming that panoramas are taking at an eye-level latitude. The floor segment is considered primarily vital for hotspot localization which gives candidate

location for the navigation of the virtual environment and the transition between the scenes.

3.5. HOTSPOT LOCALIZATION

The final step in the hotspot creation approach is hotspot localization. The detected object locations, scores, and labels in addition to the scene segmentations are combined to output hotspot locations.

The object detection step outputs the labels and locations of candidate hotspots (refer to bottom left images in Figure 4). These labels when combined will refer to multiple locations within the panoramic image. In fact, the same semantic element might be present in multiple perspective images which results in duplicated overlapping detections when mapped to the input panoramic image.

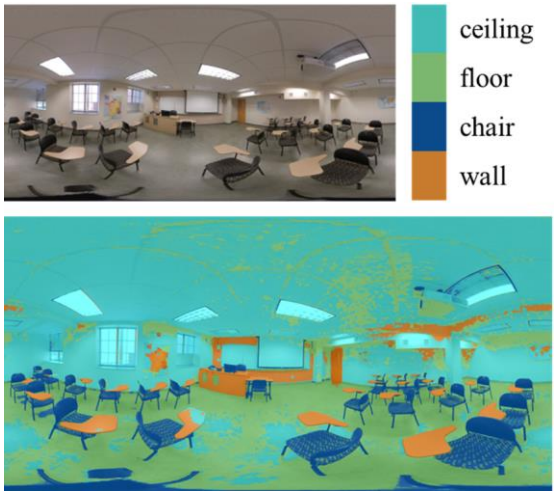

Figure 3. Image segmentation with k-means clustering algorithm using *k=4* segments. Each segment refers to different semantic elements in the scene.

In order to handle this issue, the score of each detection is considered and then non-maximum suppression is applied to keep the detection with the highest score within overlapping detections. This results in one candidate hotspot for each semantic element as shown in Figure 4 bottom right image.

Figure 4. Floor segmentation for navigation space and hotspot localization on detected chair objects

The image segmentation also provides vital information about the semantic elements in the scene. One semantic element vital for navigability is the floor. In order to detect the floor, the segmentation map is further processed by filtering out pixels that fall in the bottom part of the image. Out of these pixels, the segment with the majority number of pixels is picked as floor and is thus segmented out of the image. The top row in Figure 4 shows the segmented floor in the sample input scene. As shown in the figure the yellow line separates the segmentation and the figure on the right shows the segment with majority of pixels. This segment maps to the floor of the detected segments. The localization of the separation line is computed by identifying the y-value that achieves the maximum difference between the segmentation labels in the y-direction and in the same time being in the bottom half of the image.

4. Experimental Results

4.1. DATASET

The metaverse is formed of various virtual environments which the users can navigate. The environments can thus either be indoor or outdoor with completely different semantic elements. For example, chairs, sofas and TV monitors are usually seen more often within indoor scenes while trees, cars and road signs are seen in the outdoor. In addition, the scenes navigated by the users can vary from realistic to synthesized scenes where a realistic scene in general is formed of panoramic images usually taken by a 360° camera. We test our framework on both indoor and outdoor realistic images. The

indoor images are taken from the Sun360 dataset while the outdoor images are taken from Street View images. Figure 5 shows the detected results on sample images from these datasets.

4.2. HOTSPOT CREATION RESULTS

The hotspot creation approach contains some parameters related to number of perspective angles *P* and *T*, number of clusters *k*, and separation line localization. Upon extensive validation, the chosen values for each parameter are listed below.

- *P=36*: pan angles start at 0° and end at 360° with 10° increments
- *T=3*: tilt angles are -20°, 0°, 20°
- *k=4*: the number of segments chosen is 4 which offers enough variety for segment types
- *y0 = 0.6* x *h*: the separation line falls in the bottom 40% part of the scene

In addition, the object classes that we use uses the pretrained YOLO network on the Pascal VOC data set, which contains images from 20 different classes. These classes include chair, sofa, TV monitor, person, car, dining table labels in addition to others. Of course, additional object classes can be incorporated to be trained on the YOLO network which would result in more sematic elements identified such as doors and road signs. We show how the results from the 20 classes are obtained and this could be easily generalized on more class labels.

Figure 5 shows the output results of the hotspot creation pipeline on 4 indoor images and 1 outdoor image. As shown in the figure, various hotspot locations are added into the panoramic image based on the object detection results. The locations identified refer to chairs, sofas and TV monitors in the indoor images since these are the labels on which the network is trained. As for the outdoor image, the hotspot locations refer to cars and people. These localizations suggest that the user navigating the scene can interact with these hotspots. For example, they could sit on one of the chairs and get offered a different view of the classroom. The user could also turn on or off the TV monitor. In addition, these hotspots could be vital for the creators of the virtual environment where they could add more panoramic images at the identified locations since they are considered locations of interest. Moreover, segmentations of floor maps are identified. These segmentations allow the automatic navigability of the environments by showing candidate regions for navigation hotspots.

5. Conclusion and Future Work

In this paper, an automatic hotspot creation approach is proposed which combines two main computer vision tools: object detection and scene segmentation. The proposed pipeline is fully automatic, where for a given 360° panoramic image, candidate hotspots are identified and can be incorporated within the virtual environment to be later used by either the navigator or the creator of the environment. Automated hotspot creation has not been studied in the literature and thus this tool can be considered the first to handle such a problem. In the future, various enhancements can be added to the proposed pipeline. Training deep networks on 360° images with candidate hotspot locations can lead to an end-to-end approach to hotspot creation. In addition, the proposed hotspots can be incorporated within advanced tools in virtual environments which can help in automatically creating spaces and localizing additional objects within architectural scenes.

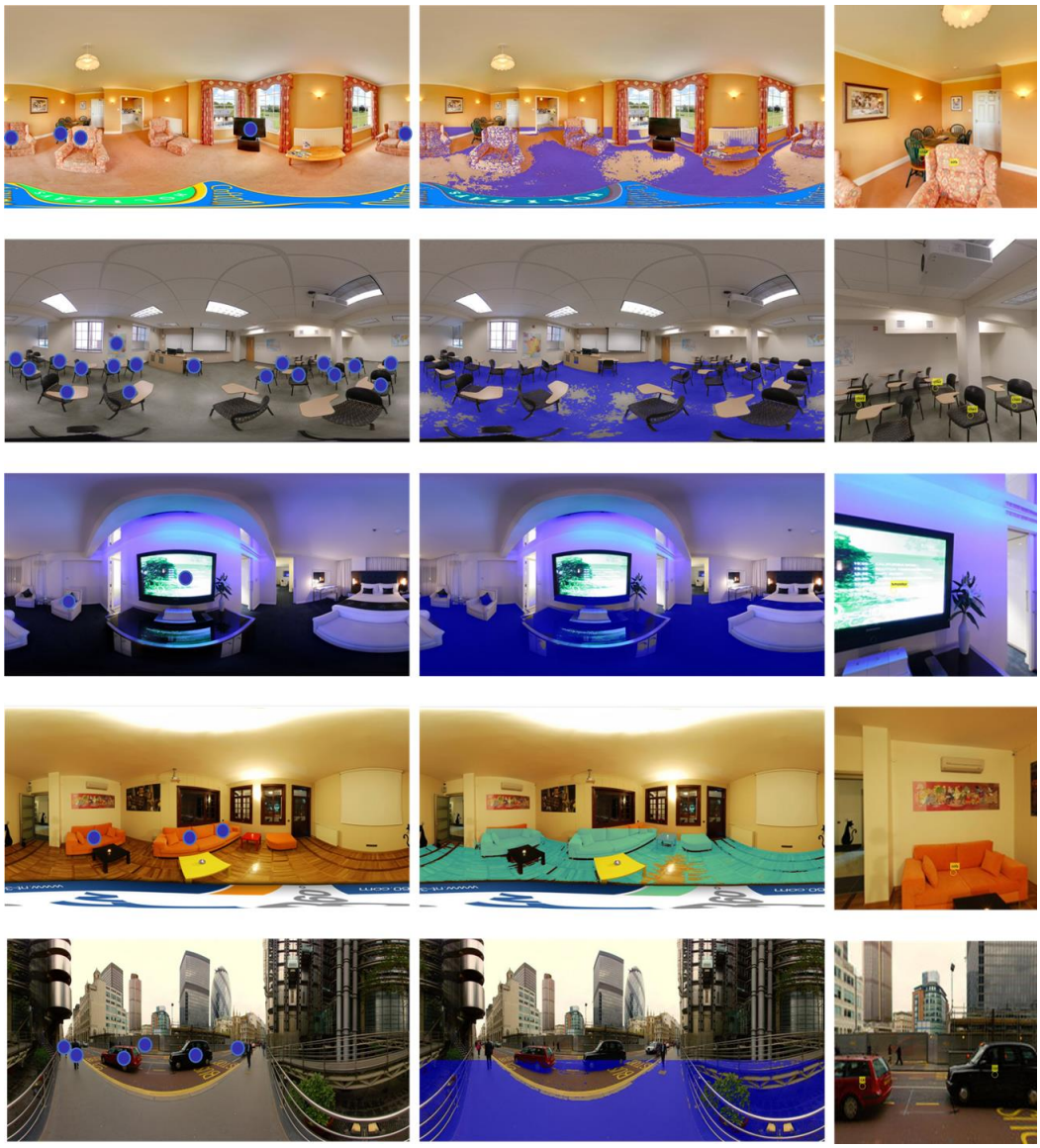

Figure 5. Hotspot creation results on sample indoor and outdoor images. The left column shows the localized hotspots. The middle column shows the segmented navigation space. The right image shows sample object detection(s) from a projected perspective image.

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DAY 1 - PARALLEL SESSION 2

TOPIC 2 - INFORMATION MANAGEMENT

METASCAPES | ARCHITECTURAL QUESTS IN THE METAVERSE

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Abstract. The paper investigates the appropriateness of CAAD software and computational design tools for the creation of metaverse content along with the workflows and limitations involved. In parallel the research aims to assess the validity of architecture design studio research in the context of the metaverse, and its capability to produce results that justify further explorations in such direction.

Keywords: *metaverse, education, architecture, computational design, optimisation*

ملخص. تبحث هذه الورقة البحثية مدى ملاءمة برامج التصميم المعماري باستخدام الحاسب الآلى لإنشاء محتوى للميتافرس، إلى جانب خطوات سير العمل والمحددات المعنية. ويهدف البحث بالتوازى إلى تقييم صحة نهج البحث فى استوديو التصميم المعمارى فى سياق الميتافرس وقدرته على إنتاج نتائج تبرر المزيد من الاستكشافات فى هذا الإطار.

الكلمات المفتاحية: *الميتافرس، التعليم، العمارة، التصميم الحوسبى، التمثيل الأفضل*

1. Introduction

Creating for the Metaverse, in its current development phase, appears to involve new opportunities for architects and novel or repurposed activities to be proposed, hosted, and supported in the virtual realm (Sun, 2021). However, while some core architectural skills and processes might be applicable to the field (Monfared, 2021), new skills and a shift in mindset,

and methods is additionally required (Jensen, 2021). Along these lines, the authors of this paper investigate the appropriateness of CAAD tools and test the applicability of architectural design methodologies for the production of metaverse content and environments.

To explore the above, an educational intensive 1-week workshop was realized at the University of Nicosia, offering the opportunity to undergraduate architecture students to engage with custom software workflows and metaverse platforms towards proposing and constructing interactive virtual environments.

The authors aimed to answer practical questions such as: could CAAD software be implemented for the creation of metaverse content and if so, what are the workflows and limitations involved? What is the potential role and possible applications of computational design tools in creating for the Metaverse? In parallel the research aimed to assess whether the architecture design studio research approach could be valid in a virtual context and capable of producing results justifying further study and exploration in such direction. In relation with the latter, the authors share David J. Chalmer's proposition that the questions that matter most are not about reality and unreality at all, but rather about the kinds of experience, agency and opportunities afforded by any environment we are responsible for: "if these are genuine realities, ones where you can have meaningful experiences, what kind of meaningful experiences are we going to have?" (Chatfield, 2022). Under such perspective, designing for physical or virtual spaces could be seen through a common lens and allowed the research team to investigate the capacity of architectural design process to produce new experiences, formulated through innovative uses and activities, for the metaverse.

The workshop brief was therefore structured to yield certain outcome, the analysis of which could provide answers to the above research questions. The participants worked in two parallel directions; A. developing a practical software skillset enabling building for the Metaverse, B. accumulating sufficient theoretical background knowledge, including fundamental concepts pertaining the Metaverse domain, in order to propose an innovative use/activity/experience for their proposals. They experimented with the creation of digital models using architectural 3D modelling design tools and actualized custom workflows involving paradigms from disciplines such us game developing and computational design to launch proposals for selected Metaverse platforms. The design development was forked in three pipelines implementing specific software workflows and file types, effectively identifying the required CAAD methodologies and classifying distinct Metaverse platforms. Five proposals were produced and discussed in the study, producing conclusive findings, and revealing a fertile ground for further architectural research in the Metaverse.

2. Workshop

The workshop was hosted under the Architecture Catalysts Course at the Department of Architecture of the University of Nicosia in Cyprus. Architecture Catalysts are elective, intensive one-week courses, whose content vary every semester depending on the interests of faculty and visiting specialists. The courses are intended to add flexibility to the curriculum and provide a productive academic break during the semester. With the catalyst in place, the faculty can respond to newly developing research or design practices offering motivating and exciting opportunities to students and participants.

The specific Catalyst Workshop ran during Spring Semester (14th– 18th March 2022) and was attended by thirteen, third-year students studying at the department of architecture divided in five teams. The workshop brief was structured so that the participants could work in two parallel directions: accumulating sufficient theoretical background knowledge and developing a practical software skillset enabling them building for the Metaverse.

Finally, the participants were voluntarily asked to submit their proposals to *The Next Top Metaverse Build*, a virtual buildathon, competition and accelerator program helping spotlight the next wave of Metaverse entrepreneurs and builders. The competition offered the opportunity to build, pitch and test ideas in front of industry-leading Metaverses, protocols, organizations and investors.

2.1. PART A. THEORETICAL FRAMEWORK

This part of the workshop aimed at formulating a foundation of peripheral knowledge from which proposals could be initiated. Like a design studio research assignment, the participants were initially tasked to analyze their virtual sites, corresponding to their assigned Metaverse platform. As such, they were requested to carry out research on the key characteristics of the platforms and register relevant metrics and data for the predominant activities and users. The students were requested to pose and answer questions such as: Who is the target audience, what are people using the platform for, how do users interact? Additionally, students were given key readings to consider, attended lectures from specialists in the field and were introduced to and discussed fundamental concepts relating to the domain.

The authors inherited an open-ended and purposely broad title for the workshop: *Metascapes*, deriving from the prefix meta- combined with the word –scape, was chosen to encompass a wide variety of interpretations while denoting a quest for a plausible Metaverse future. By discussing the title, the participants were encouraged to consider the role of the metaverse as a groundbreaking technology. Would it perform as an escape or a genuine

connection to everyday life and activities? Is it emerging beyond our current reality, or alongside? Are we steering towards the idea of an augmenting layer or an immersive dystopian alternative to the physical world?

Additionally, participants were introduced to the fact that online virtual environments and gaming platforms present early versions of the Metaverse, exhibiting multiuser participation in a range of domains. Understanding the evolution and potential innovations promised by an emerging Metaverse involves some lessons on the precedent efforts in building virtual worlds (Sun, 2022). In this perspective, virtual societies, spaces, and identities present nothing new, nonetheless the adoption and integration of blockchain technology fuels new applications and a proliferation of the aforementioned virtual worlds and activities.

In parallel, the importance of virtual interactions and their hosting environments, during and after the pandemic lockdowns, was highlighted. Namely, the paradigms of museums and galleries which have virtually opened their gates to visitors and physical spaces which have acquired permanent extensions into the virtual world were discussed (Levin, 2021). Simultaneously, the NFT movement disrupting the institutions of the art world was introduced. Within this context, digital art works can now be unique, verifiable, and tradable driving the emergence of virtual exhibition platforms and spaces, the design of which is recently commissioned to architectural firms (Stouhi, 2021).

Lastly, architecture in the Metaverse era was approached and deliberated in relation to the mandate of the physical world. Crossing the doorstep of the Metaverse, one can experience spaces stripped of their structural or environmental constraints, tasked to support virtual or augmented happenings. Navigating, involves hyperlinking, teleporting, or flying, and gaming, albeit still the predominant use, is giving way to other human activities.

While some suggested that Digital twins will act as the "foundations of the Metaverse"(Frearson, 2021), the authors support that the place of architecture is yet to be established. Architecture is defined as the process of conceiving and facilitating the delivery of build environments to host human activities. By translating the above assumption, the research team aimed to investigate the capacity of the architectural design studio process to produce virtual environments for novel or re-imagined Metaverse activities. The outcome was therefore evaluated based on responding to the workshop brief in terms of sufficiently formulating and designing for a novel activity. For the purpose of this study, the ability of the participants to propose and articulate a new activity (or a synergy of activities), was perceived as a key measure in the capacity of the design studio process and its applicability in the Metaverse domain. Succeeding in proposing new activities and designing virtual environments to support them would demonstrate competences

already tested and verified in architectural education and therefore validate the applicability of the process as an effective framework for architectural contributions to the Metaverse.

2.2. PART B. TECHNICAL FRAMEWORK

This part of the workshop aimed at developing and adapting technical knowledge and skills to aid participants building their proposals. The authors approached this part with the assumption that online 3D modelling tools (native platform builders) offered by various metaverse platforms are currently limited in creating, editing, and optimizing builds. From this standpoint, the research team posed the question of whether CAAD software, part of the curriculum, could be implemented for the creation of metaverse content.

Students at the department of Architecture of the University of Nicosia are formally exposed to several software packages but are specifically more experienced in Rhinoceros3D and its graphical programming editor Grasshopper (by Robert McNeel & Associates) It was therefore practical for the teams to choose the above packages as the tools to test the paper hypothesis.

To streamline the process, the research team prescribed three pipelines within which the participants could research and develop their projects (Table 1). Each pipeline was associated with specific file types identifying distinct paths to metaverse platforms. As such the participants operated in the “Voxel”, the “Polygon” and the “Game Engine” pipelines. The Voxel pipeline was handling *.vox file types, the Polygon Pipeline was corresponding to *.gltf files whereas the Game Engine Pipeline was addressing specific workflows from the 3D modelling software to gaming engines such as Unreal Engine or Unity associate with specific Metaverse platforms.

TABLE 1. Workshop pipelines.

Pipeline	**Files Types**	**Metaverse Platform**
Voxels	*.vox	Sandbox, Cryptovoxels, other
Polygons	*.gltf	Decentraland, other
Game Engines		Somnium Space, MONA, other

Subsequently, each team selected a pipeline and was requested to visit the corresponding Metaverse platforms and familiarize with their technical features, requirements, and limitations. Students were requested to identify and catalogue available plot sizes, permitted number of polygons, maximum

file sizes, material and texture requirements and other relevant technical information.

In parallel, students were asked to experiment, research and develop a consistent information workflow to transfer their designs from Rhinoceros3D to the corresponding Metaverse platforms. As such students needed to investigate the use of exporting and importing plugins or translate through various software to reach the destined Metaverse platform. Throughout the course the scale of the 3D model had to be constantly monitored and maintained, an often-ambiguous process.

The research team understood that geometry size limitations imposed by various metaverse platforms in terms of numbers of polygons or voxels, or file sizes imposed a significant drawback in the workflow. Optimization strategies in regard to maintaining design intent emerged as a major task that drove the development of the proposals.

Finally, the intrinsic characteristic of interactivity exhibited by virtual environments and supported by various metaverse platforms attracted special focus and was elevated to a central design element in several proposals.

3. Proposals

During the workshop five proposals were developed along the pipelines explained earlier. The results include two proposals in the Polygon Pipeline (Decentraland), one proposal in the Voxel Pipeline (Sandbox) and two proposals in the Game Engine (Unity/MONA) pipeline. Each proposal and its characteristics are briefly described in the next paragraphs.

3.1. LUSH (DECENTALAND)

LUSH (Figure 1) is an awareness platform, designed to inform, donate and buy NFTs that benefit environmental development and the preservation of endangered flora; a garden space, which is used for gathering, education and play.

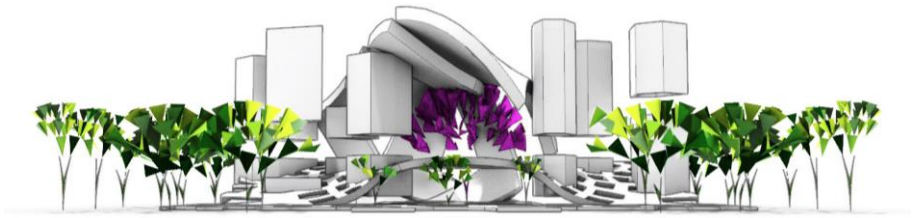

Figure 1. LUSH Proposal.

The project was designed, adapted, optimized and tested for Decentraland on 4 Parcels with 64 x 64 m in size. The main design element of the proposal are the trees that represent various species. These models (of trees) can be acquired by the virtual community and populated (planted) elsewhere in Decentraland or other Metaverse platforms, therefore contributing to the initial cause: educating the community and preventing further flora extinction.

The trees were modelled in low-polygon resolution and were generated in Grasshopper, using an L-System algorithm. Unique models were produced by randomly changing the parameters of the tree model, such as number of branches, number of branching generations, number of leaves and color values.

The geometry was exported from Rhinoceros3D via a plugin, including materials and texture. The file was uploaded as a series of assets into Decentraland´s Native Builder. Interactive elements, such as buttons, linked to donation sites and NFTs, were added via the builder.

3.2. CTRLshift (SANDBOX)

CTRLshift (Figure 2) is a customizable and gamified virtual Non-Fungible Token (NFT) gallery space that can foster interactions between visitors and engage the audience.

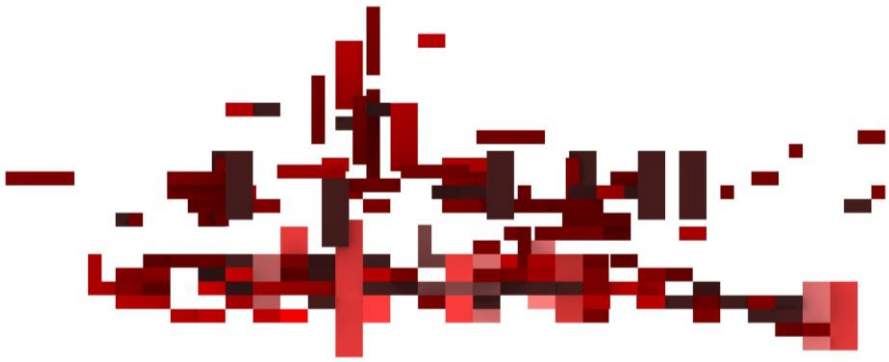

Figure 2. CTRLshift proposal.

The project was designed, adapted, optimized, and tested for the Sandbox metaverse platform on one Land Parcel of 96 x 96 m in size. The concept pertains the customization of virtual space. The environment represents a shifting gallery made of different types of block geometries. Some blocks are animated in space, some are portable, and some are fixed. The portable blocks allow for space customization by the user, to host other activities or implement specific scenarios, in a flexible game-like environment.

The geometry was created in Rhinoceros and translated through Magicavoxel (a commercial/freeware software) before imported in Voxedit, Sandbox´s native Builder. Game mechanics, such as animations and interactions were prepared in Gamemaker, Sandbox´s custom game design tool. The software includes additional assets such as buttons, weapons and avatar bots some of which were incorporated in the design.

3.3. VORTEX (MONA)

Vortex (Figure 3) is generic exhibition space for built environment presentations. As such the virtual space can be used to exhibit models that perform as portals to experience real-scale versions of the structures on exhibition. The proposal can find applications in the Real Estate, Archaeology, Education, AEC, and other sectors producing building scale digital models. A fractal space that enables the visitor to teleport inside the exhibits to experience 1:1 scale buildings on display.

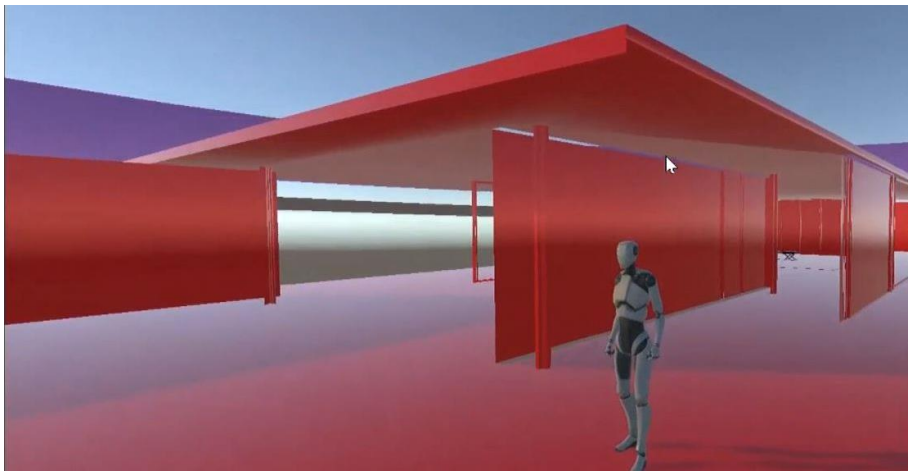

Figure 3. VORTEX proposal.

The project was designed, adapted, optimized, and tested for the MONA Metaverse platform and has a size of 180 mb. The geometry consists of a singular pathway gallery, shaped as a helix. Presentation panels and educational interactive media are placed on the exterior surface of the project. Scaled models are positioned along the central axis of the helix and are accessible through portal links, strategically located inside the gallery.

The geometry was modelled using Rhinoceros3D, including materials and textures and was exported to Unity. A Unity template, provided by MONA, was implemented to translate the model file into the virtual

environment. Interactive elements such as portals for teleporting between the main exhibition space and the scaled models were also added in MONA.

3.4. META-MAZED (DECENTRALAND)

META-mazed (Figure 4) is a gamified virtual space that aims to engage visitors through a maze type of environment. It presents an effort to implement interactive features of real-world escape rooms such as keys, riddles and buttons into a metaverse environment. The project is organized in levels of increasing difficulty which the user needs to complete. The winners are rewarded with Access-NFTs, providing entry to specific social events.

Figure 4. META-mazed proposal.

The project was designed for Decentraland on 2x3 Parcels with 32 x 48 m in size. It develops upon the platform's inherent spatial parameters such as the minimum height an avatar can jump, the maximum height it can walk over (bridge) and the maximum walkable slope (45°). It also implements materiality (transparency) to trigger the user´s perception into identifying which parts of the environment are walkable.

The geometry was exported from Rhinoceros3D via a plugin, including materials and texture. The file was uploaded as a series of Assets into Decentraland´s native Builder. The various interactivity elements, offering the gaming experience, were added via the builder.

3.5. ODYSSEY (MONA)

The ODYSSEY (Figure 5) is an allegorical proposal that aims to engage the visitor in a journey of experiences and surprises. The project was designed, adapted, optimized, and tested for the MONA metaverse platform. Odyssey

aims to cause extreme spatial stimulation to its users, by embracing the potentials of animation and lack of physics in a metaverse environment.

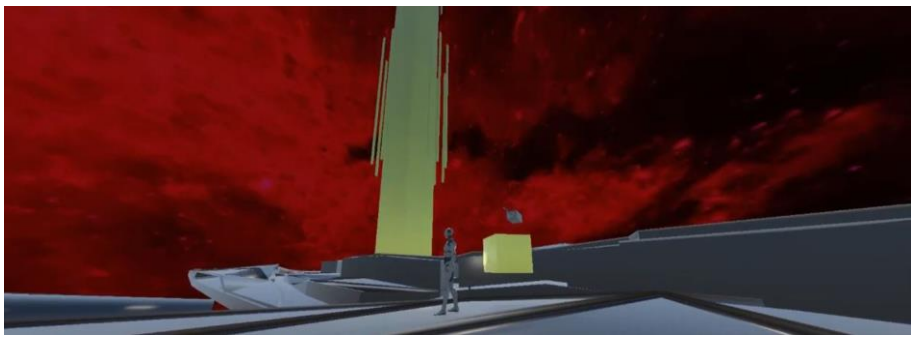

Figure 5. ODYSSEY proposal.

Upon entering the virtual environment, the user has a clearly visible goal to reach, an infinite tower. The journey takes the user from one extreme spatial experience to another through portals, shaped as parts of the tower. There are strong contrasts between these environments, from open to closed, bright to dark, monochrome to colorful and static to animated. Spatial experiences include a tunnel of rotating rings with hallucinogenic patters, or a sealed triangulated space with sharp edges. Additionally, one can experience an open-air platform with a striking sci-fi sky texture or a labyrinth with animated clashing walls, a reference to *the Symplegades*. No matter how persistent the navigation is, the user is unable to reach the infinite tower, denoting the importance of the journey over the goal.

The geometry was modelled using Rhinoceros3D, including materials and textures and was exported to Unity using the aforementioned template. All interactivity elements, animations and lighting features were added via Unity.

4. Discussion

4.1. THEORETICAL EVALUATION

In terms of proposing and articulating new activities, synergies, and experiences, all five teams were able to respond to the brief. While some of the projects are founded on existing uses or activities, like galleries or exhibition spaces, they manage to infuse or complement the proposals with innovative elements resulting in new ideas and pertinent results.

The LUSH project manages to link virtual to physical worlds through the means of sponsoring the planting of real trees and raising awareness on

pressing environmental issues. The idea of generating virtual trees that are unique, sharable and purchasable aligns with current activities recorded in major decentralized Metaverse platforms, has inherent 3-dimensonal and spatial qualities and has not been encountered beforehand by the research team.

The CTRLshift project manages to elevate the idea of an NFT gallery into a gamified public space of interactions, with certain levels of control by performing users or artists. As such, the elements of customizability and interactivity of space, beyond the obvious and commonly encountered updating of the exhibits, present unique characteristics that justify innovation in a metaverse context.

The META-mazed project focuses on providing novel experiences by proposing the idea of a virtual escape room. A popular form of entertainment in the physical world, with an inherent spatial structure, gets a virtual reinterpretation which offers innovative possibilities aligned with the lack of physical constraints encountered in virtual environments. The project explores the potential of virtual spatial configurations enhanced by elements of interactivity to offer new entertainment activities for the metaverse.

Vortex project can be categorized under virtual exhibition spaces but with a twist. The key element that differentiates the specific project is the fractal approach in the organization of the space itself. The proposal explores the navigating possibilities offered by virtual environments to hyperlink and teleport users between spaces and scales. As such the visitor could be observing a scaled model or a 2D representation but has the option to teleport to the interior to explore and experience it in real scale.

Finally, Odyssey attempts to use symbolism and narrative to structure a fictional cosmos. A journey of experiences and surprises with no definitive conclusion aims to create a virtual place that encompasses meaning and didactic value. The project hints that virtual environments could support collective and shared experiences revealing a virtual *genius loci* or the existence of Metaverse places.

4.2. TECHNICAL EVALUATION

All five teams have managed to realize consistent workflows from a 3D modelling software to their chosen platform and to translate their projects from a familiar modelling environment to interactive metaverse scenes. The workflows support the argument of the research team for a classification of Metaverse platforms based on three pipelines and their corresponding requirements. As such the Voxel, Polygon and Gaming Engine Pipelines can be recognized as valid pathways that can lead from CAAD software to native metaverse builders and platforms. The Game Engine pipeline used in Vortex and Odyssey, was directly realized through an *obj file format,

imported to Unity. The polygon pipeline, implemented in LUSH and META-mazed required exporting to a *gltf file that (performed via the glTF-BinExporter by Aske Doerge before moving to a Metaverse platform native builder. Realizing the Voxel pipeline presented challenges for the CTRLshift project team. Exporting the geometry from Rhinoceros3D and optimizing it for the Sandbox required exchanges between three software. The files were exported from Rhinoceros3D in *.obj file format before imported in Magicavoxel, to be converted into *.vox format. From there, the files were placed in Voxedit, Sandbox´s custom Builder. The transition caused inconsistencies (changes in scale), which the students had to overcome. Magicavoxel would only allow for objects of max. 5x5x5m to be imported consistently at a time from Rhinoceros3D, due to a max. 256 voxels importing limitation. To address this logistical workload, a simple algorithm was developed in Grasshopper, to split the entire design into blocks of 5x5x5m. Once all the blocks were imported in Magivoxel the entire model was exported in a *.vox file format before imported in Sandbox´s Voxedit for further editing.

Most metaverse platforms operate through browsers and are therefore very limited in handling large files or high numbers of polygons and voxels. All proposals identified the need for optimization, as a core design strategy that would enable delivery of the projects without sacrificing the design intent. The above task was handled by all teams, either through the use of modelling or computational techniques. In the case of META-mazed the team had to comply with the 60000 triangles limitation imposed by Decentraland which meant that meshes needed to be significantly simplified. A reduction came when all cylindrical elements (pipes) were translated into orthogonal cross sections. In the case of LUSH the design called for multiple tree models to support the concept. Initial trials only allowed for a single tree (commercial 3D model) to be uploaded on Decentraland before the platform's polygon allowance was reached. The use of computational design tools for generating the trees provided a practical solution while resulting in a unique polygonal-art character for the project.

Materials and Textures was another area explored as part of the above workflows. Along with geometries, all teams fared at consistently translating materials and textures from a 3D modelling software to the respective metaverse platforms. While the above task was accomplished at a basic color/texture level, in the case of META-mazed, the team has additionally managed to implement material properties such as transparency, reflectivity and light emissions from the Rhinoceros3D model into the Decentraland Builder. This was achieved by using only PBR-materials (Physically-Based-Render) and altering the Alpha Transparency.

5. Conclusion

The workshop and outcome presented in this paper verifies the appropriateness of CAAD software and computational design tools for creating Metaverse content. All results demonstrate a translation from a 3D modeling environment to a Metaverse platform through finite and repeatable steps. In addition, the results support the classification of three workflow pipelines proposed by the research team. The authors aim to continue exploring other software packages to identify further simplifications in the identified pipelines. Computational tools have been implemented to tackle optimization issues, logistical workload or as design tools to generate a multiplicity of solutions. Limitations were mainly imposed by the constraints of the metaverse platforms or the complexity of transitioning through various software packages while maintaining consistent models and materials. Finally, a number of breakthroughs were recorded in material processing and texture transitions with the implementation of PBR materials.

In terms of assessing the validity of architecture design studio research in the context of the Metaverse, the authors support that the resulting proposals present an indicative sample of the suitability of the process. While the authors understand that empirical analysis is difficult to be developed, the fact that all teams have responded to the brief, by assimilating and addressing the multi-parameter nature of the problem, presents a considerable finding. As such, all teams have proposed pertinent uses, activities and experiences realized as occupiable virtual architectural solutions.

The results justify further explorations with possible benefits for the architectural education. The research enabled key realizations that could turn advantageous for architectural curricula. Fundamentally, Metaverse spaces are inherently exposed to the user. This attribute enables real time testing and feedback on architectural scenarios by specific users or the public, adding new dimensions to the design process. Additionally, designing for the Metaverse can be selectively disconnected from the multi-parameter complexity of the physical world and intentionally focused only on specific spatial qualities. This property appears to fit the early years of architectural education aiming to explore and experience essential spatial concepts such as scale, perspective, colour, light etc. Finally, building for the Metaverse involves technical discipline, self-auditing, and optimization strategies that only digital fabrication currently imposes during the architectural education. Building for the Metaverse is therefore entailing the enhancement of CAAD skills and methodologies.

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A FRAMEWORK FOR CREATING A HYBRID EXPERIENCE FOR NFT ARTWORKS THROUGH 3D PRINTING

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Abstract. Technology has become a fundamental part of our environment, yet the borders between the physical and virtual realms become even more blurred. The introduction of the Metaverse is one of the most recent and notable innovations. It, just as any other technological advances, adapts to evolution in user needs serving as a link between the real and digital realms. While people can buy goods and services with a certain currency in the physical realm, cryptocurrencies and non-fungible tokens (NFTs) are used for transactions in the Metaverse. NFT provides customers a certificate of ownership, which means that their virtual commodities or assets such as lands or objects cannot be replicated. They may also be used to represent social standing, just like tangible goods and services. It has become increasingly common to come across museums displaying artworks or artists who sell their artworks as Non-fungible tokens (NFTs) on digital platforms such as Rarible, Mintable or OpenSea. This research discusses the 3D printability of NFTs and proposes a framework in order to create a hybrid experience for 3D printed NFT artworks. The results have shown that 3D printing of NFTs provided users/customers a hybrid experience in both realms, maintaining the artworks' uniqueness and rarity, proof of ownership, as well as physical copies in hand. Moreover, the artists who were afraid of publicly displaying their artworks for the concern of being copied have created 3D printable designs that enabled them to easily and safely promote their designs to the public.

Keywords: *NFTs, 3D printing, digital fabrication, Metaverse*

ملخص. أصبحت التكنولوجيا جزءًا أساسيًا من بيئتنا، ومع ذلك أصبحت الحدود بين المجالين المادي والافتراضي أكثر ضبابية. يعد إدخال الميتافرس أحد أحدث الابتكارات وأبرزها فهو

تمامًا مثل أي تطورات تكنولوجية أخرى، يتكيف مع التطور في احتياجات المستخدم ليكون بمثابة رابط بين العالمين الحقيقي والرقمي. بينما يمكن للأشخاص شراء السلع والخدمات بعملة معينة في المجال المادي، تُستخدم العملات المشفرة والرموز غير القابلة للاستبدال في المعاملات في الميتافرس. توفر الرموز غير القابلة للاستبدال للعملاء شهادة ملكية، مما يعني أنه لا يمكن نسخ سلعهم أو أصولهم الافتراضية مثل الأراضي أو الأشياء. يمكن استخدامها أيضًا لتمثيل المكانة الاجتماعية، تمامًا مثل السلع والخدمات الملموسة. أصبح من الشائع بشكل متزايد العثور على متاحف تعرض أعمالًا فنية أو فنانين يبيعون أعمالهم الفنية كرموز غير قابلة للاستبدال على منصات رقمية مثل Rarible أو Mintable أو OpenSea. يناقش هذا البحث قابلية الطباعة ثلاثية الأبعاد للرموز غير القابلة للاستبدال، ويقترح إطار عمل من أجل إنشاء تجربة هجينة لأعمال الرموز غير القابلة للاستبدال الفنية المطبوعة ثلاثية الأبعاد. أظهرت النتائج أن الطباعة ثلاثية الأبعاد للرموز غير القابلة للاستبدال وفرت للمستخدمين أو العملاء تجربة مختلطة في كلا المجالين، مع الحفاظ على تفرد الأعمال الفنية وندرتها، وإثبات الملكية، بالإضافة إلى النسخ المادية في متناول اليد. علاوة على ذلك ، فإن الفنانين الذين كانوا خائفين من عرض أعمالهم الفنية علنًا من أجل القلق من نسخها، ابتكروا تصميمات ثلاثية الأبعاد قابلة للطباعة تمكنهم من الترويج بسهولة وأمان لتصميماتهم للجمهور.

الكلمات المفتاحية: *الرموز غير القابلة للاستبدال، طباعة ثلاثية الأبعاد، تصنيع رقمي، الميتافرس.*

1. Introduction

In 2021, an NFT (Non-Fungible Token) was sold as a digital file in JPEG format, which everyone can access and copy for free, was sold for $ 69.3 million (NYTimes, 2021), which attracted the attention of the whole world to these assets. Using blockchain technology, NFTs are crypto assets that authenticate to the uniqueness of virtual assets and are certified with their developer. A new age in the blockchain ecosystem, which at first exclusively contained cryptocurrencies, has started with NFT (Vidal-Thomas, 2022).

While one of the most recent and noteworthy innovations, Metaverse, acts as a bridge between the physical and digital worlds, most of the artists are discouraged to use digital platforms for displaying or selling their artworks due to the fear of unauthorized reproduction. This case is also valid in creating, sharing and trading the digital artworks since the authorship and uniqueness of the digital assets become questionable.

2. Blockchain technologies and NFTs

The companies such as Meta acknowledge the huge upheaval that humankind is undergoing and have developed innovative solutions. The idea of a Metaverse dates back to 1992 Neal Stephenson's science-fiction novel Snow Crash in which he fictionalized a virtual world. Later on, similar concepts were developed in numerous science-fiction books and movies, notably Steven Spielberg's movie Ready Player One in 2018. Although the concept was introduced decades ago, the notion of the Metaverse has become popular

in the last few years since we are in the midst of a huge cultural transformation. It is more than simply a virtual realm or online surfing; it also has its own economy and currencies based on blockchain technologies.

Many attempts have been made long before the emergence of blockchain technology, in order to establish a digital currency with global validity on the internet (Liu et al., 2022). However, these initiatives had to be ended due to the problem called "double spending" (Zheng et al., 2021). The same digital currency could be used in two different trading transactions by causing the sabotage/fraud of one of the sellers (Pinzon and Rocha, 2021). All digital files that can be stored on the Internet are a string of data bits and are relatively easy to copy (Akbar et al., 2021). For example, a pdf document is sent to another person. When sent, a digital copy of the document is sent to the recipient and the original remains with the sender. Sending the document to another person will not prevent the person from accessing it. This situation gives users insecurity and trouble. Although the system provides the opportunity to reproduce digital information and share it with other people, it was a critical security problem for digital currencies. It has the nature to cause a deficit in transactions (Pisa and Juden, 2017).

Blockchain is considered secure and basically refers to a distributed digital database (Liao and Katz, 2017). A digital ledger is an electronic record of data kept on a computer (Franks, 2020). Distributed refers to the simultaneous processing and storing of records among a number of computers connected to a network. The blockchain departs from conventional centralized databases, where data is processed and saved on a single server (Gururaj, 2020). The distinction between a centralized and decentralized (distributed) computer network is depicted in the Figure 1 below, where the dashed lines signify the data flow.

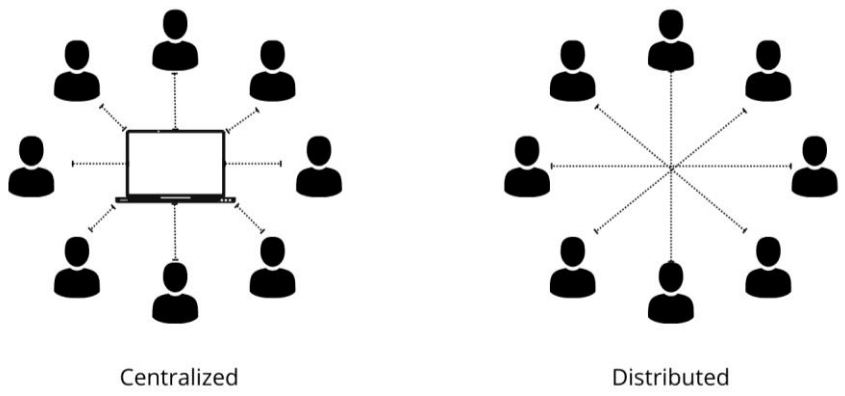

Figure 1. Centralized and distributed network.

As you can see, a centralized network uses a single primary server to handle and store all of the data. All of the data will be exposed if this system is compromised or hacked. On the other hand, each computer, or node, in a decentralized network processes and stores data. Each blockchain node that receives a copy of the full ledger is able to include new records to it. Before new transactions can be included in a block, the majority of nodes must acknowledge that they are authentic (Wright and Serguieva, 2017). As a result, the blockchain becomes safer since it would take a successful breach of more than 50% of the network to compromise the data. Because the ledger's data is visible to everyone on the network, it also encourages accountability and transparency.

Another significant parameter of emergence of blockchain technology is that the blockchains are designed to be decentralized since the creators of this technology intentionally did not want any one individual, company, bank, organization, local authorities, or country to monitor or supervise a blockchain (Atzori, 2017). Instead of looking for security and trust in the full faith and credit of a government or the financial resources of a large bank, members of the blockchain community of users, investors, and developers find security and trust in a peer-to-peer network of users that each contain a full copy of the blockchain as well as in the blockchain's encryption technology, which enables transactions without the interaction or supervision of counterparties or custodians (Murray, 2022).

In the current "proof of work" model of blockchain formation, a person can retain the right to add a new block by downloading the entire blockchain and completing a series of difficult mathematical calculations known as cryptographic "hash" processes (Sobti and Ganesan, 2012). This person is referred to as a miner or minter. As mentioned above, the blocks created by mining and minting under the proof of work model could contain bitcoin, tokens (NFTs), or other collections of data. The blocks are created using hash calculations and attached to the blockchain.

Forging or minting, as opposed to mining, is more likely to be used to describe the creation of an NFT when the "proof of stake" approach is applied. A consensus mechanism will be chosen from this group to forge the block, and the other participating nodes will decide to validate the block. This technique requires those who wish to be qualified for the bonuses of creation to stake cryptocurrency in a wallet in order to acquire the right to be a validator.

An NFT (non-fungible token), a particular class of blockchain-based cryptographic token, is utilized to identify digital assets. Due to how simple it is to replicate digital data, NFTs specifically offer a mechanism to demonstrate the ownership and validity of digital assets, something that was not truly achievable before. In this way, the digital assets are protected to a high level. This is mostly important for the artists who display their artworks in digital

platforms as digital assets in different formats. A simple copy and paste or screenshots would be enough for "having" the artwork however an authenticity can only be provided through tokenization today.

As previously mentioned, the NFT logs a minting transaction that is integrated into a block, encrypted, and attached to a blockchain. There is a conscious effort to limit the amount of data (i.e., the file size) of the assets that are to be identified into the NFT since blockchains typically use a proof of work model for creation of blocks and the most popular chain for art NFTs, Ethereum, enforces gas fees for the formation of NFTs. In simple terms, the bigger the file, the longer it will take a minter to detect a matching address for the block and the more gas will be used to attach the block to the chain. Therefore, the block must have a very small graphic file size if it is to include an actual artwork file such as a.jpeg, .gif, or .png. For example, CryptoPunks are able to be directly coded into their NFT and transferred on the chain due to its small file size, extremely low resolution, and huge pixelation (only 24x24 pixels, or 24 dpi resolution or 0.001-megapixel resolution) (Murray, 2022).

A smart contract (your certificate of ownership) that refers to a bundle of metadata, amongst many other things provides access to your NFT file, is what you actually purchase when you purchase an NFT (Malsa et al., 2021). To enable customers to clearly identify what their purchase rights them to, NFT markets generally show token metadata on the transaction page. The token metadata presented on a listing from the Mintable.app marketplace is shown in the Figure 2.

In any case, the encouragement due to the authorship protection in NFTs has become critical in terms of both trading digital artworks and experiencing artworks in digital display media without a concern about the authorship. However, the gap between the digital artwork and the owner does not shrink since the ownership exists fully on the digital platforms as a stored data. Although the one who pays for the artwork gets to own the artwork, the preview images for example can still be downloaded even if no authorship can be claimed. Therefore, this paper proposes a framework in which the NFTs can be materialized through 3D printing. In this way, 3D printing of NFTs can provide a hybrid experience in both realms, maintaining the artworks' uniqueness and rarity, proof of ownership, as well as physical copies in hand. Moreover, the artists who were afraid of publicly displaying their artworks for the concern of being copied can create 3D printable products that help them to easily and safely promote their arts to the public.

Token Metadata


```
{
 "symbol": "Mintable Gasless store",
 "image": "https://d1iczm3wxxz9zd.cloudfront.net/c92a4640-3852-
4686-b629-c80405f258da/000000-
0000000000/676088944993951721371096243868483153217394812728325425221970 35
 "animation_url": "",
 "royalty_amount": 500,
 "copyright_transfer": false,
 "address": "0x8c5aCF6dBD24c66e6FD44d4A4C3d7a2D955AAad2",
 "tokenId":
 "676088944993951721371096243868483153217394812728325425221970 35
 "resellable": true,
 "original_creator":
 "0x957947392EEF123ACb103925dfE8E3784177BBF2",
 "edition_number": 1,
 "description": "<p>I am relaxing</p>",
 "auctionLength": 0,
 "title": "Do not disturb",
 "url":
 "https://metadata.mintable.app/mintable_gasless/676088944993951
 "file_key": "",
 "apiURL": "mintable_gasless/",
 "subtitle": "Do not disturb",
 "name": "Do not disturb",
 "auctionType": "Fixed",
 "category": "Art",
 "edition_total": 1,
 "gasless": true
```


Figure 2. Token Metadata on Mintable.com.

3. Methodology and framework

An NFT has a huge potential for 3D printing since the design and execution files are already stored as digital artifacts. That is, these files are readily included into an NFT, directly or by a third-party hosting site that stores the data. Therefore, a framework (Figure 3) is proposed in which the NFT enthusiasts have access to the related folder labeled with the NFT code. There are several files in this folder, including print settings instructions and a tutorial on how to assemble the separate components into the full model. The methodology is divided into four main steps: Collaboration with NFT artists for creating a network and database; Creating STL files and uploading on GitHub; Minting NFT artworks on a Ethereum blockchain based trading platform; Tracking the transactions. This framework aims to provide a transition from digital to physical where experiencing both media become possible.

In order to create an NFT artist network, several accounts on social media were contacted and their NFT accounts are reviewed. The specifications regarding the printability were discussed and a database was constructed.

After the creation of the database, a private GitHub profile was created in order to upload STL files and the data in the profile was restricted in order to seal the identity of parties of transactions. Then, 2D vector-based NFTs were extruded in the modeling platform and the 3D files were refined. The NFTs were uploaded to Mintable, a free trading platform based on Ethereum blockchain. A preview image, item description and listing details were entered and the GitHub link was inserted into private/unlockable content. After listing the NFTs, a number of auctions were received and the NFTs were sold. After each transaction, the GitHub page was checked and the number of download values were recorded.

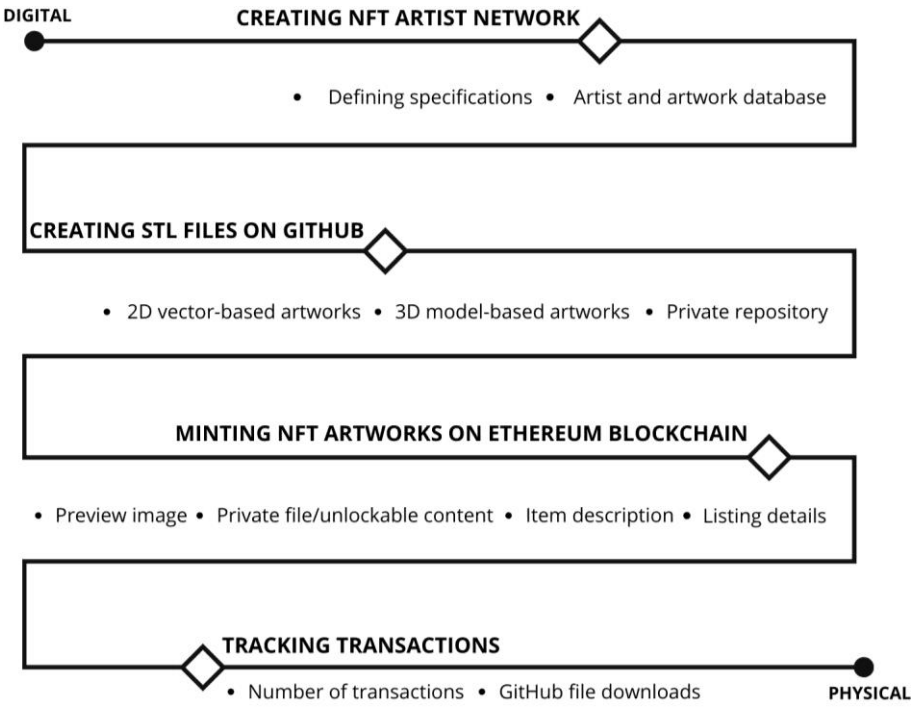

Figure 3. Methodology of the framework.

4. Application and results

The proposed system was conducted with the NFT artist XXX as the starting point to validate the overall system. Four of the artworks have been converted to STL files through modeling on Rhinoceros 3D/Grasshopper, using Image Sampler and the optimized forms were 3D printed (Figure 4). Two of the artworks were 2D drawings originally so they were converted into lines, and

their extrusion (Figure 5) provided a possibility of printability. The other two files were already in 3D format; however, they were not printable due to the mesh topologies. Therefore, the 3D forms were optimized and their mesh faces were reduced in order to be able to print them. At the end of the printing, each artwork was used as a decoration or as a product such as a painting on the wall or a keychain, in which they have found their way of engagement with their audience in the physical realm.

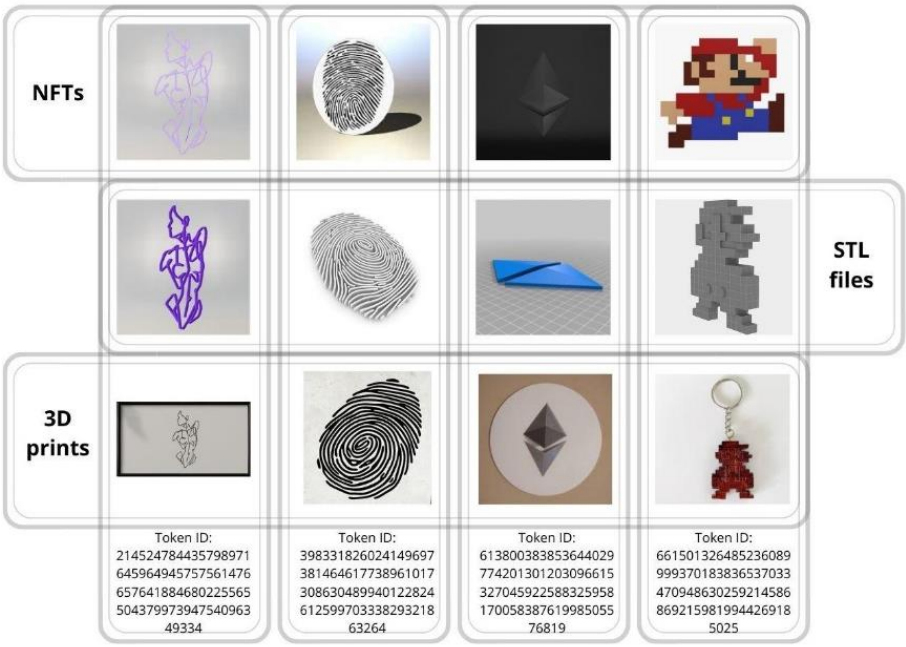

Figure 4. NFTs, conversion to STL files and 3D printing.

Figure 5. The 2D artwork transformation into 3D printable product

5. Conclusion and discussion

It can be concluded that this framework has provided a hybrid experience for art enthusiasts. Although the number of downloads is trackable, whether the artworks get to be printed is still a question. The identity is undisclosed in blockchain systems and in such transactions, therefore, no one will be consulted and asked to reveal their identity.

Another challenge is that each STL file needs a separate unique download link on GitHub profile, however, it would be complicated and not feasible if the dataset increases. In future studies, the links should be generated automatically or other ways of providing links should be explored.

As a result, the findings have shown that 3D printing of NFTs provided users/customers a hybrid experience in both realms, maintaining the artworks' uniqueness and rarity, proof of ownership, as well as physical copies in hand. Moreover, the artists who were afraid of publicly displaying their artworks for the concern of being copied have created 3D printable artworks that enabled them to easily and safely promote their arts to the public.

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QUALITATIVE KNOWLEDGE GRAPH FOR THE EVALUATION OF METAVERSE(S)

Is the Metaverse hype or a promising new field for architects?

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Abstract. With the advancement of augmented and virtual reality technologies both in scale as well as accessibility, the Metaverse (Stephenson, 1992, Hughes, 2022) has emerged as a new digital space with potential for the application of architectural creativity and design. With blockchain integration, the concept of the Metaverse shows promise in creating a "decentralised" space for design and creativity with rewards for its participants. As a platform that incorporates these technological components, does the Metaverse have utility for architectural design? Is there something truly novel in what the Metaverse brings to architectural computing, and architectural design? The paper constructs a qualitative knowledge graph that can be used for the evaluation of various kinds of Metaverses in and for architectural design. We use Design Science Research methods to develop the knowledge graph and its evaluative capacity, stemming from our experience with two Metaverses, Decentraland and Cryptovoxels. The paper concludes with a discussion of knowledge and practice gaps that are evident, framing the opportunities that architects might have in the future in terms of developing Metaverse(s).

QUALITATIVE KNOWLEDGE GRAPH FOR THE EVALUATION OF METAVERSE(S)

Keywords: *Metaverse, Virtual Reality, Digital space, Augmented Reality, Blockchain*

ملخص. مع تقدم تقنيات الواقع المعزز والافتراضي من حيث الحجم وإمكانية الوصول، برزت تقنية الميتافرس كمساحة رقمية جديدة مع إمكانية تطبيق الإبداع والتصميم المعماري. وعن طريق إدماج تقنية البلوكتشين، أصبحت تقنية الميتافرس واعدة في إنشاء مساحة "لامركزية" للتصميم والإبداع مع إصدار مكافآت للمشاركين فيها. وهنل يكمن السؤال: كمنصة تضم هذه المكونات التكنولوجية، هل لدى الميتافرس فائدة بالنسبة للتصميم المعماري؟ هل هناك شيء جديد حقًا فيما تجلبه إلى مجال الحوسبة المعمارية والتصميم المعماري؟ تنشئ هذه الورقة البحثية رسمًا بيانيًا معرفيًا نوعيًا يمكن استخدامه لتقييم أنواع مختلفة من الميتافرس في التصميم المعماري ومن أجله. نستخدم فى هذا البحث أساليب بحث علوم التصميم لتطوير الرسم البياني للمعرفة وقدرته التقييمية والنابعة من تجربتنا مع اثنين من منصات الميتافرس: ديسنترالاند وكريبتوفوكسلز. تختتم الورقة بمناقشة الفجوات الواضحة فى كل من مجالى المعرفة والممارسة، وتأطير الفرص التي قد تكون للمعماريين في المستقبل من حيث تطوير عوالم الميتافرس.

الكلمات المفتاحية: *الميتافرس، الواقع الافتراضى، الفراغ الرقمى، الواقع المعزز، تقنية البلوكتشين.*

1. Introduction

Envisioned as the next evolution of the internet as part of the Web 3.0 system, the Metaverse (Stephenson, 2011) has emerged as a new space where architectural creativity and design can be applied. Etymologically a combination of the word ‘meta’ and ‘universe’, the Metaverse as a concept was first introduced in Stephenson’s novel “Snow Crash” as a parallel digital universe where agents- (humans in our case) have a second life, distinct from their real one. Since then, the idea has appeared as a mainstay of science fiction media from the Matrix trilogy of films (Wachowski and Wachowski, 1999) to games like Cyberpunk 2077 (2020). Metaverse realities and interpretations have ranged from virtual utopias to dystopian warnings of the abuses of technology. Though distinct in its many iterations, the core concept of the Metaverse is a hypothetical version of the internet as a singular virtual world experienced with a life-like degree of immersion through virtual reality and augmented reality headsets.

Recent technological advancements have turned the Metaverse from a fictional hypothetical of science fiction to an achievable reality. In fact, the constituent technologies for the Metaverse have existed for a long time, in one form or another. Virtual and augmented reality technologies have steadily advanced in terms of performance, cost, and accessibility since their advent in the 1980s. Facebook, one of the world’s largest tech and social networking companies, changed its name to Meta in 2021, announcing a renewed focus

and influx of capital and resources in the development of the future of the Metaverse. As artists, designers, and architects have begun studying, experimenting, and creating with the immersive, virtual components of the Metaverse and its associated technologies, the Metaverse has shown new creative potential and collaboration. (Suzuki et al., 2020) Virtual reality lends architects an unprecedented understanding and access to space and design capabilities with automation, scripting, and 3D modelling. The integration of blockchain and the concept of decentralised commerce and ownership through NFTs and Metaverse real estate re-examine concepts of capital and ownership. Gamification and social networking allow clients, users, and creators alike to engage with architectural content through a variety of mediums and experiences.

However, these developments hide the danger and consequences that implementation of the Metaverse could bring, such as the 'sin of Déjà vu' (Maver, 1995), i.e recreating older ideas, failing to take into account failure or critically understanding what has come before us. The Metaverse could replicate and potentially augment many of the existing failures of pre-existing systems thus necessitating a framework from which to evaluate the unprecedented development of the system and its contingent technologies. Further, the limitations of the technologies themselves as well as the issues and complications created by human interaction with these elements must be considered for sustainable and ethical growth of the Metaverse as a concept.

Within the paper, we attempt to construct an evaluation framework of the Metaverse for architectural design, with the scope of making the Metaverse useful to architects, as either a space to design for or as a space to design in. The evaluation framework is structured in such a way to avoid bias and potential issues that arise from the current lack of validation, critique, and evaluation while maintaining a flexibility that may be adapted and refined as more Metaverse architecture projects and tools develop.

The paper introduces the concept with framing the problem and the hype of the Metaverse and its associated technologies and current innovations, before discussing the motivation for the paper. It details the construction of the evaluative knowledge graph, its justification, adaptability, and reasoning, with a specific focus on the Metaverse framework in relation to architecture as a principle, considering the key benefits, detriments, and potential applications of the concept for architects. The paper examines not only the Metaverse components of blockchain, virtual reality, and social networks but also the interaction of users, specifically design-focused architectural users with this system, namely through the use and understanding of virtual space, design and testing potentials, and education/social community building and interaction.

Finally, a conclusion and discussion section complete the paper with suggestions for future work and vectors to be developed with an eye on the future of not only the Metaverse but also architectural work in relation to it.

2. Problem Framing and Motivation - Beyond the Hype of the Metaverse.

Lee et al. (2021) provide an excellent review of the technological foundations and virtual ecosystem for creating a Metaverse, exploring the dimensions and potential impact of the Metaverse. Uniquely they introduce the Metaverse as an instance of a world in the physical to digital continuum, where the Metaverse is a continuation of a digital twin. This also follows the idea of the Crypto-Twin (REDACTED, 2022) where a Metaverse is a blockchain-enabled digital intelligent twin that can enable governance decisions in a physical space. Suzuki et al**.** (2020) propose the creation of a Metaverse as the convergence of Internet of things sensors, where research collaboration can thrive on a global level. Osivand (2021) discusses the building elements of the Metaverse and further speculates on the nature of further digital and cybernetic arts that can be created on the Metaverse, identifying this as a potential infrastructure. Thus, we observe that most discussions on the Metaverse are consumed with discussing the constituent parts (and this paper is not immune to this) and the speculative "what if" that we can build with the Metaverse. Within the Gardner Hype cycle, the two anticipatory constituents are the expectation cycle, i.e., where people expect technology will develop, and the actual technology s-curve, i.e., the actual development of a technology (Steinert and Leifer, 2010). Cheng et al. (2022) discuss in particular Metaverse hype, identifying early social virtual reality platforms as Metaverse prototypes, framing the hype around the technology but also critiquing specific implementations by Microsoft and Meta, framing, in the end, the opportunities and potential impacts: Securing and enabling Digital twins, User addiction and its management, the unsuitability of current 5G and network architectures for full realistic virtual representation and the issues of latency of both the network and IoT devices. Within this hype, the motivation for our paper stems from the need to establish a rigorous guide of the Metaverse for architects, when the Metaverse is used for or in architectural design.

3. Blockchain as Infrastructure

Blockchain is a distributed network of computer nodes that collectively run a virtual state machine, where transactions can be recorded, and code can be run in the form of software classes code called smart contracts. Due to their reliance on cryptographic measures to record the transactions and changes to

the state machine into blocks, the reliance on financial incentives to participate in the network, but also removing barriers to participation, blockchains are conceptualised as trust machines (Shyamasundar and Patil, 2018), able to offer to projects that use them the creation of peer-to-peer economies through crypto-economics. Within the crypto-economics envelope, one is able to create tokens, both fungible and non-fungible (i.e., unique, not interchangeable with another) that allow a complex utility to be constructed when used within a Metaverse or another digital universe. We consider the use of public, permissionless blockchain as critical infrastructure for the existence of the Metaverse, as without it, the Metaverse becomes a Virtual reality, a closed garden platform.

4. Methodology

Methodologically we used the lens of Design Science Research (DSR) to develop a knowledge graph that can be used by architects and researchers alike to evaluate Metaverses, either ones that have already been built or futures ones. Within DSR (vom Brocke et al., 2020) one uses empirical understand of the needs of an environment, in our cases the needs of architects operating in the digital space, and knowledge to rigorously construct theories and artefacts that are useful and provide innovative solutions to the aforementioned needs. In our case, we used our empirical knowledge of using two currently fully operational Metaverses, “decentraland” and “cryptovoxels”, and the knowledge sourced from literature, to develop an artefact, the knowledge graph, that acts only as a basis for evaluation of other Metaverses. The DSR process contains five activities, 1. Problem Identification and Motivation, 2. Define the Objectives of the Solution, 3. Design and Development, 4. Demonstration and 5. Evaluation. Within Our approach we have completed activities 1 and 2 and our knowledge graph can be used as a framework for beginning activity 3, i.e. design and development. This means that architects seeking to create Metaverses that solve a problem or address a societal need can use our graph to guide the development of their solution and then use post ergo for evaluation at activity 5. An obvious constraint of our knowledge graph is the empirical basis on only two current Metaverses, however there are very few Metaverse platforms out there that are functional with a blockchain component that is a minimum requirement for a Metaverse to develop. We can further validate the graph by applying it to other Metaverses, but also, we can enrich it by incorporating missing features from new or improved technologies and solutions.

5. Defining the Criteria Important for Architects

We have identified empirically by using Decentraland and Cryptovoxels a set of possible uses of the Metaverse for architecture, itemised below in no particular order.

Project visualisation / exploration
Marketing engagement, virtual portfolio, showcase
Pre-occupancy assessment
Orientation, UX, fire escape simulations,
Layout experience and optimisation tool
Public annotation of designs before construction
Competitions and Participatory Design exercises/voting by the public
Education of architects/engineers
Blockchain-based Digital Intelligent twin for large-scale buildings operations
Metaverse as a public discussion forum with an immersive 3D world able to show data visualisations, problematic areas, design proposals and design solutions
Testing environment for new (mixed) uses of buildings
Urban scale digital crypto-twin of a neighbourhood or a whole city

Further, the Metaverse must perform well in terms of certain criteria in order to be used for architectural work in the above use cases. We then group the criteria into 6 categories discursively: Platform, Visual Representation, Design capabilities, Level of Gamification, Blockchain integration and User experience. An analysis of the criteria follows.

Figure 1. Six Criteria in which Metaverse should be efficient for Architectural use cases.

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5.1 PLATFORMS

A Metaverse platform that is accessible will play a critical role in architects' decisions on what to use the Metaverse for. An example can be accessing it through Virtual Reality (VR) or even Augmented Reality if at the right physical spot, to present a design to clients. However, in the case of a live demo or a consultation, it might be much more efficient to simply use a standalone PC or Mac version depending on other software the architect uses. In the case of just marketing engagement for new clients the web browser version might turn out to be the most efficient due to the minimal amount of entry barriers. Even this short argumentation about use-cases signifies that a true Metaverse should not be bound to VR as some of the early definitions state.

5.2 VISUAL REPRESENTATION

Some of the current Metaverse projects like Sandbox and Voxels (former Cryptovoxels) have the voxel stylized visuals which might seem like a modelling constraint, there exist issues of readability, relatability and understandability. In case of an example of user interaction in a design that is still under development, if the clients acknowledge that what they explore is stylized it can help keep the design process in the abstract for longer without focusing on not important details like furniture and fixtures. This is quite usually a serious problem for architects to keep clients in the abstraction long enough despite their desire to start deciding on details such as the tiles and door knob designs.

The main criteria are then the scale accuracy of objects and the spaces we experience. With this requirement, architects will be able to consult and present their real-world projects in the Metaverse. Taking the stylization into account we can form a realism scale which starts with heavily abstracted and stylized (circa 1 m sized voxels similar to Minecraft) through low-poly stylization, extrusions, and small voxels (or variable scale voxels similar Cryptovoxels), to detailed models, high-poly and realistic models. Higher stylization will affect the scale; however, higher realism is technically demanding in terms of computing resources both for the platform and the device of the user. We can therefore define a stylisation-realism gradient and use a scale to differentiate between different ways of rendering geometry.

Figure 2. The Stylisation-Realism scale in modelling

5.3 DESIGN CAPABILITIES

5.3.1 3D Modelling Standards

The most important feature in this regard will be importing features and standards. The Metaverse Standards Forum was established in June 2022 and so far, all the significant Metaverse building companies seem to want to be involved in its discussion about standardisation (Lewis, 2022). The format in the centre of the discussion is USD (Universal Scene Description) initially invented by Pixar and brought to attention by being adopted by Apple AR applications ("Apple Open Source," n.d.). The USD file can contain. glTF 3D models with physically based rendered materials which seem to be a popular candidate for web and lower-performance platforms. Making this format fully available and exportable in architecture CAD programs will be a huge advantage as well.

5.3.2 Modelling precision

Another important feature is precision modelling. This might include some form of adjustable snapping to principal axis directions which is present in all current architecture modelling software. What architects also need is the ability to input exact numbers when making an operation like move, scale and rotate. Without this feature, any modelling has to be strictly done prior to the Metaverse and this invalidates the interactivity for example in scenarios where one is sharing an immersive space with clients while making adjustments.

5.3.3 Scripting

When architects work with scripting capabilities, enabling a visual scripting environment is always a good way to increase adoption even by those who do not write hard code. Some experienced architects can work with just a simple Software Development Kit, which usually calculates with a higher level of code writing skills. However, making such a software developer kit (SDK) as accessible as possible to code non-professionals might be another key aspect of architects using the Metaverse for their work.

5.3.4 Limitations

One large limitation of current Metaverse projects is the vertex count of imported 3D models. For example, Decentraland (2018) still holds this limit at 10 000 vertices per parcel which leads to very dramatic compromises in both modelling and interactions possible to be done. Another important limitation lies in textures. Their resolution is seldom limited to relatively small values like 512x512 px and the number of textures per model is also usually limited to just one. There are ways to overcome such limitations using baking different images into one texture, however, the resolution limitation makes it very hard to achieve reasonable results. In almost all current Metaverse projects, there is already some form of height limitation on users' parcels (Stinson, 2022). This has to be taken into account since the limitation is not parametric and usually applies to the whole explorable world. Comparing such general limitations with our physical cities will pave the way to more meaningful zoning rules for the Metaverse. A crucial limitation currently used in Metaverse projects is the file size for the uploaded models. This is understandable, however, could be replaced by web3 and decentralised storage implementations (Balduf et al., 2022) or loading data directly on user interaction from other storage. If this approach shall become one of the standards, it has to be streamlined and simple to employ, rather than a hack hidden in the forums.

5.4 LEVEL OF GAMIFICATION

One key question to be answered regarding the level of gamification is if the gamification principles do not invalidate some of the architects' use cases. For example, a platform time limit on being present in a new design would ruin the experience of the clients. Such an example is chosen ad absurdum, however, in subtler contexts a strong gamification principle might be obstructing a legitimate use case. Since many Metaverse projects might arise from actual video games and their engines (for example Fortnite, Roblox or Minecraft) their openness to new use-cases must be evaluated even though they might have been created as a creative sandbox game.

Architecture has been shaped by physics and gravity. Therefore, an automatic presence of physics will be welcome by architects, however being able to create own rules for more daring designs aimed only at the Metaverse should be an option available.

Metaverse themes also affect the gamification level. Some of the current Metaverse projects are loudly promoting their theme (space, cowboys, pokémon-like world…) which only constraints the possibilities of using the project in useful work for architecture. This is usually reflected by creator asset library content, environments and UI or even colours.

5.5 BLOCKCHAIN INTEGRATION

To secure authorship of creations and enable new business models for architects, a Metaverse must integrate blockchain/Decentralised ledger technologies, which create peer-to-peer economies to not rely on large Metaverse providers. The type of blockchain and its features will have an impact on some of the functionalities along with security and availability. For example, if Ethereum is selected, it automatically means users might avoid committing to transactions as much as possible due to the possibility of high network fees unless some of the layer 2 chains are supported.

Another important aspect is the level of tokenization. Is there a possibility for a space of new creations already a Non-Fungible Tokens, which the user must buy? Can the owner of a parcel, a virtual piece of land, delegate the right to build to his or her architect? Does each Metaverse have its own native fungible token to be used in transactions? Are all collectable in-game objects also NFTs? Is there a dedicated marketplace or can the items be traded outside each Metaverse? Are the creations compatible with other Metaverses, i.e. can one transfer a design across? An interesting criterion for the novel business plans of architects lies in the crypto-economics (rather tokenomics) of the Metaverse project. Are there any incentives to build new creations? Is there a Play2Earn mechanism? What are the mechanisms to create value? Can a successful design be reused? Are there royalties for the author if her or his design gets reused?

The governance of a Metaverse project is also of high importance. Blockchain allows ownership of the Metaverse by its users, allowing the collective decision-making for strategic decisions. After building one's portfolio in a Metaverse, one wants to keep a certain amount of control over the project through governance coins of it. There is also an interesting potential for satisfied customers who might form an alliance with their architect just based on similar values. On the other hand, the existence of a central entity to make decisions might help the project to succeed.

The last of the criteria based on blockchain integration is ownership of the Metaverse. Is it owned by a decentralised entity like a DAO or a private for-profit company? Such information might be useful in determining the long-lasting of one's creations.

5.6 USER EXPERIENCE

Any upcoming technology must persuade potential clients by having an inviting user experience. Only the early adopters usually withstand cumbersome workflows, misleading user interface (UI) and other obstacles. In order to welcome new architects to the Metaverse the process of creating a new account while learning about key principles of crypto and the tokenomics of the Metaverse has to be as smooth as possible to not create an entry barrier.

A clear and non-obtrusive user interface is very important. All the more if we take into account that modelling and designing is time-demanding work and achieving the flow state while doing so could be jeopardised by an annoying badly designed ever-present UI element or its interaction.

The same can be stated about the general ease of use. This criterion includes camera manipulation, movement, responsiveness, even sound design, building tools and the way one interacts with them and the overall feel of using the Metaverse as a tool. While some of the possible problems can be overcome by practice and training, even gamers tend not to invest a lot of time into something with hard-to-tame controls.

Finally, the level of interactivity will also play an important role. For example, a situation when an architect shows her or his design to the clients is undoubtedly a social one and the architect needs to pay attention to all the formal and informal signals his or her clients express. Failing to convey such information would deteriorate the Metaverse as a medium of social interaction.

5.7 SCORING WEIGHTS

We have assigned weights to all the sub-criteria via a discursive process within the research teams. This weighted system shall be taken as an initial attempt to classify and rate early Metaverse projects in order to discover knowledge gaps as well as gaps in the scoring itself. All the proposed weights are trying to reflect the importance the authors would give them.

TABLE 1. User Experience.

Platform		
20%		3D Standalone PC
20%		3D Standalone Mac
20%		VR
20%		Web Browser
10%		Mobile
5%		AR
2.50%		3D Standalone Linux
2.50%		Consoles
Visual Representation		
40%		Scale Accurate Objects
40%		Scale Accurate Avatars
10%		Position on the Stylization-Realism Scale
10%		Customizable Environment
Design Capabilities		
50%		Limitations
	40%	Vertex Count (at least 1 000 000 vertices per object)
	20%	Texture Resolution (at least 2048x2048 px)
	20%	File Size (at least 500 MB)
	10%	Parcel Height Limit (at least 2:1 of floor size)
	10%	Texture Count (at least 10 per object)
15%		Number Input while Modelling

10%		Snapping
10%		Asset Library
10%		Visual Scripting Environment
2.50%		glTF Integration
2.50%		SDK
Level of Gamification		
30%		Creating Own Rules
30%		No Mandatory Rules
20%		Absence of Theme
20%		Presence of Physics
Blockchain Integration		
50%		Blockchain Powered
12.50%		Tokenization and Utility
	33.30%	Spaces as NFTs
	33.30%	In-game Items as NFTs
	33.30%	Native Tokens
12.50%		Economics and Incentives
	30%	Play2Earn
	30%	Royalties
	30%	Multiple Ways to Create Value
	10%	Revenue Distribution
12.50%		Ownership
	75%	How much Decentralised is Owner
	25%	Clear Ownership
12.50%		Ownership
	75%	Involvement in Large Scale Decisions
	25%	Banning process for bad clients (reputation)
User Experience		
30%		Ease of Use
30%		User Interface
20%		Identity Creation
	75%	Information Required
	25%	Time to Create an Account
20%		Level of Interactivity
	20%	Spatio-social
	20%	Verbal
	20%	Written
	20%	Non-verbal
	10%	Visual
	10%	Monetary

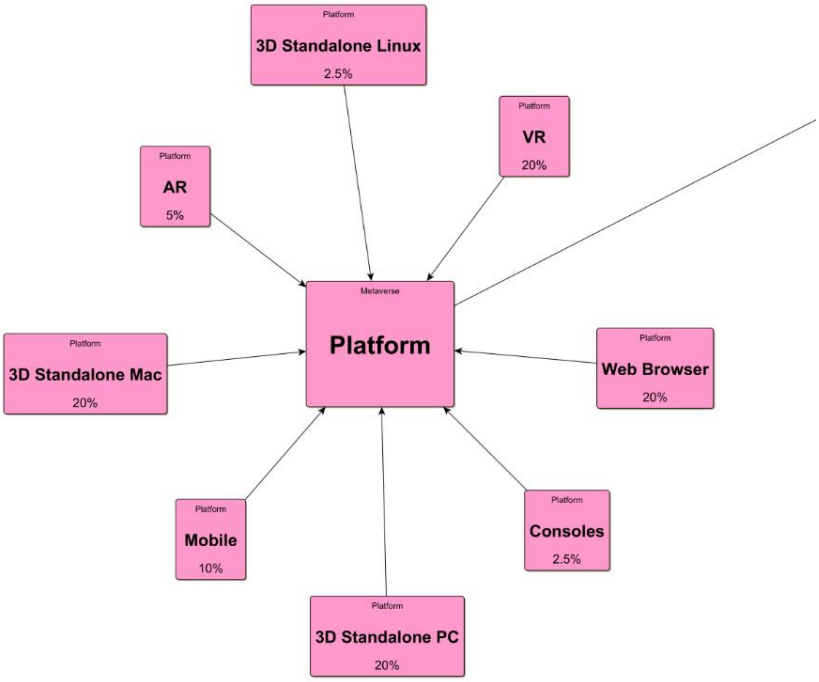

Figure 3. Platforms and their proposed weights.

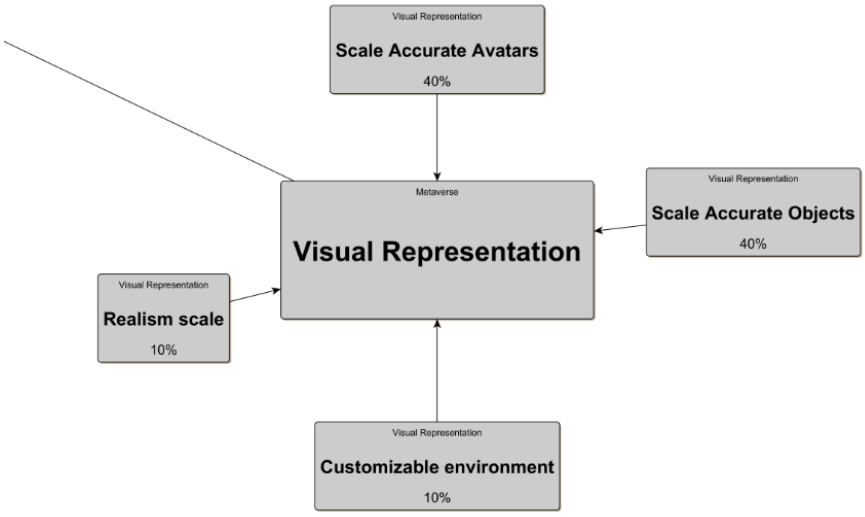

Figure 4. Visual representation and proposed weights.

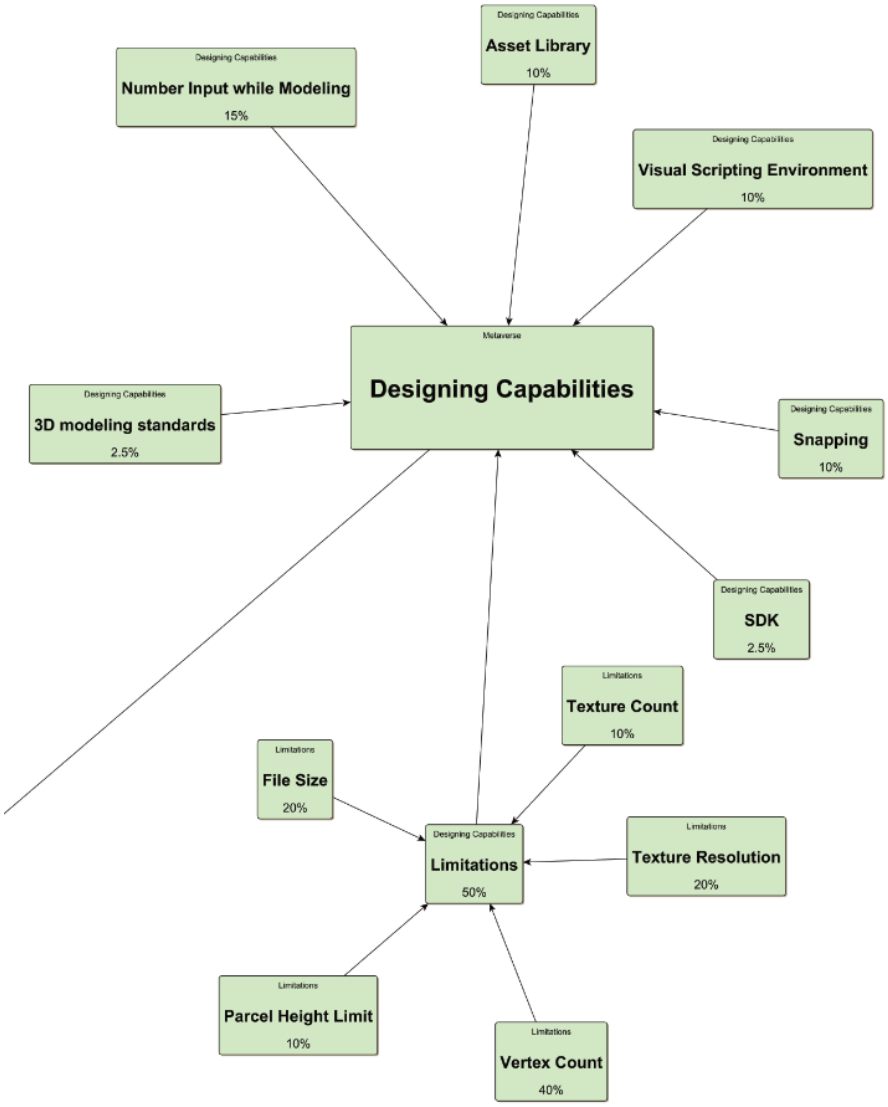

Figure 5. Design Capabilities and their proposed weights.

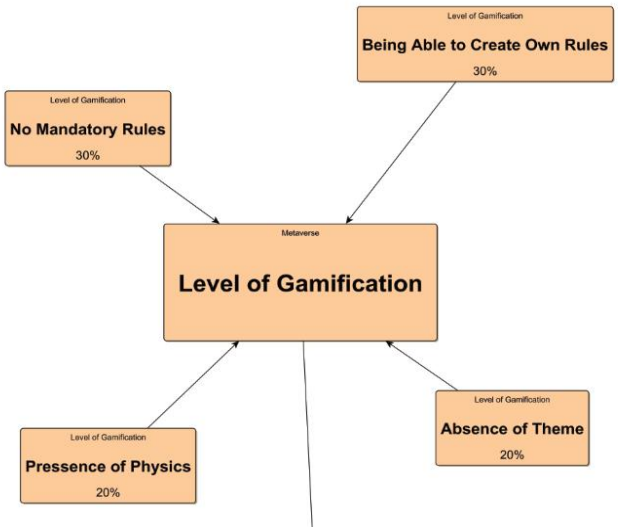

Figure 6. Level of gamification and proposed weights.

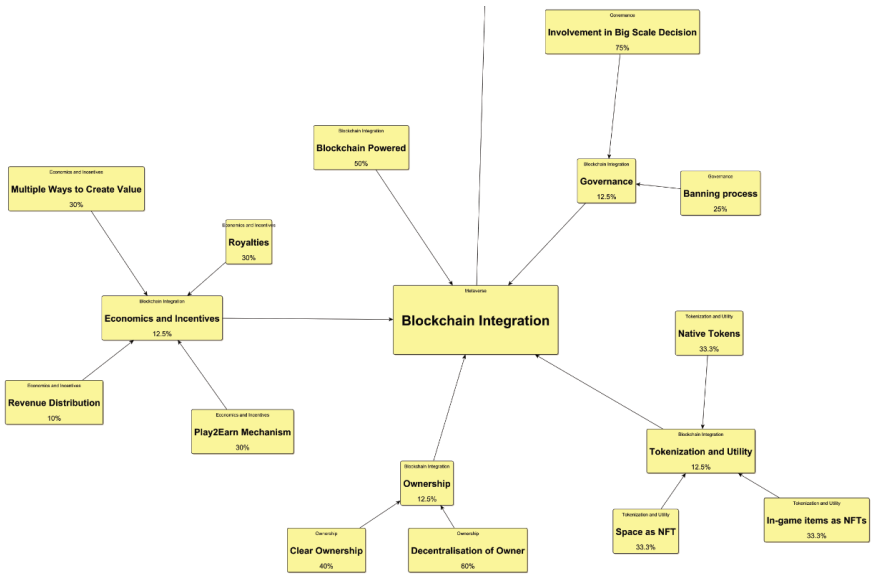

Figure 7. Blockchain Integration and proposed weights.

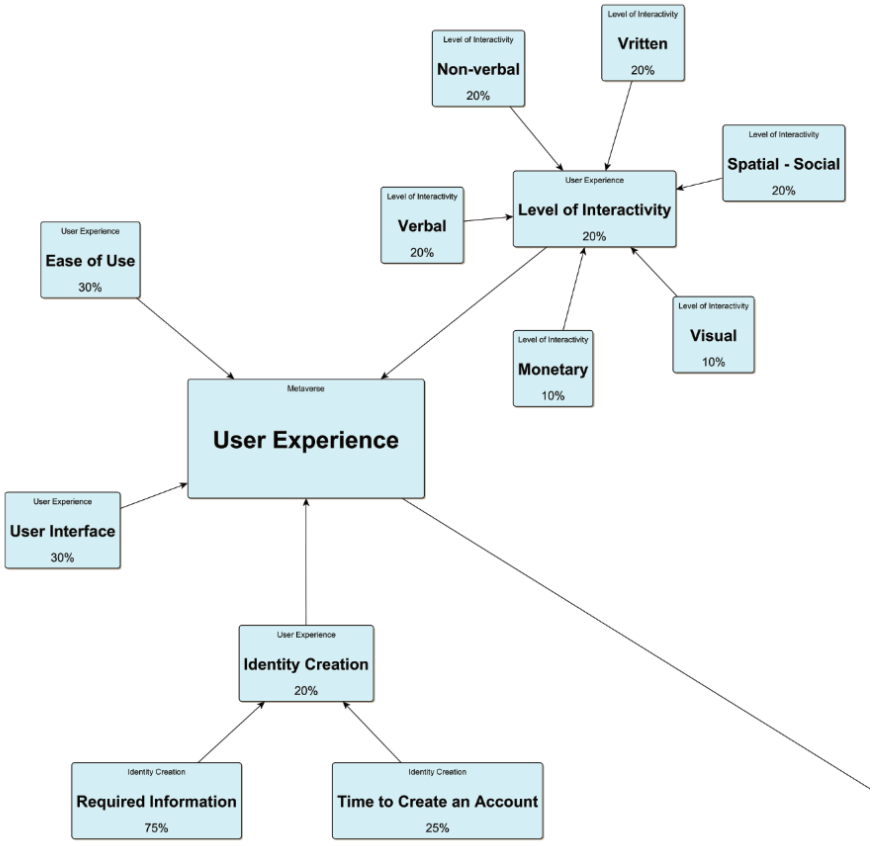

Figure 8. User Experience and proposed weights.

6. Discussion and Knowledge gaps

The development of the Knowledge graph to evaluate Metaverses brought forward two main initial questions:

- What is the difference between a Metaverse and existing VR worlds, or even multi-player games?
- What will be crucial for adoption of the Metaverse: Will the increase in social interaction in such spaces play a role, or is the realistic rendering more important, along with perhaps other criteria?

Maver's framework (1995) might be productive here in developing our evaluative knowledge graph further but also testing it. There are also particular knowledge gaps in another adjacent knowledge area that is currently developing in architecture, that of the digital twins, where there might be spillover effects in terms of tools and concept development. The lack of

benchmarks and standards is also a crucial area that might improve in the future, as currently, a researcher must navigate a lot of hype information and marketing speak rather than data that point towards true performance. The presented framework is a first attempt toward building those datasets, and we do not lay claim that our framework is complete or tested. We still have to also validate the knowledge graph via developing tests for further existing Metaverses, and within that, we might evaluate whether the framework as a set captures all of the criteria that are important, or whether there are also other indicators that might make a Metaverse useful to architects. Additionally, we believe that a wide knowledge gap is the user experience and the view the user might have in such an endeavour. For that we propose that a framework from the side of the user is developed, one that might be easy to customise for the specific type of usage, for example, social interactions, work or gaming. We foresee that there might be interesting bridges between the Metaverse framework for architects and ones for the users, where the user framework feeds into the architecture one.

7. Conclusion & Future Work

The existence of early Metaverses along with the communities that cater to them, acts against the hype of the Metaverse, solidifying the idea that architects can use the Metaverse, both for and in Architectural Design. The Metaverse building tools are at the moment crude and not well integrated, but we envision that our evaluation knowledge graph can provide architects with an easy to use, handy tool to plan ahead in using the Metaverse in their projects, but also for Metaverse creators to shape their platforms in manners that will allow architects to use them in a valuable manner. We look forward to developing this research into the rest of the DSR activities with prototype but also further validation of our evaluation graph and framework.

A follow up survey will be conducted with ArchiDAO's Discord members. They will be asked to assign weights to mentioned criteria according to their own subjective experience in current metaverse projects. After aggregating all such data we'll be able to validate our suggested weights with statistical significance as well as probably include new ones not thought of yet.

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SOLAR ENERGY CONTROL STRATEGY USING INTERACTIVE MODULES

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Abstract. The concept of interactive canopy emerged as a notable manifestation of smart buildings in architectural endeavors, using artificial intelligence applications in computational architecture, interactive canopies came as a potential response for living organisms to combat external environmental changes as well as reduce energy consumption in buildings. This research aims to explore architecture with higher efficiency through the impact of environmentally technological factors on the design form by introducing solar energy into the design process through the implementation of interactive curtains that interact with the sun in the form of an umbrella. The main objective of the umbrellas is to protect the users from the sun's harmful rays. After designing an interactive cell using Grasshopper, the methodology follows an analytical and experimental approach, the analytical section is summarized by conducting a case study of multiple models and analyzing the techniques used in these models to discover the significant advantages and disadvantages of the design. While the experimental section demonstrates the mechanism for implementing the interactive modules. The research suggests that by designing an interactive canopy that responds to external changes and senses solar radiation in ways that when the intensity of solar radiation increases and the sun is perpendicular to the dynamic units, will lead to maintaining a more balanced level of illumination. The work efficiency is studied by simulating it by Climate Studio.

Keywords: *Thermal-Visual Comfort, Computational Architecture, Kinetic Architecture, Interactive Canopies, Babylon*

ملخص. ظهر مفهوم مظلات المبانى التفاعلية كمظهر بارز للمباني الذكية في المساعي المعمارية باستخدام تطبيقات الذكاء الاصطناعي في العمارة الحوسبية. وجاءت المظلات التفاعلية كاستجابة لمكافحة الكائنات الحية للتغيرات البيئية الخارجية وكذلك للتقليل من استهلاك الطاقة في المباني. يهدف هذا البحث إلى استكشاف العمارة ذات الكفاءة العالية من خلال تأثير العوامل البيئية التكنولوجية على شكل التصميم من خلال إدخال الطاقة الشمسية في عملية التصميم عن طريق تنفيذ ستائر تفاعلية تتفاعل مع الشمس على شكل مظلة. والهدف الرئيسي من استخدام المظلات هو حماية المستخدمين من أشعة الشمس الضارة. بعد الانتهاء من تصميم خلية تفاعلية باستخدام برنامج جراسهوبر، تتبع منهجية البحث نهجًا تحليليًا وتجريبيًا. يشمل القسم التحليلي دراسة حالة لنماذج متعددة وتحليل التقنيات المستخدمة في هذه النماذج لاكتشاف المزايا والعيوب الهامة للتصميم. بينما يشمل القسم التجريبي آلية تنفيذ الوحدات التفاعلية. ويقترح البحث طرق للحفاظ على مستوى إضاءة أكثر توازناً من خلال تصميم مظلة تفاعلية تستجيب للتغيرات الخارجية وتستشعر الإشعاع الشمسي عندما تزداد شدة الإشعاع الشمسي وتكون الشمس متعامدة مع الوحدات الديناميكية. وتتم دراسة كفاءة العمل من خلال محاكاتها بواسطة برنامج استوديو المناخ.

الكلمات المفتاحية: *الراحة الحرارية البصرية، العمارة الحوسبية، العمارة الحركية، المظلات المتفاعلة، بابل.*

1. Introduction

Interactive designs are characterized by interacting with the conditions of the external environment on a daily - monthly - annual basis (Attia 2017). Its main principle is to control daylight through the use of light sensors, with the use of interactive blinds on the facade of the building, the amount of daylight entering the space can be controlled as it balances the outside vision and perception of daylight and also reduces the building's energy load and solar glare (Tabadkani et al., 2020; Lechner, 2014). The reason for focusing on the building envelope is because it is the barrier between the outdoor environment and the indoor environment. Adaptive building facades can provide improvements in the amount of energy efficiency consumption through their capacity, changing its condition in accordance with external and internal parameters (Aelenei et al., 2016). This envelope can exclude undesirable influences from the external environment while accepting desired effects. A well-designed building envelope provides 40% of the ecological solution, creating an efficient building that interacts with its surroundings (Etman, 2013; Phillips, 2013). In their study, it is demonstrated that if the artificial lighting system is combined with the natural light of the architectural space, will lead to a 30-40% reduction in energy consumption. In recent years, there has been a large body of research on lighting and its direct impact on human health and comfort on the one hand and energy

consumption on the another, daylight-based design is a new era in buildings as more designers are beginning to grasp the important value of daylight as a source of renewable energy and an alternative to artificial light. Reducing the amount of artificial light is an important step in the direction of sustainable buildings and energy savings (Mahdavinejad et al. 2012). Therefore, especially in recent years, a considerable number of modern buildings is designed with large window facades in order to solve the problem of lighting and avoid the use of electricity for lighting, but it was found that buildings in general and office buildings and companies in particular record high rates of energy consumption (EIA, 2021), the reason why this research will take administrative offices as a case study. The main objective of this research is to investigate ways that can maintain the visual comfort of administrative space in the province of Babylon, Iraq, by balancing the daylight entering the interior space and by reducing the lighting units. 100 watts of electrical power to 100 watts of light and heat. Through testing the design and implementation of an administrative space model that uses the property of dynamic disinformation, and then study and analyze the performance of this model in terms of reducing the amount of solar glare entering the space during working hours, and to identify the simulation process by mentioning the inputs and outputs. In addition to documenting the simulation process, identifying the variables and criteria used for each step-in order to help build an identifiable model tailored for the study context.

2. Literature review

Numerous studies have addressed the impact of dynamic facades on the internal performance of buildings. For example, Sanchez (2010) designed a model for a dynamic deception device. This research explores the potential of parametric techniques, programming and digital fabrication to design and build a skin responsive to bioclimate, where he studied its ability to control lighting and heat by placing sensors, the researcher chose the triangle shape in the design of the dynamic units and chose two types of transparent and semi-transparent materials. The solar cells were placed on the opaque part. Lighting and heat, as well as because of its location within the courtyards, contributed to the flow of air to the interior, and enabled the flexible shape of the panels to cover different types of surfaces. Babilio et al., (2019) also used the method of moving the deception units used in the famous sea towers and explained how to use the tensile property for the purpose of moving the panels. Through the analysis of the forces needed to tighten the panels and the presence of the research that it is possible by applying the tensile concepts for the purpose of producing modern techniques for the implementation of lightweight building envelopes characterized by rigidity

and the ability to perform their work. T, Pankratov & Grobman, Jacob (2014) built a model consisting of nine elements of deception units in the form of boxes that revolve around an axis from top to bottom and vice versa, and studied cases of central control so that the entire group is connected to a single sensor unit and decentralized, which means that each deception unit contains a sensor unit to measure the levels of illumination, their research found that decentralized disinformation provides a better distribution of illumination within the interior spaces of space. However, through the study of previous research, we found that few studies specifically address the problem of administrative spaces as a case study, despite the fact that the percentage of energy consumption in administrative and commercial spaces is high as mentioned earlier, in addition, previous studies did not consider contexts that suffer from severe climatic conditions, and lastly, previous studies did not outline the exact methodology or design stages that can be followed to design a model of dynamic deception

3. Methodology

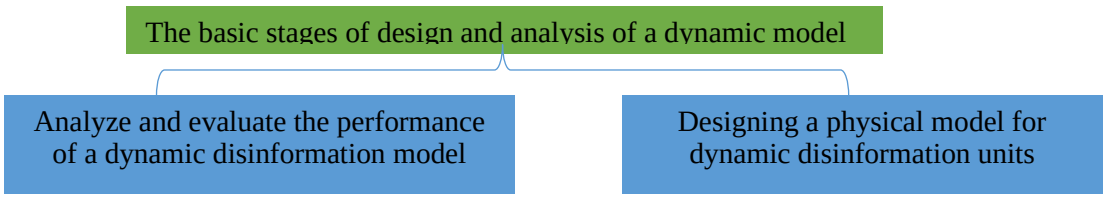
The methodology depends on the use of the analytical method using the analysis program, studying the results, and comparing them

3.1. Software used

The plugin Rhinoceros and Grasshopper were used for the purpose of dynamic unit design and canopy geometry. These two software programs, especially Grasshopper, have the ability to handle complex designs. Arduino and firefly were used for the purpose of physical model design. Firefly is a plugin included in Rhinoceros that bridges the gap between Grasshopper and Arduino as it allows data to flow almost in real time between the digital and physical worlds, while Arduino is a tool for making devices that can sense and control the physical world through Connected to sensors and controllers

3.2. Research process

This research is based on the executive and analytical method by implementing and designing a first model for a dynamic interface, and then in the second stage, the performance efficiency of this model is analyzed and studied in terms of responding to daylight by making a virtual simulation (See figure 1).



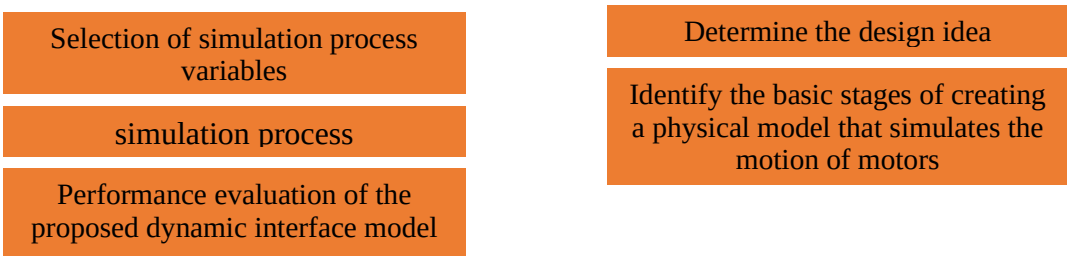


Figure 1. Research framework

4. Designing a physical model for dynamic disinformation units

This section consists of two main stages as demonstrated below:

4.1. Design Idea

In order to create the image of interactive curtains, the designer sought to combine ancient Babylonian symbols with modern technology. As a result, the revival of an architectural symbol from the roots of ancient Babylonian thought as a research hypothesis consisting of two layers, a layer indicating the star of Ishtar and a layer indicating digital applications.

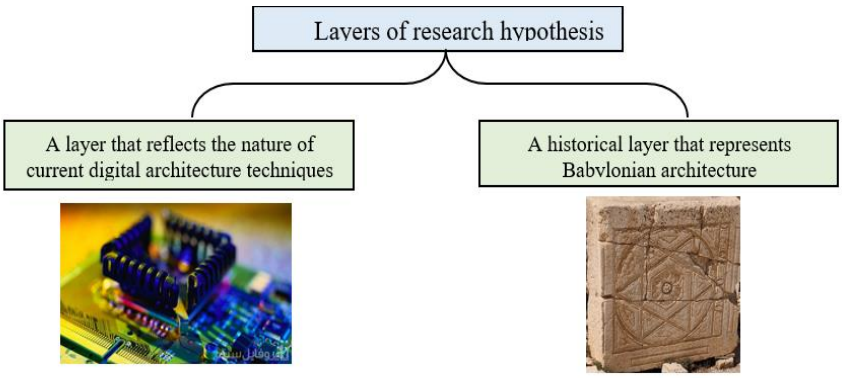


Figure 2. The concept for the design unit

A polygon consisting of six sides as found in the star of Ishtar was chosen, then the shape was divided into triangles, by connecting each point at the end of each side to the center to form six triangles that meet each other in the center of the hexagon and thus form the main axes on which it moves dynamic units. As for the last stage, it included dividing the triangles

resulting from the second stage into smaller triangles. The method of finding the center of each of these six triangles and then repeating the same lines by connecting the end and beginning of each side with the center and thus we have the form of dynamic units.

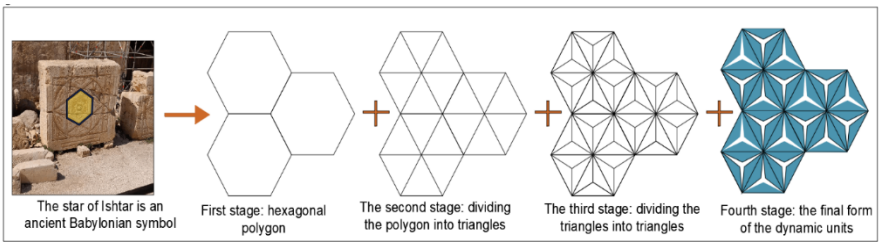


Figure 3. Stages of unit formulation

4.2. The basic stages of creating a physical model that simulates the movement of motors

The steps of creating the model suggested for the study can be divided into five stages, as follows:

4.2.1. Stage one: Determine the proposed type of movement for dynamic units:

The movement selected in the design of the dynamic units was rotation on a specific axis and the table below depicts the stages of the movement of the dynamic units in terms of the closing ratio

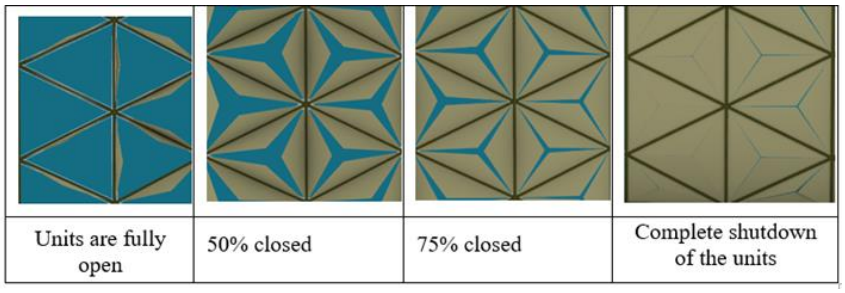


Figure 4. Stages of units' movement.

4.2.2. Stage two: The design of the sectors for the physical model

Dividing the physical model in Rhino software was designed for the purpose of understanding how the parts of the dynamic units move and the interconnection of the pieces to each other, as well as for the purpose of

preparing the pieces for the laser cutting process by drawing them in a 2D format so that the laser machine is ready for the laser cutting process

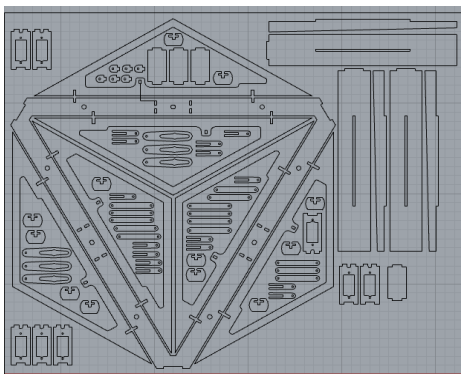


Figure 5. Designing sectors for dynamic units for the purpose of preparing them for the laser cutting process

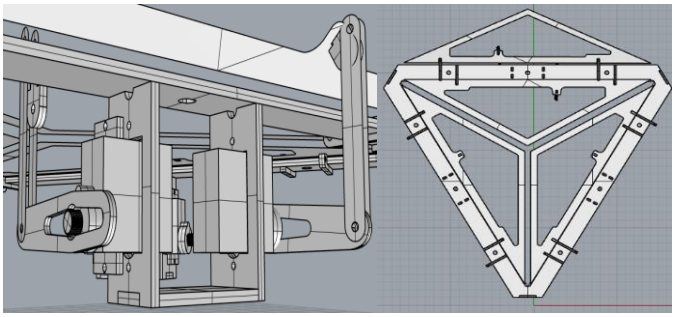


Figure 6. 3D design of dynamic unit segments

4.2.3. Stage three: Preparing the physical model.

The model was prepared from High Density Fibreboard (HDF) wood with a thickness of 3 mm and the parts were joined together to make a realistic simulation of the movement of the model.

Figure 7. A depiction of some stages for the physical model-building process

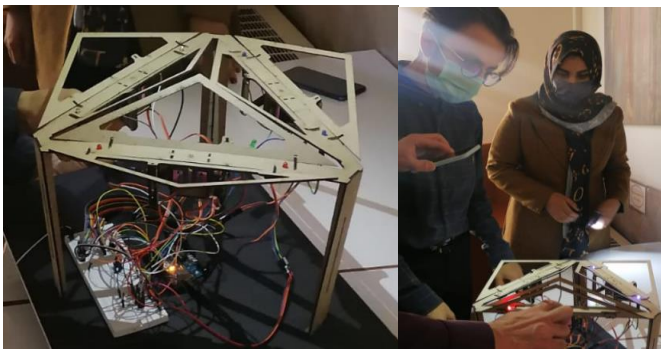
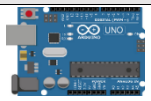
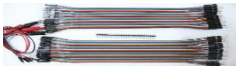


Figure8.The final form of the physical model

4.2.4 . Stage four: Identifying the required electronic sectors and linking them to the physical model.

In order to build the simulated physical model for the movement of the engines responsible for the movement of the proposed dynamic interface, some Physical Design tools were used as demonstrated in the table below

TABLE 1. Mechanical parts used in the model

Servomotors MG90S	Arduino Uno
	
Jumper Wire	Breadboard
	
Adapter 5 volts 3 amps	Resistance
	
LDR sensor	
	

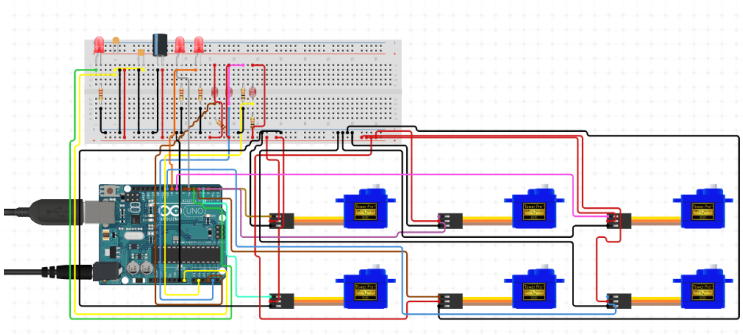


Figure 9. Simulation of the component electrical circuit of the physical model of the dynamic modules, as shown in Connecting the motors and sensor module to the Arduino board

4.2.5. Stage five: Suggesting a methodology for interacting with changing climatic conditions.

For the purpose of interaction between reality and simulation programs, the Arduino control board was used, which allows the interaction of the geometry with the sun. An LDR sensor was installed that can monitor the intensity of illumination and then link the reading to the angle of movement of the motor, and to do this step, Remap was used, a directive that works on filtering reading the minimum and maximum value of the measurements of the luminescent sensors, and then in the target section, the minimum and maximum angles were added to the movement of the servo motor

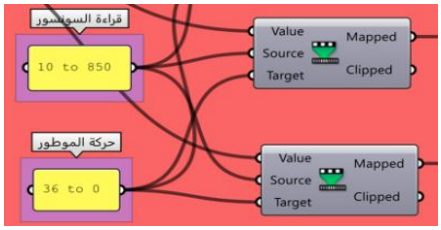


Figure 10. The Remap variables to read the light and motion sensor of the motor sensor

Where the maximum value of the sensor reading resulting from the simulation process in the case of clear and sunny skies is 850, and the minimum value represents the reading of the sensor in the case of cloudy skies or at night. For the servo motor movement value, the minimum value represents the closing of the units in the case of clear sky and sunlight perpendicular to the dynamic units, and the value 36 represents the

maximum value of the servo motor movement, where according to the tests conducted on the motor movement and the movement of the dynamic units in the physical model, it was found that when 36 degrees, the units will be fully opened and will be perpendicular to the support structure When the units are closed, the light in the interior space will decrease, which is why the designer sought to follow a mechanism, which is that the less light in the interior space, the more LED will glow, and vice versa when the amount of indoor lighting is appropriate, it decreases until it reaches zero based on the external readings.

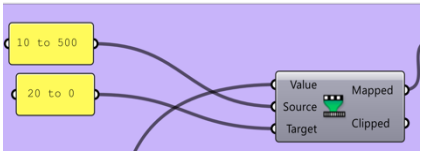


Figure 11.The minimum and maximum value of the LDE reading

The control panel is linked to the Grasshopper program via the Firefly plugin. Figure 12 shows the inputs and outputs of the Arduino board, which is to read the sensor unit as one of the main outputs, and the values of the motors' movements as basic inputs. Each motor separately and also the same process is repeated in the operation of the LED.

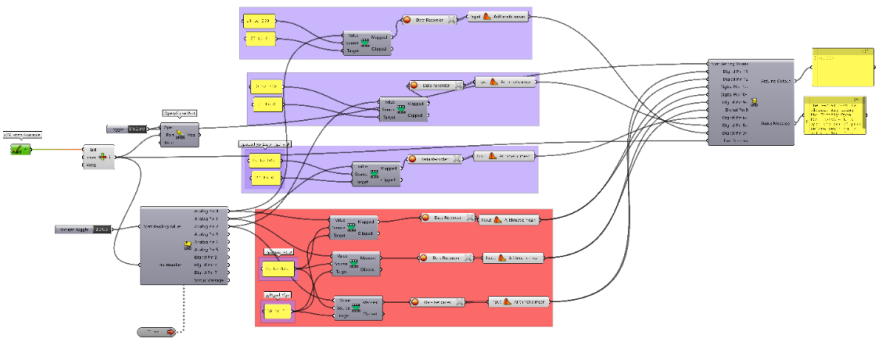


Figure 12.Arduino control panel definition strategy within Grasshopper

5. Analysis and evaluation for the performance of the dynamic disinformation model

This section includes a group of main and secondary stages. The first step begins with collecting the variables of the simulation process. The first stage of collecting the variables can be summarized as follows:

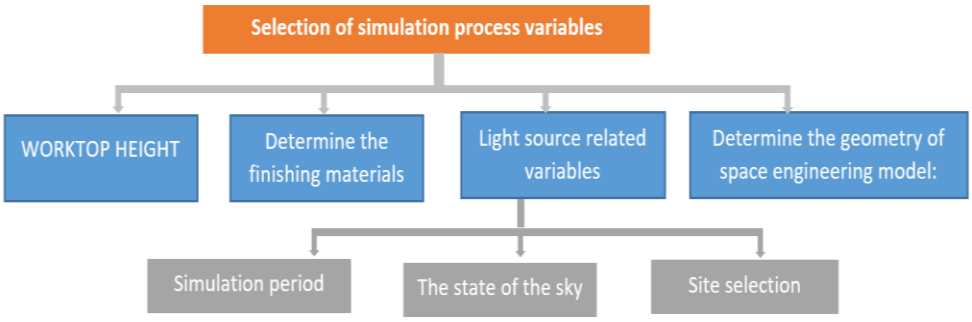


Figure 13. The first stage of determining the variables

5.1.determine the geometry of space engineering model

Dimensions of the office space used in the simulation process are shown in Figure 14.

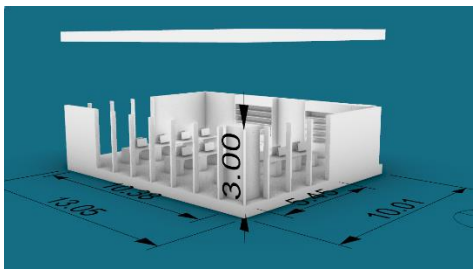


Figure 14. The internal dimensions of the researcher's space

5.2 Variables related to the light source

There are different variables directly related to the light source. These variables and the reasons for choosing their values can be explained as follows:

5.2.1. Site selection

The selected site is located in Iraq - Babil - Hilla, where the area is characterized by high temperatures. According to the simulation process that was conducted in the Climate Studio program, the results were obtained in Figure 15 for weather and climate information for the city of Hilla.

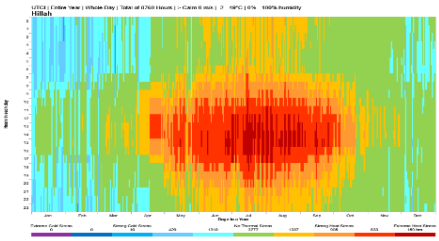


Figure .15. A picture showing the temperatures in Hilla

Also, the chosen site is located within the urban fabric center of the city of Hilla and next to many administrative and commercial buildings and on 60th Street from the western side and University Street from the southern side, which is considered an important street in the region

Figure 16. Pictures showing the elected site (source: Google Earth Iraq)

5.2.2.The state of the sky

The state of the sky has an effect on the amount of light distribution within space (Faraj, Mamdouh. 2015) in this analysis. It was chosen when the weather was clear and sunny because most of the conditions prevailing in the Iraqi climate are clear, and this situation needs to be improved due to direct sunlight that causes visual disturbance to users.

5.2.3 Simulation period

As for the selection of simulation months, the research in this section relied on choosing the first day of each month (January and August).

5.3. Variables related to material properties

The office space consists of four main parts ((Floor - Ceiling - Wall - Window)) The values of reflection differ from one material to another and thus affect the distribution of light in the interior space according to the table of Figure 17, there are standard values recommended to be used,

Building Component	Reflectivity	Visual Transmissivity
Walls and partitions	0.5	-
Ceiling	0.8	-
Floor	0.2	-
Shadings	0.9	-
External ground	0.2	-
Glass	-	0.87

Figure 17. Reflection values required for the simulation process. Source :(Carlucci, S .2015).

5.4. Worktop height

Since the space under analysis is a desk and the work is done by computer, the height of the work surface here is 1.20 cm because it represents the variable height of the employee's eye from the floor.

6. Simulations

After determining the fixed and variable inputs to the simulation process, the simulation steps begin.

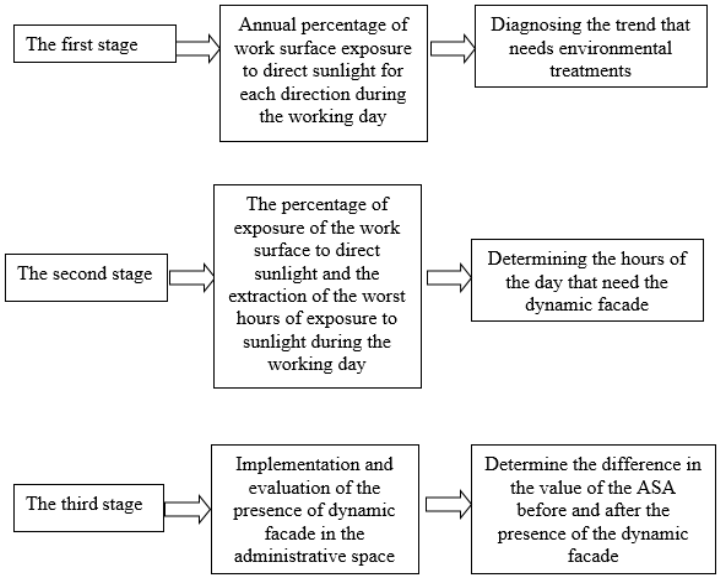


Figure 18.Determine the objectives and stages of the simulation process

The first stage: determining the path that needs environmental modification, in this stage the path that needs environmental treatment (dynamic interface) is determined by observing the values of the ASE scale of the work surface which describes the annual exposure to sunlight (ASE). where it is defined as the amount of area receiving direct sunlight, which may cause visual disturbance (glare) or increased cooling loads. Specifically, it is also expressed as the percentage of land receiving at least 1,000 lux for at least 250 hours of occupancy per year. (Jakubiec, 2014; Pilechiha et al., 2020; Mahdavinejad, 2012). It is possible to calculate the number of hours during which the work surface should not be exposed to more than 1000 lux
Measurement equation (Pilechiha et al., 2020):

$$ASE = \frac{\sum_{i=1}^{N} AT(i)}{N} \; with AT(i) = \begin{cases} 1 : at_i \geq T_i \\ 0 : at_i \leq T_i \end{cases} \tag{1}$$

At this stage, 4 simulations were performed, and the evaluation of this stage is important in determining the worst interface that gives negative results for the lighting behavior within the space. the ASE scale values are displayed on the work surface, where each value monitored by the sensors displays its location on the grid with a color gradient indicating the extent of the problem.

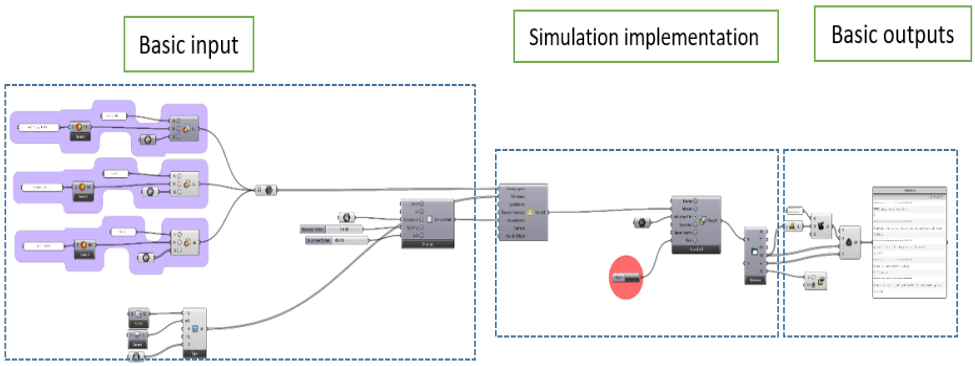
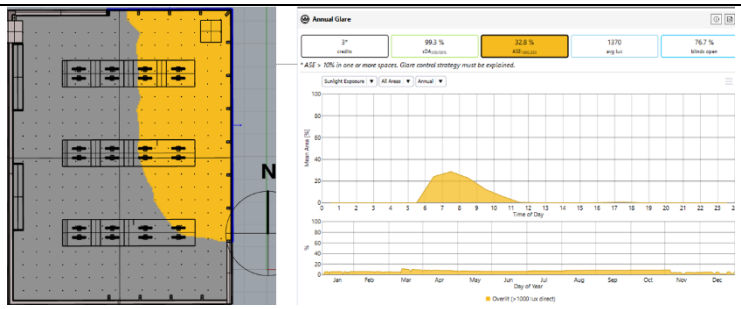
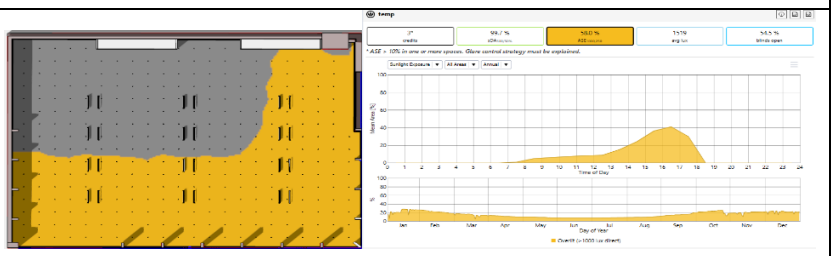
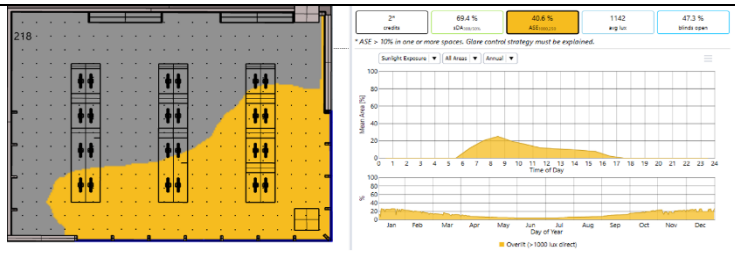
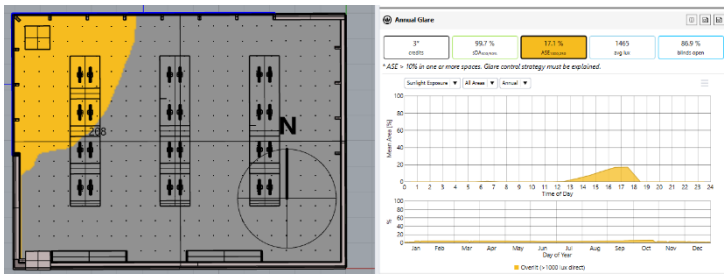


Figure 19. The full stages of the simulation process in Climate Studio

The simulation process is included in the table 2 so that the orange color indicates the amount of ASE

TABLE 2. The table below shows the results of the analysis for each of the four trends

Eastern routing results ASE =32.8%	
Western routing results ASE =58%	
Southern Direction Results ASE = 40.6%	
North routing results of ASE = 17.1%	

According to the results, the western direction can be considered the most direction in which the work surface is exposed to direct sunlight, which causes glare and affects in some way on human vision, followed by the southern direction, then the eastern direction, and then the northern direction. As shown in the figure

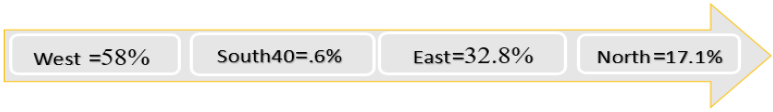


Figure 20. ranks the four trends of office space from worst to best.

According to previous studies, if the ASE value is equal to 10% or more, it indicates the visual comfort is not satisfactory, 7% can be considered a neutral value and 3% can be considered acceptable. (Advanced buildings).
In the western facade, more than 58% of the work surface is exposed to intense light of more than 1000 lux for more than 250 hours out of 1560 hours, which causes visual problems for 16 out of 24 employees during the year.
The second phase: For the second stage (determining the time periods that require environmental treatments) in this paper, the western (worst) interface was studied. In this step, the time periods needed to use the environmental improvements are determined. This is done by observing the values of the ASE scale of the work surface to the west during the working hours of the employees as one is simulated for one variable, the time period of work by keeping all the variables constant. Evaluation of this stage is important because it determines the worst time periods for the western facade

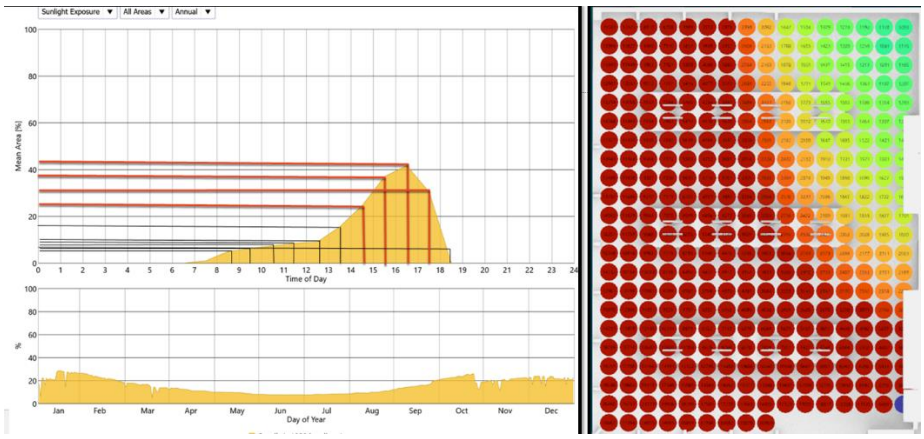


Figure 21. determining the time of day that requires environmental treatments.

The third stage: Before entering the evaluation stage, the components of the dynamic model and the proposed type of movement must be determined, and then the time rate of movement of the dynamic units

Components of a dynamic interface model:
The dynamic interface consists of a set of levels as shown below.
1- Glass: It is a pane of glass with a transmission coefficient of 0.6 that is fixed directly to the wall.
2- Dynamic Facade Support Frame: It is an aluminum frame on which the parts of the dynamic units are attached.
3- Dynamic Interface Units: Each unit consists of a plate that rotates around an axis and is suggested to be made of PTFE with a reflectivity of 0.35 and a heat-resistant and currently corrosion-resistant fluoropolymer (Blumm, A.2011).

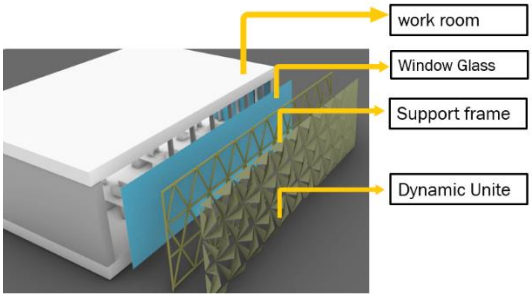


Figure 22. Components of the proposed dynamic unit's model.

7. Discussion

The discussion section will be thematized as follows:

7.1. Suggested movement type for dynamic units:
The type of motion for the proposed dynamic facade units is the rotation of the axis see figure 23.

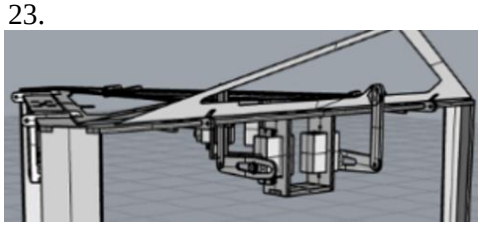


Figure 23. Movement type of dynamic modules.

7.2. Suggested strategy for dynamic interface unit's movement
The methodology used is the stability of all values with the change in the movement of the dynamic units and the ratio of opening and closing of the dynamic units, which corresponds to the distance between the point of direct light on the work surface and the center of solar radiation where the lower

the distance the dynamic units will be closed and vice versa the farther units will open, and the analysis is performed During the daylight hours specified in the previous section

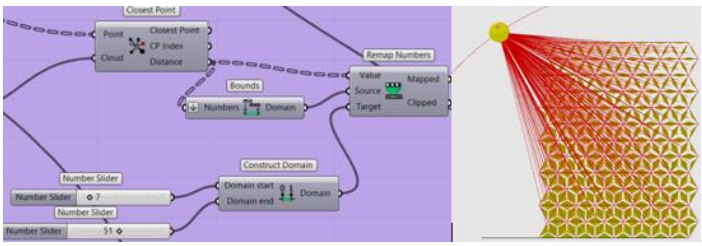
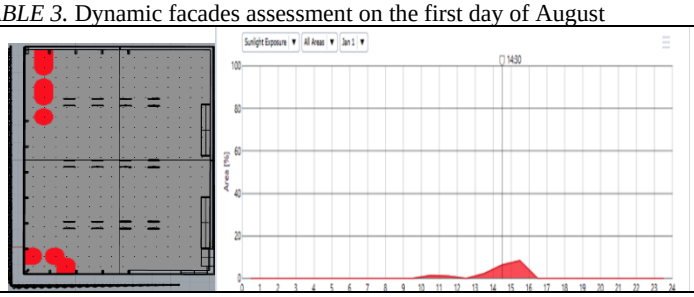
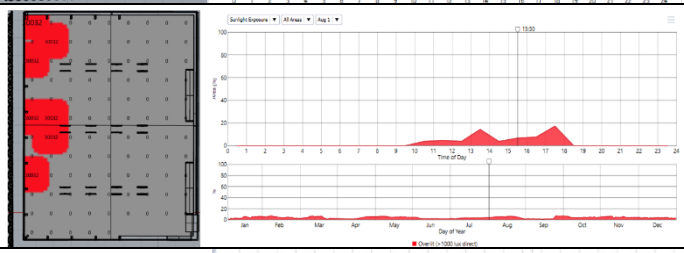
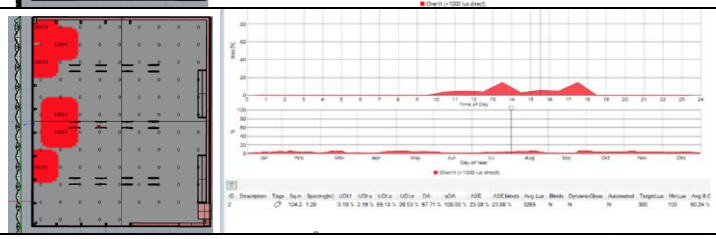


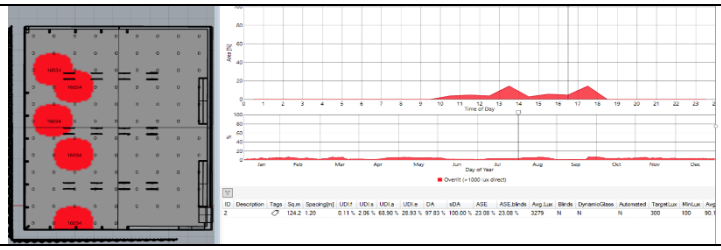
Figure 24. The relationship between the movement of the sun and the opening and closing of the dynamic units

7.3. Performance evaluation of the proposed dynamic interface model

To evaluate the performance of the proposed dynamic rendering model. The scale of the visual problem in office space had to be monitored before and after using the dynamic interface model

TABLE 3. Dynamic facades assessment on the first day of August

2:30 pm on the first day of August	
3:30 p.m. on the first day of August	
4:30 pm on the first day of August	

5:30 pm on the first day of August	

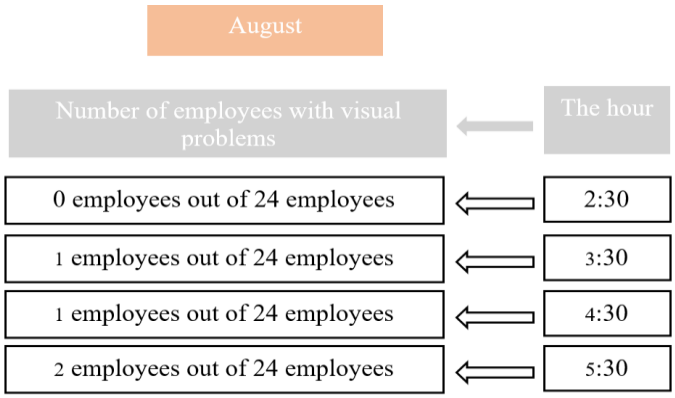
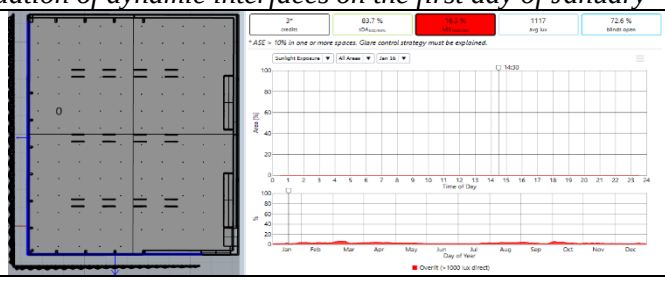
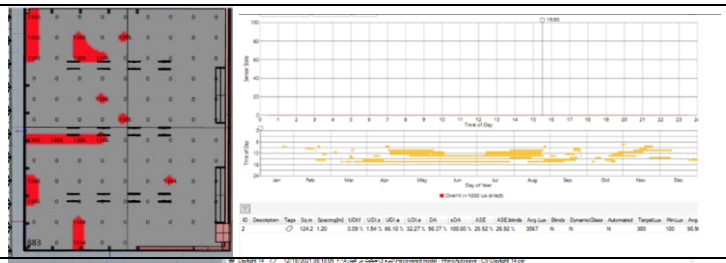
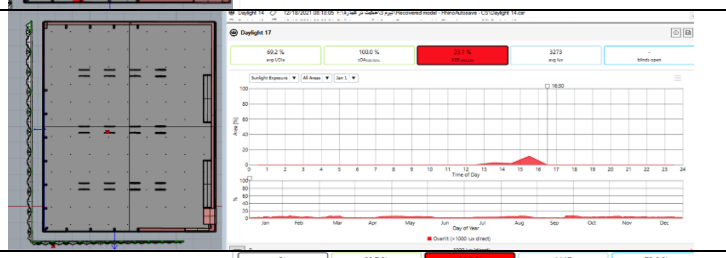
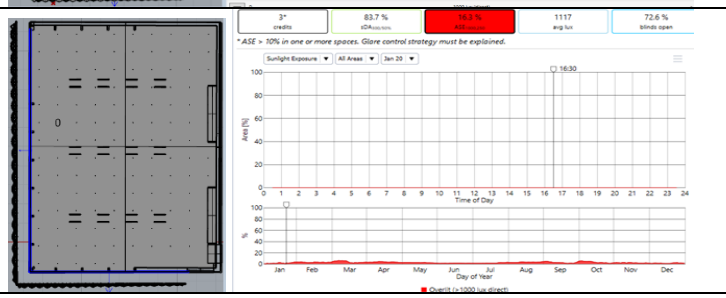


Figure 25. Results of environmental treatments for the month of August

After finding the results of the month of August, the researchers measured the effect of the presence of dynamic facades on the comfort of users for the first day of January and during the previously specified hours, as shown in Table 4.

TABLE 4. Evaluation of dynamic interfaces on the first day of January

2:30 pm on the first day of January	

3:30 p.m. on the first day of January	
4:30 pm on the first day of January	
5:30 pm on the first day of January	

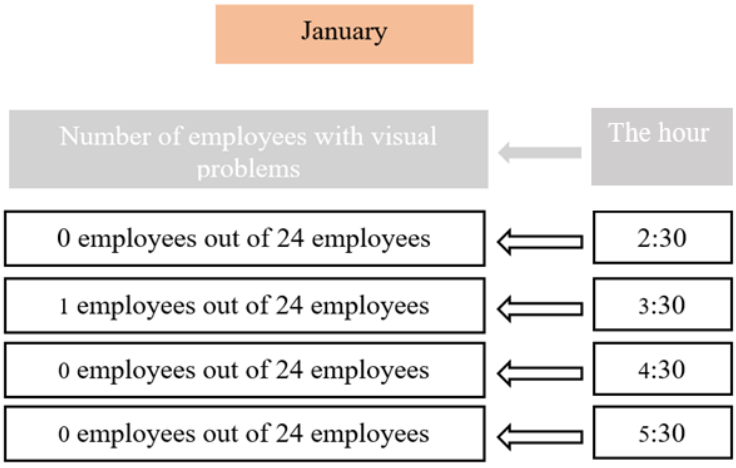


Figure 26. Results of environmental treatments for the month of January

8. Results

In this paper, an administrative space model before and after using dynamic canopies was studied and simulated by integrating grasshopper algorithms with Climate Studio environmental analysis plugin. The simulation was carried out based on the parameters of glare and brightness of daylight, the results of the simulation process show acceptable readings in reducing glare to imperceptible levels and at the same time enlarging external vision. Therefore, the strategies applied not only make space users happier and more energetic, but also improve their health through proper distribution of daylight and thus increase their productivity. Also, a method has been obtained to design a dynamic canopy to increase and maximize energy efficiency using Arduino and some electronic components.

This paper suggests using a Raspberry Pi instead of an Arduino, due to its high storage capacity and Wi-Fi, so it can be easily connected to a weather station to get weather information. This research also suggests using heating, cooling and energy saving in lighting as strategies for this study in order to achieve a more effective parameter-dependent adaptive interface. Operating in a Balance of Glare Reduction and Maximization of Outside Visibility is a precursor to future work as balancing thermal comfort and visual comfort is an objective in the design and integration process.

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LOW-COST PORTABLE WIRELESS ELECTROENCEPHALOGRAPHY TO DETECT EMOTIONAL RESPONSES TO VISUAL CUES: VALIDATION AND POTENTIAL APPLICATIONS

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Abstract. This paper validates the using a low-cost EEG headset – Emotiv Insight 2.0 – for detecting emotional responses to visual stimuli. The researchers detected, based on brainwave activity, the viewer's emotional states in reference to a series of visuals and mapped them on valance and arousal axes. Valence in this research is defined as the viewer's positive or negative state, and arousal is defined as the intensity of the emotion or how calm or excited the viewer is. A set of thirty images – divided into two categories: Objects and Scenes – was collected from the Open Affective Standard Image Set (OASIS) and used as a reference for validation. We collected a total of 720 data points for six different emotional states: Engagement, Excitement, Focus, Interest, Relaxation, and Stress. To validate the emotional state score generated by the EEG headset, we created a regression model using those six parameters to estimate the valence and arousal level, and compare them to values reported by OASIS. The results show the significance of the Engagement parameter in predicting the valence level in the Objects category and the significance of the Excitement parameter in the Scenes category. With the emergence of personal EEG headsets, understanding the emotional reaction in different contexts will help in various fields such as urban design, digital art, and neuromarketing. In architecture, the findings can enable designers to generate more dynamic and responsive design solutions informed by users' emotions.

Keywords: *Electroencephalography; Emotion Detection; Open Affective Standard Image Set; Emotiv Insight*

ملخص. تتحقق هذه الورقة من استخدام سماعة رأس EEG منخفضة التكلفة - Emotiv Insight 2.0 - لاكتشاف الاستجابات العاطفية للمنبهات البصرية. اكتشف الباحثون ، بناءً على نشاط الموجات الدماغية ، الحالات العاطفية للمشاهد بالإشارة إلى سلسلة من الصور المرئية ورسموها على محاور التكافؤ والإثارة. يتم تعريف التكافؤ في هذا البحث على أنه حالة المشاهد الإيجابية أو السلبية، ويتم تعريف الإثارة على أنها شدة العاطفة أو مدى هدوء

المشاهد أو حماسته. تم جمع مجموعة من ثلاثين صورة - مقسمة إلى فئتين: الأشياء والمشاهد - من مجموعة الصور القياسية العاطفية (OASIS) واستخدامها كمرجع للتحقق من صحة النتائج. قمنا بجمع ٧٢٠ نقطة بيانات لست حالات عاطفية مختلفة: الانخراط والإثارة والتركيز والاهتمام والاسترخاء والتوتر. للتحقق من درجة الحالة العاطفية الناتجة عن سماعة EEG، أنشأنا نموذجًا للانحدار باستخدام تلك المعلمات الستة لتقدير مستوى التكافؤ والإثارة ، ومقارنتها بالقيم التي أبلغت عنها OASIS. تُظهر النتائج أهمية معلمة المشاركة في التنبؤ بمستوى التكافؤ في فئة الأشياء وأهمية معلمة الإثارة في فئة المشاهد. مع ظهور سماعات رأس EEG الشخصية، فإن فهم رد الفعل العاطفي في سياقات مختلفة سيساعد في مختلف المجالات مثل التصميم الحضري والفن الرقمي والتسويق العصبي. في مجال الهندسة المعمارية، يمكن للنتائج أن تمكن المصممين من إنشاء حلول تصميم أكثر ديناميكية واستجابة تسترشد بمشاعر المستخدمين.

الكلمات المفتاحية: *تخطيط كهربية الدماغ، تحديد العاطفة، مجموعة صور القياسية العاطفية ، إيموتيف انسايت*

1. Introduction

Spaces play a considerable role in affecting human psychological mood, whether positively or negatively (Elsamahy, 2018). The study of the effect of the built environment on the quality of life has been given a continually increasing interest over the past few years due to its importance in regulating psychological mood – especially stress, which is defined as “The non-specific response of the body to any demand made” (Ellison & Maynard, 1992; Selye, 1974, 1977). According to Tugade and Fredrickson (2006), regulating positive emotional experiences promotes resilience to stressful events. On the other hand, Kopp (1989) discusses the importance of controlling negative emotions and distress from a developmental perspective.

The topic of emotional responses has paved its way in the field of neuroscience research. The hypothesis that hedonic items elicit from consumers more intense emotional responses and sensations than utilitarian products has been developed by researchers over the year (Bagozzi et al., 1999; Kempf, 1999; Allen et al., 2005; Hassenzahl, 2018). However, a recent study casts doubt on the fundamental difference between the emotions evoked by hedonistic and utilitarian items, demonstrating that hedonistic offers only elicit stronger feelings in a segment of customers (Drolet et al., 2007). Bettiga et al. (2020) contend that the contradiction is not caused by the absence of emotions in and of themselves but rather by the character of the emotions appraised, which is solely dependent on their empirical assessment.

The sensory information we receive from our environment significantly impacts how we feel and act (Turley & Milliman, 2000). Most studies on human emotional reactions to environmental characteristics still concentrate on several well-defined and restricted sensory aspects of the environment, although we live in highly diffuse multisensory environments and despite growing interest from various application domains (Schreuder et al., 2016). As a result, systematic knowledge concerning effective multimodal interventions that produce desired results is still lacking (Jain & Bagdare, 2011; Oakes & North, 2008; Turley & Milliman, 2000). As we live in a dynamic environment where factors cannot be considered independently, we hypothesize that understanding brainwave activity should overcome the limitations of traditional tools.

In the context of the built environment, emotional regulation through design, despite its significant potential for creating personalized design solutions, remains largely an undeveloped research area. Until now, the study of human emotional responses to visual cues depends heavily on pooled responses to surveys, which require large samples for validation and consequently eliminate individual differences in emotional responses. As such, this study focused on validating an objective low-cost tool, namely portable wireless electroencephalography, in studying human emotional responses to visual cues. While this study focuses on validating the tool, it will pave the road for more personalized design solutions in built spaces.

The paper first presents some background for the topic, highlighting the different models and tools previously employed in such investigations. The methodology of the article is then presented, and the methods utilized in the validation and analysis are justified using recent similar work. Then, the results of the study are presented and discussed. Finally, the conclusion underscores the key findings, discusses their potential applications in the computational design field, and offers recommendations for future studies.

2. Background

The circumplex model of affect (Russell, 1980) and its variant (Larsen, 1992) have been readily studied in the literature and were proven reliable in mapping and detecting human emotions. The model explains that emotions are disseminated in “a two-dimensional circular space.” Those two dimensions are defined as arousal (excitement or activation) and valence

(positivity or pleasantness). The valence level is represented on the horizontal axis, and the arousal, on the other hand, is expressed on the vertical axis, in which the circle's center point represents medium valence and arousal levels (Figure 1). The choice of identifying the valence and arousal levels was based on the fact that almost all other emotions can be classified into the orthogonal dimensions, including the six basic emotions, which are based on the work of Ekman and Friesen (1976). The model is still widely used in emotional studies (Han et al., 2022; Lipovac et al., 2022; Conrad, 2022)

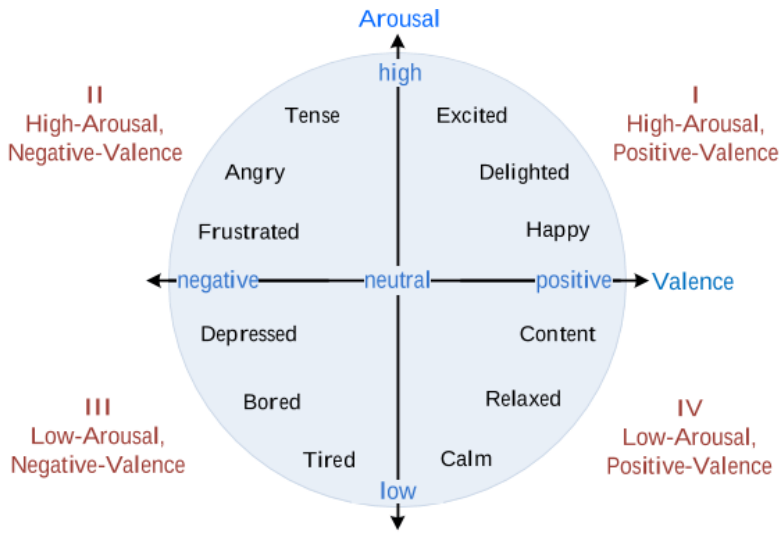

Figure 1. The circumplex model of affect (Russel, 1980)

For psychologists, the concepts of emotion and mood pose a challenge. Although the terms are commonly used interchangeably, most academics concur that the structures they stand for are separate yet closely connected phenomena. In addition, language does not necessarily reflect psychological reality, as Ekman (1994) noted. The fact that we may distinguish between emotion and mood does not necessarily imply that they are different; any distinction may be entirely semantic. The foundation of science is conceptual clarity, and various thinkers have recognized the current jargon confusion (Alpert & Rosen, 1990; Batson, Shaw, & Oleson, 1992; Bless & Schwarz, 1999).

The proposed distinctions cover a wide range of differences, from behavioral and social factors to neurological and physiologic ones. A psychophysiologist, like Panksepp (1994), might choose to distinguish the two by contrasting their respective neural or somatic correlates, whereas a psycholinguist, like Wierzbicka (1992), might choose to emphasize semantic distinctions in everyday language. Distinctions are frequently based on the researcher's particular area of interest. Of course, it seems likely that emotion and mood differ along more than one criterion, and it is simple to understand how variations in their underlying physiological processes would result in variations in phenomenal experience, which would then result in variations in expression, behavior, and linguistic descriptions of the two states.

The study of emotional responses to art had its leading tradition, including Daniel Berlyne's psychobiological model, embodied by the "new experimental aesthetics" movement of the 1970s, followed by many pieces of research such as the International Affective Picture System (IAPS) and the Open Affective Standard Image Set (OASIS). All the mentioned pieces of research did not test the viewer's emotional response but instead focused on the emotions embodied in the pictures (i.e., the tests were image-focused, not internal state-focused). In addition, the results were collected from participants using traditional surveys, which are open to subjectivity from participants. Additionally, pooled responses and mean values recorded through surveys tend to eliminate outliers, which could be important to study to understand the variety of emotions different people experience in response to visual cues.

Many published papers focus on emotion detection from facial recognition using artificial intelligence, such as the one presented by Jain et al. (2018). However, Rhue (2018) gives proof that a person's race affects how facial recognition software reads their emotions. The study contrast the emotional analysis provided by two different facial recognition services, Face++ and Microsoft AI, using a publicly accessible data set of images of professional basketball players. Both services perceive black players as more likely to experience negative emotions than white players. Even after accounting for smile intensity, Face++ continually perceives black players as more irate than white players. Microsoft views black players' equivocal facial expressions as more scornful than anger, and it registers contempt as opposed to anger. Garcia and Penichet (2017), there are five main ways for emotion detection – facial expressions, body gestures and movements, psychological state, speech, and text – using technology. For this research

and to avoid bias created using AI, we opted for EEG and brainwaves as they would lead to the most accurate results and avoid any racial baises.

Blanco et al. (2019) used low-cost wireless electroencephalography (EEG) headset to quantify the human response on a single-trial basis in relation to various cognitive states. Ramirez et al. (2015) also introduced a neurofeedback approach to treat elderly people diagnosed with depression using music. The users were allowed to manipulate expressive parameters in music performances using their emotional state. The results showed a significant decrease in alpha activity, which can be interpreted as an improvement in the depression state. Li (2020) has stated that emotions are not always detectable using traditional models, and it would be useful if a computer could understand or detect the user's emotions. Emotiv's SDK was utilized, which gave him access to four measurements: Engagement, Excitement, Meditation, and Frustration. Although those measurements were useful for the pilot study, he was concerned by the validity and reliability of those indicators.

Age-related changes in the relationships between the brain and behavior can be studied using a variety of research approaches, according to developmental experts. Many people believe that one of the most effective and reasonably priced techniques for examining these developmental changes is the electroencephalogram (EEG) (Bell & Cuevas, 2012), which is defined as a technique for capturing an electrogram of the scalp's electrical activity, which has been demonstrated to represent the macroscopic activity of the brain's surface layer beneath. According to Bell and Cuevas (2012), scientists like the EEG because it makes it possible to examine developmental changes without significantly affecting continuing normal behaviors. They have employed EEG methods to investigate relationships between brain electrical activity and working memory performance during early childhood (Wolfe & Bell, 2004) and toddlerhood (Bell, 2012, 2001), as well as recall memory performance (Cuevas, Raj, & Bell, 2012). Additionally, we have described the month-to-month variations in infant brain development using EEG (Bell & Fox, 1992, 1994; Cuevas & Bell, 2011).

To conclude the background of this study, we validate utilizing low-cost, portable EEG headsets for the emotional detection of the six measurements indicated before in relation to the valence and arousal reported in the OASIS. Said otherwise, we transform the emotional data received from the EEG headset onto The circumplex model of affect (Russel, 1980). We use a

validated set of visual cues, namely the OASIS dataset, to carry out this transformation.

2. Methodology

2.1. MATERIALS

The images displayed in this study are from OASIS (Kurdi, 2017), which is obtained initially from online sources such as Pixabay, Google Images, and Wikipedia (Kurdi & Banaji, 2016). This set of images was chosen because of their availability and relation to the type of emotions being tested. The standard size of the images is 500 x 400 pixels. 30 images were chosen from the dataset based on three primary criteria. 1) Their valence and arousal levels in order to present the whole spectrum of results (Figure 2). 2) Their standard deviation results from the OASIS dataset to have the minimum variation between different individuals. 3) Their level of appropriateness to be presented in the culture of the experiment. So, for instance, we opted not to choose images with explicit sexual activity. Also, to ensure that the responses are a mere indication of an instant emotional state, each image was displayed for a maximum of 10 seconds. The images are categorized by ’” ’OASIS’s first and second authors “merely to facilitate the use of the stimulus set.” The categories used in this study are scenes and objects.

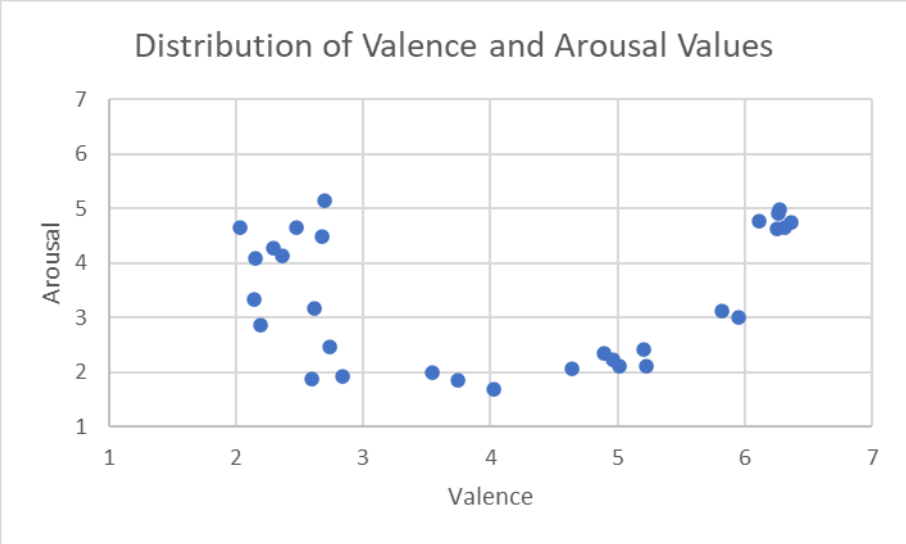

Figure 2. Distribution of Valence and Arousal Values

An Electroencephalography (EGG) headset – Emotiv Insight 2.0 (EMOTIV Insight 2.0 - 5 Channel Mobile Brainwear® - EMOTIV) – was used to translate the participants' psychological signals into six measurements in a 100-grade point system. Those measurements are Engagement, Excitement, Focus, Interest, Relax and Stress. The headset manufacturer provides computer software (EmotivBCI) which – as described by the manufacturer – is a technology that enables you to operate devices directly using your brain activity, as opposed to using a mouse, keyboard, touchscreen, or voice as an intermediary interface. Brain waves are transformed into digital signals via EMOTIV technology, which may then be used to operate an infinite variety of digital outputs, including games, Internet of Things (IoT) devices, communication tools, and audio/visual material. We used the Performance Matrix, which allows passive, ongoing control depending on the current cognitive state, including focus, excitement, interest, engagement, stress, and relaxation indicators.

2.3. SAMPLING

The first step entailed attaining the approval of the Institutional Review Board at the American University in Cairo. To follow the IRB recommendations, participants were allowed to leave the experiment at any time they felt uncomfortable without giving an explanation.

Two sampling strategies were used for recruiting participants: 1) Quota Sampling, in which random participants are selected, ensuring that specific characteristics – such as gender – are equally represented to reach a more universal result. 2) Referral/Snowball sampling in which participants refer us to others interested in the study as they might be challenging to locate given the current circumstances. Since we do not have the participants contact info, a recruitment survey was open to the public on different platforms in which they provided their contact and demographic information to ensure their eligibility for participating in this research following the quota sampling strategy and the minimum age required – 18. The selected participants were contacted by phone or email, depending on their preference indicated in the recruitment survey, to specify a timing to experiment. The experiment was conducted in a controlled environment to measure the specified variables without external influences.

2.4. PROCEDURE

Each participant was assigned the 30 chosen images – samples are shown in Figure 3 – from the 900 images dataset. This technique is mainly used to avoid participant fatigue (Fernández-Caballero, 2016). The experiments took place in a closed office environment, and each participant was examined individually to prevent any unexpected data contamination. The participants would be seated comfortably in a chair facing a large screen and were asked to relax and breathe. The research team greeted the participants pleasantly to reduce their stress. Before wearing the headset, the participants are given a general description of the study and the definition of the different aspects being measured. The headset was then placed, and the contact of the sensors on the participant's head using the provided software.

Figure 3. Sample Images

Each image was shown to four participants, and their brainwave activities were recorded along with the images being displayed. Additionally, the research team took notes of any abnormal activity conducted on the software as it might result from an external factor, which further helped the data modeling process. After the completion of the experiment, participants were asked to fill out a standard questionnaire, including gender, age, etc. They also had an exit interview in which they were asked about their overall feedback on the experiment and how to improve the surrounding conditions if possible. Due to the time constraints, we could present the result of four participants: 3 females and 1 male. We also cross-referenced the result and found no significant variation between the two genders in the six aspects tested.

2.5. DATA ANALYSIS

The images used in this study can be divided into two categories according to Kurdi (2017): Objects and Scenes. Each of these categories was studied

independently to have more accurate results and insights into the triggers of emotional responses. The six emotional states were tested to see if there is any direct correlation between them and the valence and arousal values indicated by OASIS, and a linear regression model using the six emotional responses was created to identify the prediction accuracy of those responses in relation to valence and arousal levels in the two indicated categories.

3. Results

First, we tested the results' normality for the six emotional states – Engagement (En), Excitement (Ex), Focus (Fo), Interest (In), Relax (Re), and Stress (St) – using Shapiro–Wilk test. The results showed that distributions for En, Ex, Re, and St indicate a significant departure from normality, so we concluded that the distributions are not normal. Second, we analyzed the correlations between those parameters and the score values reported by OASIS dataset for valence and arousal using Spearman's rho for nonparametric data and Pearson for parametric data. The results also showed no direct correlation between any of the six emotional states tested and valence or arousal values extracted from OASIS. We opted to create multiple linear regression models for estimating valence and arousal values using the six parameters. Two models were created for the valence estimation: each for a category of images and the same for arousal estimation. Results of valence prediction are shown in Tables 1 and 2.

TABLE 1. Significance of Coefficients to estimate valence in the scenes category

Coefficients [a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-20.095	14.996		-1.340	.205
	En-mean	.204	.158	.527	1.290	.222
	Ex-mean	-.203	.098	-.924	-2.072	.060
	Fo-mean	-.289	.184	-.367	-1.572	.142
	In-mean	.547	.290	.458	1.887	.084
	Re-mean	.091	.263	.281	.347	.735
	St-mean	.073	.421	.137	.173	.866

a. Dependent Variable: Valence
b. Selecting only cases for which Category = Scenes

The model for the valence estimation in the scenes category yielded an R^2 value of 0.527, which is better than all the correlation values indicated above. On the other hand, the estimation of valence in the objects category yielded an R^2 result of 0.929.

TABLE 2. Significance of Coefficients to estimate valence in the objects category

Coefficients [a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-46.386	26.006		-1.784	.149
	En-mean	.370	.057	1.184	6.474	.003
	Ex-mean	-.035	.043	-.159	-.812	.462
	Fo-mean	.018	.084	.046	.216	.839
	In-mean	.901	.616	.421	1.464	.217
	Re-mean	.323	.207	.669	1.559	.194
	St-mean	-.559	.379	-.911	-1.475	.214

a. Dependent Variable: Valence
b. Selecting only cases for which Category = Objects

The R^2 values for the arousal regression model for the scenes category and objects category are 0.210 and 0.539, respectively. The coefficients significance results are shown in Table 3 and 4.

TABLE 3. Significance of Coefficients to estimate arousal in the scenes category

Coefficients [a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	4.258	13.172		.323	.752
	En-mean	-.132	.139	-.503	-.952	.360
	Ex-mean	-.029	.086	-.193	-.334	.744
	Fo-mean	.199	.161	.373	1.233	.241
	In-mean	.043	.255	.054	.171	.867
	Re-mean	.260	.231	1.175	1.122	.284
	St-mean	-.307	.370	-.852	-.830	.423

a. Dependent Variable: Arousal

b. Selecting only cases for which Category = Scene

TABLE 4. Significance of Coefficients to estimate arousal in the objects category

Coefficients [a,b]

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-53.965	45.885		-1.176	.305
	En-mean	-.008	.101	-.037	-.078	.941
	Ex-mean	.122	.076	.807	1.616	.181
	Fo-mean	.081	.149	.297	.546	.614
	In-mean	1.510	1.086	1.020	1.390	.237
	Re-mean	.564	.366	1.687	1.542	.198
	St-mean	-1.194	.668	-2.813	-1.786	.149

a. Dependent Variable: Arousal

b. Selecting only cases for which Category = Object

The results prove our initial hypothesis that a low-cost, portable EEG headset can be used for emotional detection, especially when the visual cues fall under the category of objects. Also, it is easier to accurately predict valence than to predict arousal using the six emotional states mentioned before. It is also worth noting that there are discrepancies between the significance of different emotions to predict valence or arousal when the category chances. For example, engagement showed the highest significance in predicting valence in the objects category. On the other hand, excitement was the most significant predictor of valence in the scenes category. Similarly, stress showed the highest significance in predicting arousal in the objects category and focus, on the other hand, focus showed the highest significance in the scenes category.

4. Discussion & Conclusion

This paper validates the usage of low-cost, portable EEG headsets for emotion detection. The findings support the initial hypothesis and prove that valence and arousal levels can be accurately predicted using six emotional states: Engagement, Excitement, Focus, Interest, Relax, and Stress. The study sets a cornerstone for further research in different fields as the EEG headsets are widely available and expanding as the new "Fitbit for the brain." Using EEG signals yields unbiased, accurate results, which can be used to inform decisions in a variety of contexts. Also, it opens up the door for emotional regulation. The idea of emotion regulation in multiple contexts has been proposed in previous studies.

David and Oltean (2015) work titled: "Technology use in promoting effective emotion-regulation: Applications in the workplace, parenting and for children" investigated different emotion regulation strategies using virtual reality, robotics … etc. However, technology was only used to create different contexts and understand the skills required for the regulation. On the other hand, the smart architecture by Fernández-Caballero et al. (2016) showed direct real-time implementation of technologies and frameworks in emotion detection and regulation. However, due to the complexity of their proposal, the multiple monitoring systems they are using, and the sensitivity of the environment they are operating in, it is concluded that the success of such a project is highly dependent on the acceptance of experts and patients.

Using portable, wireless EEG headsets can overcome such a problem. With the emergence of virtual realities and metaverse, understanding the emotional reaction to different contexts is a crucial step. We think that in the upcoming years, Oculus – the most known VR headset – shall integrate brainwave sensors which will add to the experience of users to a great extent. Such an implementation will significantly affect our approach to designing architectural spaces. Kim, Park, and Choo (2021) found significant differences between the ratio of alpha and beta waves for subjects experiencing a VR space with varied architectural aspects. However, this type of data is only understandable by experts in the field. The validation of low-cost portable EEG headsets in accurately detecting emotions can provide more insights to the general public about their feeling and preferences of the built environment. In addition, collecting analytics from individuals living in the same environment can provide more significant insights to designers and policymakers into ways of positive, informed interventions.

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DAY 1 - PARALLEL SESSION 3

TOPIC 4 - VIRTUAL ENVIRONMENTS AND EMERGING REALITIES

HOW METAVERSE EVOLVES THE ARCHITECTURAL DESIGN

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Abstract. Architects have long relied on visualization tools to develop their concepts for specific design problems. From the early traditional drawings to the three-dimensional visualizations and virtual environments, all have enabled architects to demonstrate design outputs relatively early in the process. Real-world projects are similar to what architects imagined from the beginning. In other words, the design process has always started by creating the digital representation of a project and then attempting to replicate it in real life. Once the digital representation of design parts is complete, architects prepare their design for construction. However, the final visualization emerges from actual architectural functions, structure constraints, Gravity, materiality, privacy, and physical laws, meaning that architecture evolves the digitally represented visualizations. With the growth of the metaverse, all physical restrictions are being eliminated, and architects can expand the boundaries of how spaces can be represented regardless of being virtual or physical. As a virtual environment on the internet, the metaverse redefines the rules of architecture and offers endless possibilities for architectural innovation. This article aims to explore the role the metaverse plays in designing architecture. It outlines the fundamental concepts of the metaverse to identify significant elements that could influence architecture design.

Keywords: *architectural design, digital representation, metaverse, visualization.*

ملخص. لطالما اعتمد المعماريون على أدوات التصور الرقمى لتطوير مفاهيمهم لمشاكل التصميم. بدءا بالرسومات التقليدية المبكرة إلى التصورات ثلاثية الأبعاد والبيئات الافتراضية، فقد مكنت جميعها المعماريين من إظهار مخرجات التصميم في وقت مبكر نسبيًا من العملية التصميمية. وفى الواقع فإن مشاريع العالم الحقيقي تشبه إلى حد كبير ما يتخيله المعماريون منذ البداية. بمعنى آخر، فقد بدأت عملية التصميم دائمًا من خلال إنشاء التمثيل الرقمي للمشروع ثم محاولة تكراره في الحياة الواقعية. بمجرد اكتمال التمثيل الرقمي لأجزاء التصميم، يقوم المعماريون بإعداد تصميمهم للبناء. ومع ذلك، يظهر التصور النهائي من خلال الوظائف

المعمارية الفعلية، والمحددات الإنشائية، والجاذبية، والمادية، والخصوصية، والقوانين الفيزيائية، مما يعني أن العمارة تطور التصورات الممثلة رقميًا. مع نمو تقنية الميتافرس، يتم التخلص من جميع القيود المادية، ويمكن للمعماريين توسيع حدود كيفية تمثيل الفراغات بغض النظر عن كونها افتراضية أو مادية. وبذلك فإن الميتافرس يعيد تعريف قواعد العمارة كبيئة افتراضية على الإنترنت ويوفر إمكانات لا حصر لها للابتكار المعماري. تهدف هذه المقالة إلى تحديد المفاهيم الأساسية للميتافيرس واستكشاف الدور الذي يلعبه في التصميم المعمارى.

الكلمات المفتاحية: *التصميم المعمارى، التمثيل الرقمى، الميتافرس، أدوات التصور الرقمى.*

1. Introduction

The term "metaverse," which combines the word "meta" (which means beyond) and the word "verse" from the word "universe," refers to the next-generation Internet, in which users can interact with software applications and other users as avatars (Duan et al., 2021). The metaverse is best understood as a frictionless 3D web with three key components: presence, interoperability, and standardization. Metaverse is not a brand-new idea. The term was first used in Neal Stephenson's science fiction book "Snow Crash" in 1992. In this book, Stephenson defined the "metaverse" as a vast virtual environment that exists alongside the real world and in which people communicate via digital avatars (Stephenson, 1992). After rebranding Facebook to Metaverse, the 1992-proposed concept known as "metaverse" has gained widespread popularity (Far and Rad, 2022). The metaverse once thought of as a solitary virtual universe, is currently changing into a multiverse in which virtual worlds overlay the actual one. There will be seamless integration between actual and virtual spaces, people, and activities (Tang and Hou, 2022). The physical and virtual worlds become more entwined because of the opening of new paths made possible by the metaverse (Gaafar, 2021).

On the other hand, there is no denying that architects play a vital role in developing creative projects in the metaverse (Figure 1). Architecture is viewed as a container for places, people, and activities. The emerging duality of the metaverse will change not only architectural requirements but also the very nature of architecture in terms of form and function. It is determined that the core of designing metaverse architecture combines virtual and physical entities, such as architectural features, human presences, and artifact properties, to host hybrid and dynamic activities (Tang and Hou, 2022). Hence, there is excellent potential in the architectural requirements of the metaverse, which can serve conventional architectural practices.

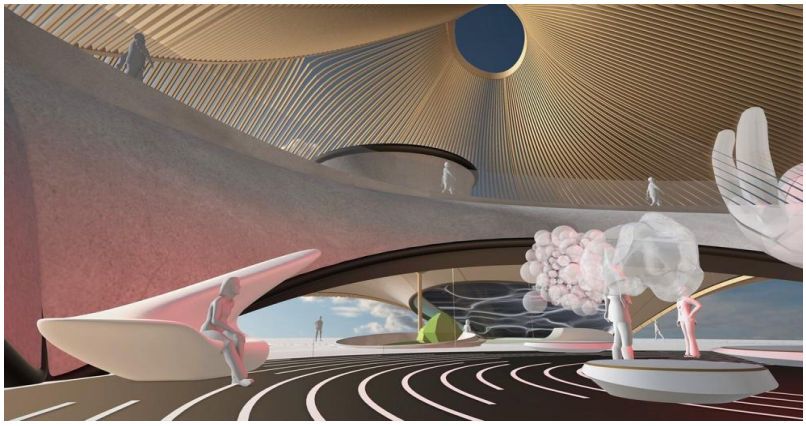

Figure 1. Liberland metaverse (Image credits: Zaha Hadid Architects)

2. Methodology

To identify the role and effectiveness of the metaverse on architectural design, it is essential to build theory from its main features. The goal is to establish a firm empirical grounding based on metaverse that can be used in architectural design. The metaverse architecture will be examined in three phases and compared to the conventional architectural processes in each step. These phases include tools, design methodologies, and place characteristics. For the first part of the study, we classified the tools into the recent cutting-edge technologies used in the metaverse and some virtual environments including game engines, artificial intelligence (AI), digital twin, and AR (augmented reality)/VR (virtual reality)/XR (extended reality)/MR (mixed reality). Secondly, the design methodologies of virtual environments are analyzed. Finally, the place characteristics of the metaverse and conventional architectural designs are compared. The comparison focused mainly on studying the place-making of both virtual and physical realms. Figure 2 shows the roadmap of the research. This approach helps to detect the current bottlenecks in architectural design, which can be solved by retrieving knowledge from metaverse applications.

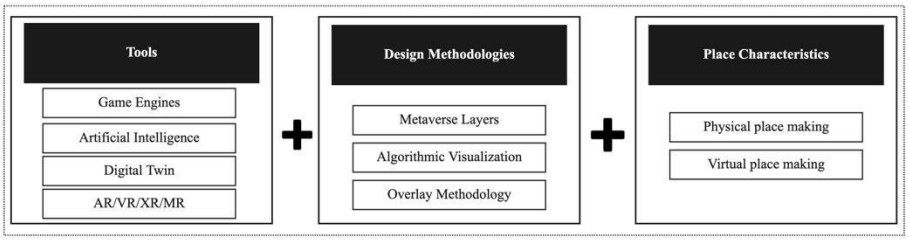

Figure 2. Research roadmap (by authors)

2.1. TOOLS

"The buildings and communities of the near future will be planned with the aid of some development of these theories (new technologies). Whether or not they are planned by architects may pretty well depend on the way architects today prepare to use such tools". (Eames, 1954)

2.1.1. Game Engines

Gaming is anticipated to be a key use case for the metaverse due to its immersive nature. Tech companies have already included metaverse components into well-known games like Animal Crossing, Fortnite, and Roblox, the latter of which reported having over 49 million daily active players in November 2021. Specifically, Second Life, a platform for online social interaction free of plotlines and obstacles, was the first effort on the internet to replicate a metaverse world (Robinson, 2022). Second Life was created as an empty place to be filled with content created by users, in contrast to games with predefined surroundings. This characteristic naturally drew the attention of architects and urban planners. Because it is more than simply a game and serves as a hub for creative expression in online and offline cultures.

On the other hand, it is common for conventional architectural design to illustrate architectural works using various visualization techniques like renderings or videos. While 2D representations have traditionally been utilized to convey designers' intentions, 3D representation technologies are now employed more often (Hamzeh et al., 2019). Architects use 3D modeling software like 3ds Max, Blender, Cinema 4D, or Maya to create 3D models. The models created for real architectural projects often concentrate on construction details and leave out minor details that are less important to the topic (Branco and Leitão, 2018).

Contrarily, 3D modeling for the metaverse may need new talents and a change in perspective to integrate expert knowledge from various domains, such as user interface, content, character, and game design. To do so, game engines are used to create the spaces within the metaverse. Although numerous game engines on the market are easily accessible, the research of Smith and Trenholme (2008) demonstrates that first-person shooter (FPS) game engines often contain more extensive capabilities for modifications. Unity and Unreal are the most remarkable ones. However, in terms of cost and quality, Unity is one of the most well-balanced engines and is readily available to every user (Schoreder, 2011).

Fortunately, some university architecture studios have used game engines as central design instruments in conventional architectural designs. Students got a much-enhanced understanding of the spaces and took advantage of time-based design opportunities not available when working in other media. They highlighted four main advantages of real-time modeling with game engines over physical scale modeling, including comprehension of scale, engagement

of other senses with sound, understanding of space and time, and the ability to interact with others in a virtual space (Johns and Lowe, 2006). However, real-world projects lack the extensive use of game engines, and very few practical methods can enable a professional designer to effectively interact and collaborate with end-users/clients on a functional level (Edwards, Li and Wang, 2015).

2.1.2. Artificial Intelligence

As a pervasive field, artificial intelligence (AI) is even influencing the field of architecture. Pattern recognition in architectural drawing, early-stage design, space planning, automatic generation of the new design, dynamic optimization of architectural design, crowdsourced design, digital fabrication, and form-finding optimization are among the architectural issues dealt with artificial intelligence (As and Basu, 2021).

Besides, AI in the metaverse advances automation for designers, and it surpasses conventional approaches. However, there has not been much progress in using AI to simplify user interaction and enhance the immersive experience. Existing artificial intelligence models are often quite complex and demand high levels of computing. Consequently, it is essential to create artificial intelligence models that are light and efficient (Lee et al., 2021). Since the virtual environment within the metaverse is vast, it might not be possible to make these improvements and maintain the user experience while employing artificial intelligence at its peak efficiency. Additionally, these technologies will always need to function at a high level of performance and stay up to date as the number of users grows (Nalbant and Uyanik, 2021).

2.1.3. Digital Twin

The idea of a digital twin (DT) was first introduced in 2002 by Dr. Michael Grieves of the University of Michigan. The idea claims that every system comprises two sub-systems: a virtual system that holds all the data relevant to the physical system and the physical system itself. As a result of the connection between these two systems, information can flow between the physical and virtual systems (Grieves and Vickers, 2016). It is believed that incorporating DT design principles into the metaverse can provide consumers with natural/actual qualities, increasing the appeal and usability of the metaverse (Far and Rad, 2022). We can use 3D reconstruction methods to create digital twins in the metaverse for structures, items, and settings that already exist in the real world (Zhiliang and Shilong, 2018).

Contrastingly, in conventional architecture, DTs are produced by computers, 3D scanners, and developers based on actual physical things (Far and Rad, 2022). They are mainly used for construction approaches. However, the adoption of DT in the construction industry was relatively low until 2018

compared to the other industries. Most of the projects applying digital twin technology to the construction phase focus on the structural systems integrity of the object (Opoku et al., 2021). Moreover, construction researchers emphasized the contrasts between BIM and Digital Twin, despite the similarities in their definitions. The aim, technology, end users, and a facility's life stage are some of the ways that BIM and Digital Twin differ from each other, according to Khajavi et al. (2019). In the body of construction knowledge, the applications of BIM have been thoroughly studied. While contractors utilize BIM to manage production, conduct constructability analysis, site, and safety management and perform conflict detections and material take-off throughout the design phase of a project, it does not work with architects and engineers (Volk et al., 2014).

2.1.4. VR/AR/MR/XR

Virtual reality (VR) refers to a computer-generated environment that closely resembles reality to the person experiencing it. Although virtual reality is not a new technology, current applications of the tool include a variety of markets such as gaming, education, design, architecture, and the metaverse. According to (Drew Hill et al., 2019), virtual reality is increasingly being adopted as a tool for architectural visualization and presentation in the late stages of the design process. However, numerous advantages that make VR useful in the final phases of the design process indicate that it may also be useful in earlier stages like analysis and concept development. In architecture, VR technologies can create settings for improved stakeholder collaboration, enable a better understanding of complex designs (A.G, 2019), identify design issues (Romano, S. et al, 2020), and represent building geometry to help users understand a project and make a better design decision (Bille et al, 2014), and support collaborative decision-making (Zou et al, 2018). Besides, the metaverse utilizes VR as a platform where multiple users receive identical information and interact in real-time (Lee et al., 2021). Beyond the boundaries of pure virtual spaces, augmented reality (AR) offers users different experiences in their actual surroundings with an emphasis on improving the real world. The user interaction with digital entities in augmented reality has been significantly improved from the very first development (Lee et al., 2021). Augmented reality (AR) technology allows users' visual areas to be expanded with relevant information (Branco and Leitão, 2018). On the other hand, in real-world architecture, AR is used in many fields such as construction maintenance and productivity and architectural and environmental planning (Alizadehsalehi, Hadavi and Huang, 2020).

Although there is no widely accepted definition for MR, it is essential to have a phrase that characterizes the alternated reality between the two extremes of augmented reality and virtual reality (Lee et al., 2021). MR is another version of AR. To create new habitats where digital and physical items may interact in real-time, mixed reality (MR) mixes the virtual and physical

worlds (Apollonio et al., 2011). Users can experience the metaverse through many other realities in physical and virtual realms because of the MR continuum's diverse categories (Pakanen et al, 2022). Besides, in real-world projects, MR is used in many fields, including the AEC industry, prefabrication, site survey, and remote design problem-solving (Alizadehsalehi, Hadavi, and Huang, 2020).

Extended Reality (XR) is the term for the real and virtual worlds that wearable technology creates (Gaafar, 2021). The XR, as used in computer technology and wearables, refers to real-and-virtual mixed settings and human-machine interactions. VR, AR, and MR are all parts of XR. In other words, XR may be characterized as a phrase that unifies AR, VR, and MR under one heading, reducing ambiguity for the general audience (Alizadehsalehi, Hadavi and Huang, 2020). In the metaverse, users in the physical world can control their avatars through XR and user interaction techniques for various collective activities such as content creation (Lee et al., 2021). XR technologies, which simulate building projects in multidimensional digital models and exhibit many features, can significantly aid all phases of a project in the Architecture, Engineering, and Construction (AEC) sector (Alizadehsalehi, Hadavi, and Huang, 2020).

2.2. DESIGN METHODOLOGY

Design for a real-space is constrained by physical laws (Kim, Lee, and Lee, 2017). However, virtual design approaches differ from real-space design procedures. Furthermore, as the metaverse is still in its early phases of development, neither academia nor industry has a consensus on how it should be structured (Duan et al., 2021). Nevertheless, some attempts have been carried out to deal with this problem. For instance, layered metaverse methodologies were established by some researchers. Additionally, design methodologies of digital games, as the most similar environment to the metaverse, and the algorithmic approaches of 3D modeling, as a methodology for the effortless generation of adaptable visualizations, can be adopted.

2.2.1. Metaverse Layers

To meet the requirements of the metaverse, this virtual world needs structures. For this means, a seven-layer metaverse design was developed by Jon Radoff. The levels include infrastructure, human interface, decentralization, spatial computing, creator economics, discovery, and experience. Additionally, a generic three-layer Metaverse design (Figure 3) was proposed by Duan et al. (2021). The seven levels of Radoff's metaverse are broken down into the three phases below based on Duan's suggested architecture: A) Infrastructure: This layer establishes the fundamental and physical necessities, such as the blockchain, network, and processing power. B) Interaction: This layer links

the Infrastructure and Ecosystem levels, where the metaverse's contents are formed. C) Ecosystem: This is the Metaverse, a parallel digital universe. This layer combines AI, economics, and user-generated content. The Interaction layer connects the Infrastructure and Ecosystem in this suggested broad architecture of the metaverse. This approach looks at the architecture of the metaverse from a more macro viewpoint.

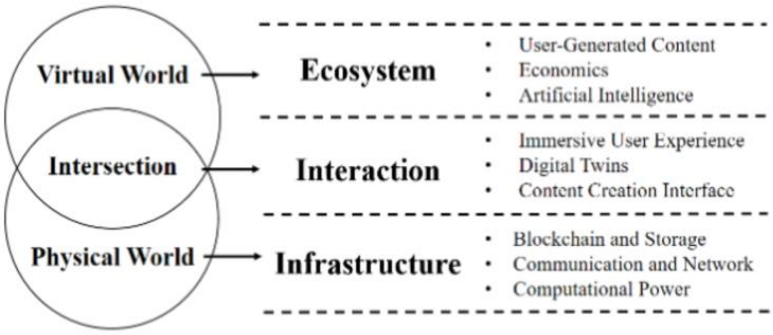

Figure 3. Three-layer architecture of the metaverse (Duan et al., 2021)

2.2.2. Overlay Methodology

To train designers and architects to design and build virtual environments with higher efficiency, Kim et al. (2018) have suggested the Overlay methodology to design the virtual space within digital games. As both real and virtual environments have interactive space characteristics, it is persuasive to apply the design approach or procedure from real space to a virtual environment (Kim, Lee, and Lee, 2017). Therefore, the Overlay design methodology was inspired by Ian McHarg's design approach for landscape architects (Mcharg and Mumford, 1969). The steps in the Overlay methodology are as follows. After developing the game's concept, the type of its place is first defined as described in the place-making in virtual environments of classification method research (Kim, Lee, and Lee, 2017). Secondly, the recommended information is extracted from the classification methodology, and players' activity is developed as bubble diagrams, Player Activity Map (PAM). Finally, developers design each layer in a defined order: story, natural environment, artificial environment, and media with information, file them all together and build a master diagram (Kim et al., 2018) (Figure 4).

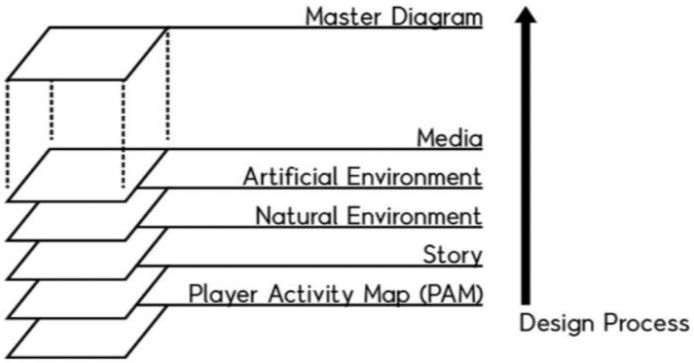

Figure 4. Overlay design methodology (Kim et al, 2018)

2.2.3. Algorithmic Architectural Visualization

According to Gerber and Ibaez (2014), algorithmic design (AD) refers to creating architectural designs using algorithmic descriptions. In contrast to conventional design methods, algorithmic design entails the architect creating software that creates the digital model rather than the model itself. Since the resulting algorithmic descriptions are parametric, they can;

- model more complicated geometries that would generally need much time to construct;
- automate time-consuming, repetitive operations; and
- quickly generate a variety of design alternatives.

When using algorithmic design, the architect creates the program that creates the digital model, using a combination of geometric, symbolic, and mathematical representations of the objects. While the spread of this design approach creates a challenge for visualization, the algorithmic architectural visualization (AAV) process, which makes it simple to create adaptable visuals, looks like the solution. AAV depends on the parametric descriptions of the rendering tasks that follow after the parametric description of the architecture is included, along with the model's description. As a result, camera placements and alignments follow the project's logic, and modifications to the design also result in modifications to the visualizations.

This methodology consists of two tasks that can only be programmed and automated as far as the rendering software in use allows. The level of detail depends on both the project's development stage and the purpose of the render itself. These phases include establishing scenario features, such as sunshine, sky, and other environment settings, and detailing the model to generate ambiances, which may require specifying furniture components, coatings, lighting, etc. (Branco and Leitão, 2018).

2.3. PLACE CHARACTERISTICS

In determining the elements that affect place characteristics and the sense of place, scholars have conducted research in both physical and virtual realms. Placemaking's core concept can be traced back to the 1960s, when urbanists and activists like Jane Jacobs (Jacobs, 1961) and William H. Whyte (Whyte, 1980) utilized their theories to reshape the structure of cities, focusing on people rather than cars and shopping. The process by which humans turn the tangible environment into a living place that hosts their activities is described as place-making (Schneekloth, and Shibley, 1995). Place-making refers to various actions to increase the chances of good places forming or flourishing. New developments, improvements to existing places, or interventions that create an activity in a space can be considered place-making.

2.3.1. Place-making in Physical Environments

There are several dimensions of place-making in physical environments. Researchers have found interdependent aspects to it. For instance, Punter (1991) believes that place aspects include form, activities, and meanings. Likewise, Canter (1977) suggests form, activities, and conceptions. Subsequently, physical features, individual features, activities, and meanings were proposed as the main factors of a place. (Falahat, 2006) Besides, a more recent work covers the physical, psychological, and social domains.

Architecture, even in its conventional form, intends to enhance the quality of human experiences while turning spaces into places of living. Fortunately, some researches focus on the place-making problem. The identified features of place in physical environments are listed in Table 1.

TABLE 1. Physical Place Features

source	realm	place features
(Punter, 1991)	Physical	form- activities- meanings
(Canter, 1977)	Physical	form- activities- conceptions
(Falahat, 2006)	Physical	Physical features- individual features- activities - meanings
(Al-Kodmany, 2012)	Physical	physical- psychological- social

2.3.2. Place-making in Virtual Environments

The place is a concept that may be applied in various settings, not only physical ones. Many virtual environments can be thought of as having their distinct place-ness. The aspects of place are quite significant in this realm because place-based, embodied explorations of virtual environments make it

easier to study a place than in natural settings (Quiring, 2015). Virtual place making is identical to physical place making because it has been built on communication networks between humans, their environments, social traditions, and other personal experiences. A virtual place's layers, functionality, interaction, communication, and perception contribute to its sense of place (Piercy, 2019) These factors are the elements that give meaning to each place and provide reasons for users to have emotions and attachment to a virtual environment.

Accordingly, several researchers examine the place-making of digital games to help reflect on the sense of place within virtual spaces. While (Purzycki, 2019) devised a framework based on setting, community, events, perception, and meaning, (Piercy, 2019) believes the three pivots of social, audio-visual, and developer-based communications comprise the virtual places within games. On the other hand, (Kim, Lee and Lee, 2017) classify virtual places based on five principles of story, space shape, space and action dimension, user complexity, and interaction level. He further explains and classifies the terms. First, the story is about providing an engaging narrative, divided into two categories representing and generating. Space Shape refers to the structures of implemented virtual places. Based on the edge of the space and the flexibility of the player's direction, it is divided into spot, linear, chain, and face. Space and action dimension refers to the corresponding movement and implemented dimensions needed for the user to direct the character inside the space. There are four different varieties of it: 2D-2D, 2D-3D, 3D-2D, and 3D-3D. Finally, while user complexity is known as simultaneous utilization of the place by several users that can be separated into single, group, and massive, the interaction level is described as the amount of engagement between the user and the virtual place, classified as none, partial, and all.

The identified features of place in virtual environments are listed in Table 2, and (Kim, Lee and Lee, 2017) classification conditions of virtual places are represented in Table 3.

TABLE 2. Virtual Place Features

source	realm	place features
(Purzycki, 2019)	Virtual	setting- community- events-perception- meaning
(Piercy, 2019)	Virtual	social communication- audio-visual communication- developer based communication
(Kim,Lee and Lee 2017)	Virtual	story- space shape- space dimension- user complexity-interaction level

TABLE 3. Virtual Place Classification Principles, adapted from (Kim, Lee and Lee, 2017)

Principle	Variable	Description
Story	Representing	Player follows the given story line (close ending).
	Generating	Player generates a new story (open ending).
Space Shape	Spot	Player freely moves around in a limited space that has boundaries.
	Linear	Player is guided to a move toward certain direction in a limited space.
	Chain	Combination of Spot and Linear. The player is allowed to move freely in a spotted space, and moves to the next spotted space to play further.
	face	Unlimited space with player's free movement
Space and Action Dimension	2D-2D	Require two axises (XY) to build the world, requires two axises (XY) to the players to play the game
	2D-3D	Requires 2 axes (XY) to build the world and requires more than 2 layers of two axes (XY) to the players to play the game
	3D-2D	Requires 3 axes (XYZ) to build the world and require 2 axes (XY) to the players to play the game
	3D-3D	Requires 3 axes (XYZ) to build the world and requires 3 axes (XYZ) to the players to play the game
User Complexity	Single	Player is the only one in the game (a single player at a time)
	Group	More than two players play the game together, sharing same goals
	Massive	More than two groups of numerous players play the game simultaneously, with various goals.
Interaction Level	None	No interaction between the player and the environment except as the boundary of a void space
	Partial	Player can interact with designed limited environment resources in the space
	All	Player can interact with every environment resources in the space

3. Results

The results of the article are drawn by assessing and comparing the main characteristics of the metaverse architecture and conventional real-world architecture. This comparison helped us detect the similarities and differences between these two fields and the potential opportunities they can obtain due

to the bottlenecks. As shown in Table 4, although game engines have succeeded in taking the attention of both architects and metaverse designers, real-world projects lack the extensive use of this powerful tool. Additionally, metaverse and architectural design contain structures and layers to construct their design projects. However, these structures differ from each other. Furthermore, metaverse and actual architecture mainly differ in terms of the features of the place. While both virtual and real architectural places rotate on the pivot of meaning and story, interaction is the element that architecture has not paid enough attention though being one of the prominent factors of virtual places. A place exists in a natural environment whether or not you interact with it. In a virtual environment, though, the place loses its meaning with no interaction. A more extensive overview of the two realms of conventional and metaverse architecture is provided in table 4.

TABLE 4- Results

Results' Highlights
While every single detail can be highlighted in the metaverse design, architectural projects concentrate on construction details and leave out minor details that are less important to the topic.
Real-world projects lack the extensive use of game engines as a virtual platform to interact with others.
AI has been used to its maximum potential in architecture, whereas there has not been much progress in using AI to simplify user interaction and enhance the immersive experience in the metaverse.
While the digital twin in the metaverse mainly focuses on the design phase, architecture mainly utilizes this tool for construction, focusing on the structural systems.
VR/AR/MR/XR tools focus mainly on construction, prefabrication, and the AEC industry instead of architectural design, while metaverse benefits from these tools.
Although containing different design methodologies, virtual places drew inspiration from architectural design methodologies in some cases.
Both architectural and metaverse designs contain structures and layers, although they do not have the same functions.
Meaning and story remain the core concept in both virtual and physical spaces.
For virtual places, interaction has a great degree of importance.

4. Conclusion

This study aimed to investigate how the metaverse influences architectural design. It defined the fundamental ideas of the metaverse to pinpoint important components that could affect architectural design. Along our journey, we also provided insight into recent developments and tools that link the physical and virtual spaces. Based on our comparative review of the three

phases of tools, design methodologies, and place characteristics, we concluded that each design has its challenges and opportunities with similar and different features, which can help both fields to boost their place qualities. Yet, further research is needed to explore the design development process and how architecture professionals use 3D modeling software for different design briefs in the metaverse and real-world design problems.

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MEMORABILITY OF SPATIAL FEATURES IN VIRTUAL REALITY

Süleymaniye Experience

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Abstract. The goal of this study is to uncover and understand the user's perception of spatial features as they interact with cultural heritage in a virtual environment. The virtual reality (VR) experience adopted Kaufmann's three-fold imagery conception to structure the research methodology, which suggests that linguistic representation, visual imagery representation, and exploratory activity all have a strong relationship during the problem-solving/creative process. Since it has distinctive spatial features, the Süleymaniye Mosque in Istanbul was chosen for the VR experience as part of the scope. Following the VR experience in two sessions, it was analyzed using semi-structured interviews, sketching, and route extraction. The initial findings of this study revealed differences in individuals' perception and memorability of spatial qualities in the VR environment.

Keywords: *virtual reality, immersive experience, memorability, cultural heritage, virtual heritage.*

ملخص. الهدف من هذه الدراسة هو كشف وفهم تصور المستخدم للسمات المكانية أثناء تفاعلها مع التراث الثقافي في بيئة افتراضية. اعتمدت تجربة الواقع الافتراضي مفهوم كاوفمان للصور ثلاثية الأبعاد لهيكلة منهجية البحث، والتي تشير إلى أن التمثيل اللغوي وتمثيل الصور المرئية والنشاط الاستكشافي جميعها لها علاقة قوية أثناء حل المشكلات أو العملية الإبداعية. نظرًا لأنه يحتوي على ميزات مكانية مميزة، فقد تم اختيار مسجد السليمانية في اسطنبول لتجربة الواقع الافتراضي كجزء من نطاق البحث. بعد تجربة الواقع الافتراضي في جلستين، تم تحليلها باستخدام المقابلات شبه المنظمة والرسم واستخراج المسار. كشفت النتائج الأولية لهذه الدراسة عن اختلافات في إدراك الأفراد وتذكر الصفات المكانية في بيئة الواقع الافتراضي.

الكلمات المفتاحية: *الواقع الافتراضى، التجربة الغامرة، تجربة التذكر، التراث الثقافى، التراث الافتراضى.*

1. Introduction

Immersive technology advancements provides numerous advantages in documentation, presentation, and visualization (Addison, 2000) and open up a new research area for cultural heritage (CH). This digital CH, known as virtual heritage (VH), creates computer-based reflections of objects, buildings, built environments, and sites with archaeological, aesthetical, and historical value (Tan and Rahaman, 2009). VH creates exceptional interactive experiences that facilitate users' learning, creativity, and collaboration, often through entertainment. Educational purposes, documentation against destruction, reconstruction of damaged or demolished monuments, interacting with monuments, and observing artifacts from various scales/angles are some of the reasons why cultural heritage objects are visualized in computer environments (Noh et al., 2009).

Previous VH research in architecture had primarily focused on design activities in virtual environments (Dorta, 2004; Schnabel et al., 2004). Although VH experiences offer numerous opportunities, integrating them with design and educational activities can be challenging (Champion, 2006; Chen and Kalay, 2008; Tan and Rahaman, 2009). This integration raises the question of whether novel ways of interacting with the physical environment change users' perceptions, comprehension, or spatial experiences.

Spatial experience shapes memory's architectural organization. Remembering architectural images is an important memory device for materializing and preserving the flow of time and making it visible; concretizing remembrance by containing and projecting memories; and inspiring reminiscence and imagination (Treib, 2009). As a result, the purpose of this study is to discover the implicit and minor differences between individuals in their perception of spatial features during the immersive experience of CH in VH.

2. Spatial Experience in VR Environment

In a virtual reality (VR) environment, the observer mentally separates from reality and enters an artificial three-dimensional world (simulation). Due to these interactions, this shift engages in various interactions such as being present, moving around, changing the location and properties of objects, and receiving sensory reactions as in the real world. VR environments are computer simulations made from images that act as if the senses are experiencing physical reality (Sherman et al., 2009). According to Pimentel and Teixeira (1993), the three essential characteristics of VR are "immersion," "interaction," and "three-dimensional graphic world." Sherman and Craig (2003) add "emotional feedback" to this list of characteristics. *Immersion* is frequently used to describe an emotional or mental state. It refers to mentally leaving the real world and entering the virtual world (Sherman and Craig, 2003). *Immersion* is the selective focus on the studied knowledge while excluding outside influences. According to Pimentel and Teixeira (1993), it also acts as a powerful lens for extracting knowledge, transforming it from input into experience. *Interaction* refers to various actions performed in a virtual reality environment. Depending on the goal of creating the VR environment, the mode of interaction varies. *Three-Dimensional Graphic World* is the creator's mental space. This environment can be based on a real or imagined place. Finally, *Emotional Feedback* is the perception of the observer's feelings as a result of their presence and actions.

In natural environment perception, the observer is surrounded by spatial information from different points. Alavesa et al. (2017) present a study that connects VR and spatial experience, with a focus on the concept of memorability. Their findings indicate that spatial similarity influences memorability in virtual reality environments (Alavesa et al., 2017). Unlike their study (Alavesa et al., 2017), this study does not include an active gameplay session in the case studies. Reggente et al. (2020) introduce a variant of the well-known loci method for assessing the memorability of non-spatial elements in a spatial virtual environment. Reggente et al. (2020) discover a link between the presence of landmarks in the spatial environment and the memorized 3D object, as well as verbal recall and memorability. This study differs from Reggente et al. ‘s (2020) work in the following ways: I use of a CH as a spatial environment, (ii) recall of architectural elements rather than arbitrary 3D objects, (iii) experiment set in two stages of 10 minutes and 1 minute rather than 20 seconds, and (iv) use of Kaufmann's (1980) imagery conception as part of the research method.

3. Methodology

As previously stated (Pimentel and Teixeira, 1993; Tan and Rahaman, 2009), perception, comprehension, memorability, and spatial experience in VR environments differ from person to person. Aside from the movement route and the detail of the spatial environment features, the duration and frequency of an experiment may influence user memorability. A qualitative research framework is developed to better understand the differences between individuals following the immersive experience of CH in VH. Geir Kaufmann (1980) contributes to theoretical debates with his concept of verbal, visual, and experiential imagery, which considers the restructuring of individual information from one domain to another. The VR experience in the scope of this study used Kaufmann's (1980) three-fold imagery conception to structure the research methodology.

The basic principles of Kaufmann's (1980) theory are illustrated in Figure 1, which suggests that linguistic representation, visual imagery representation, and exploratory activity all have a strong relationship during the problem-solving/creative process. According to Figure 1, a pure verbal representation is superior when an individual has a high level of familiarity with the task at hand, allowing for quick, stable, and generalizable problem-solving performance. Visual imagery as a symbolic system becomes more prominent as new features emerge in a problem situation, assisting the verbal symbolic function. The requirement for open, exploratory activity grows in direct proportion to the novelty of a problem.

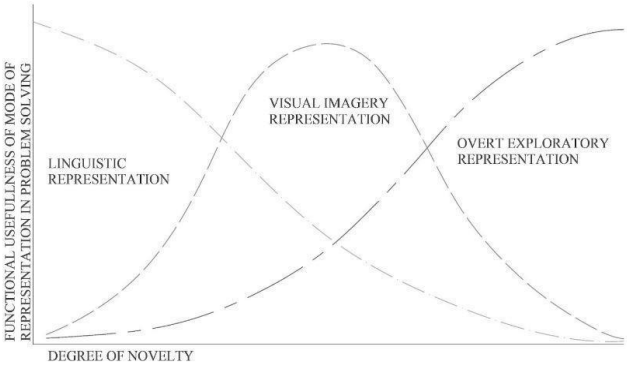

Figure 1. Kaufmann's (1980) three-fold representation modes.

Since experience is subjective and holistic, it is hard to isolate any modes of representation from others. Keeping these difficulties in mind, Kaufmann's conception of imagery (Table 1) is used in this study in the data collection and analysis part of the experiments. In other words, Kaufmann's (1980) concept

of imagery has been adopted for data collection structuring in relation to actions of memorizing and remembering the space.

TABLE 1. Layers of data collection.

Modes of representation	Data collection method
Verbal imagery	Semi-structured interview
Visual imagery	Sketching
Experiential imagery	User route extraction as a part of their spatial experience

Kaufmann (1980) emphasizes the significance of familiarity and repetition in the experiments and their results. In contrast to Kaufmann's proposition, this study focuses on the available features of CH's spatial experience in a VR environment rather than problem-solving or creative processes. In the scope of this study, a case study, Süleymaniye Experience, was designed to understand the verbal, visual, and experiential factors of spatial memory in VH VR environments. Figure 2 illustrates the experiment setup framework.

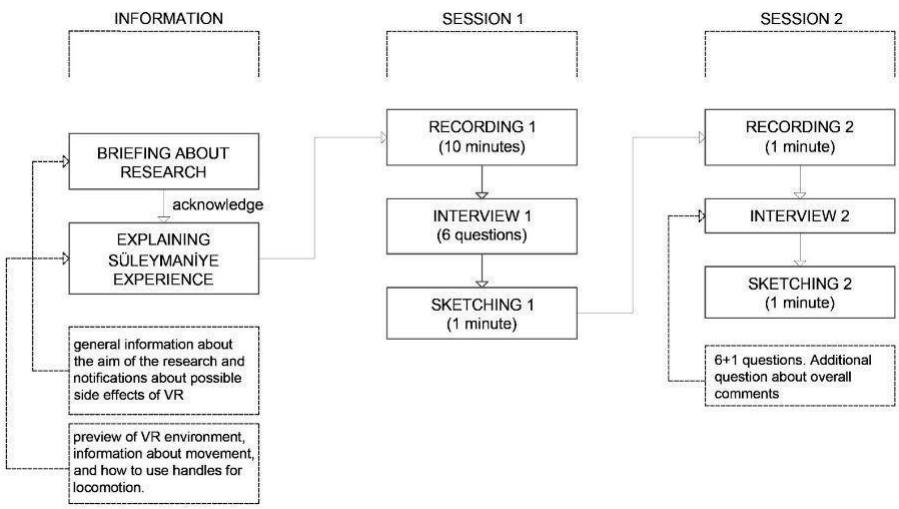

Figure 2. Diagrammatic illustration of the case study.

4. Case Study: Süleymaniye Experience

4.1. AIM AND SCOPE

The purpose of this research is to reveal and understand the user's perception of spatial features as they interact with CH in VH. As part of the scope, the Süleymaniye Mosque in Istanbul, built between 1551 and 1557 by Architect Sinan, was chosen for the VR experience. The Süleymaniye Mosque was chosen due to its distinct spatial characteristics in comparison to other Ottoman Mosques. This spatial richness is expected to keep multiple levels of perception active throughout the experience. Another reason for selecting this monument is that it is accessible to a variety of users for a wide range of purposes throughout the day. Süleymaniye Mosque is a part of both locals' and tourists' daily lives, and it still functions as a mosque.

4.2. ENVIRONMENT AND TOOLS

To create virtual environments, various hardware, software, and techniques can be used. According to Pimentel and Teixeira (1993), selecting these components can increase or decrease immersion. In this study, an interactive journey for Süleymaniye Mosque was created using Unreal Engine 5 (a game engine), allowing the user to experience the interior and exterior of the building. Before initiating on this VR journey, the authors created a 3D solid model of the Süleymaniye Mosque in the Rhinoceros CAD environment. Ali Saim Ülgen's (1989) 2D drawings (surveys) were the primary source for the 3D modeling task.

Users can move around in virtual space using teleport-style locomotion. This movement was made possible by *Oculus Quest 2* and its hand trackers. These tools used a 'arc-like' digital indicator, allowing users to move around in the permitted areas, including predefined teleportation points such as minaret balconies, domes, portals, and shadirvan. For locomotion, the authors defined 22 points for the exterior and 12 points for the interior (Figure 3). These points were highlighted in the model with 3D labels. Users were free to move on/around the walkable surfaces that comprise the mosque's overall form in addition to the teleportation experience (Figure 4).

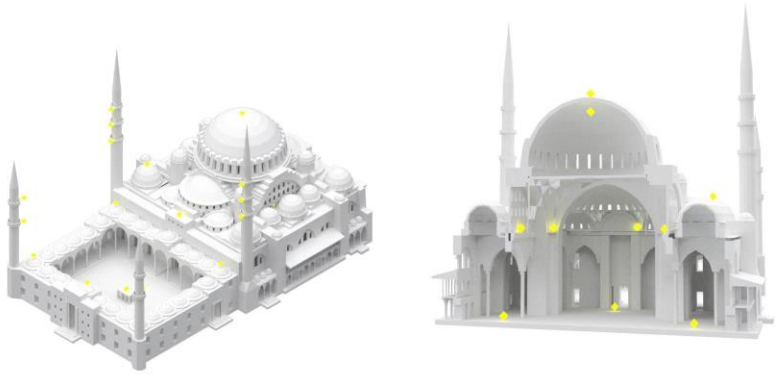

Figure 3. Locomotion points defined on the digital model.

Figure 4. Locomotion points in VR environment.

4.3. EXPERIMENTS

The virtual experiment was divided into two sessions. The respondents in this study were eight undergraduate architecture students who had visited the Süleymaniye Mosque at least once. Since the Süleymaniye Mosque is well-known among Istanbul residents, finding unfamiliar respondents for the study was difficult. As a result, it was decided that the structure should be familiar to all respondents. The corridors of Taşkşla Campus (Faculty of Architecture at Istanbul Technical University) were chosen for the experiment because of their large area, which allows walking long distances with the VR headset and trackers, implying movement in the VR.

During the first session, respondents were allowed to remain in the virtual environment for 10 minutes. Their experience was documented using Oculus

Quest 2, and after 10 minutes, respondents were surveyed using a semi-structured survey.

Finally, for 1 minute, respondents were asked to draw a scale-free hand sketch of their experience (referring to Kaufmann's "visual imagery"). Then, in the second session, respondents were allowed to stay one minute in the virtual environment. For the second experience, the recording, survey, and sketching were repeated.

The following questions about the qualitative and quantitative architectural features of Süleymaniye Mosque were included in this prepared survey:

1. Which architectural element(s) did you observe?
2. Which space(s) of the monument did you visit?
3. If you visit more than one space, can you put them in an order according to their sizes?
4. Which space was the brightest/most luminous?
5. Which space(s)/viewpoint(s) did you visit most often?
6. Which space(s)/architectural element(s) did you perceive both from the interior and exterior?
7. What are your overall comments considering these two experiences?

4.4. OUTCOMES AND FINDINGS

Based on the recorded sessions of the respondents, the authors mapped their movements (both moving around and teleporting) and created line-based diagrams. Then, these line-based diagrams were superimposed to see the similarities and differences between the experiences (Figure 5).

Respondents became acquainted with the tool, interface, and Süleymaniye Mosque during the first 10-minute session. Despite this training session, respondents were able to give adequate answers to all questions. Following the first session, respondents were confronted with the six questions. Given this, the respondents were informed about the questions before beginning the one-minute second session. Tables 2-7 show the responses of respondents to questions 1–6. The common denominator of the responses to the seventh question was that the respondents tended to count the spatial components that can be counted in the second stage and expressed this verbally.

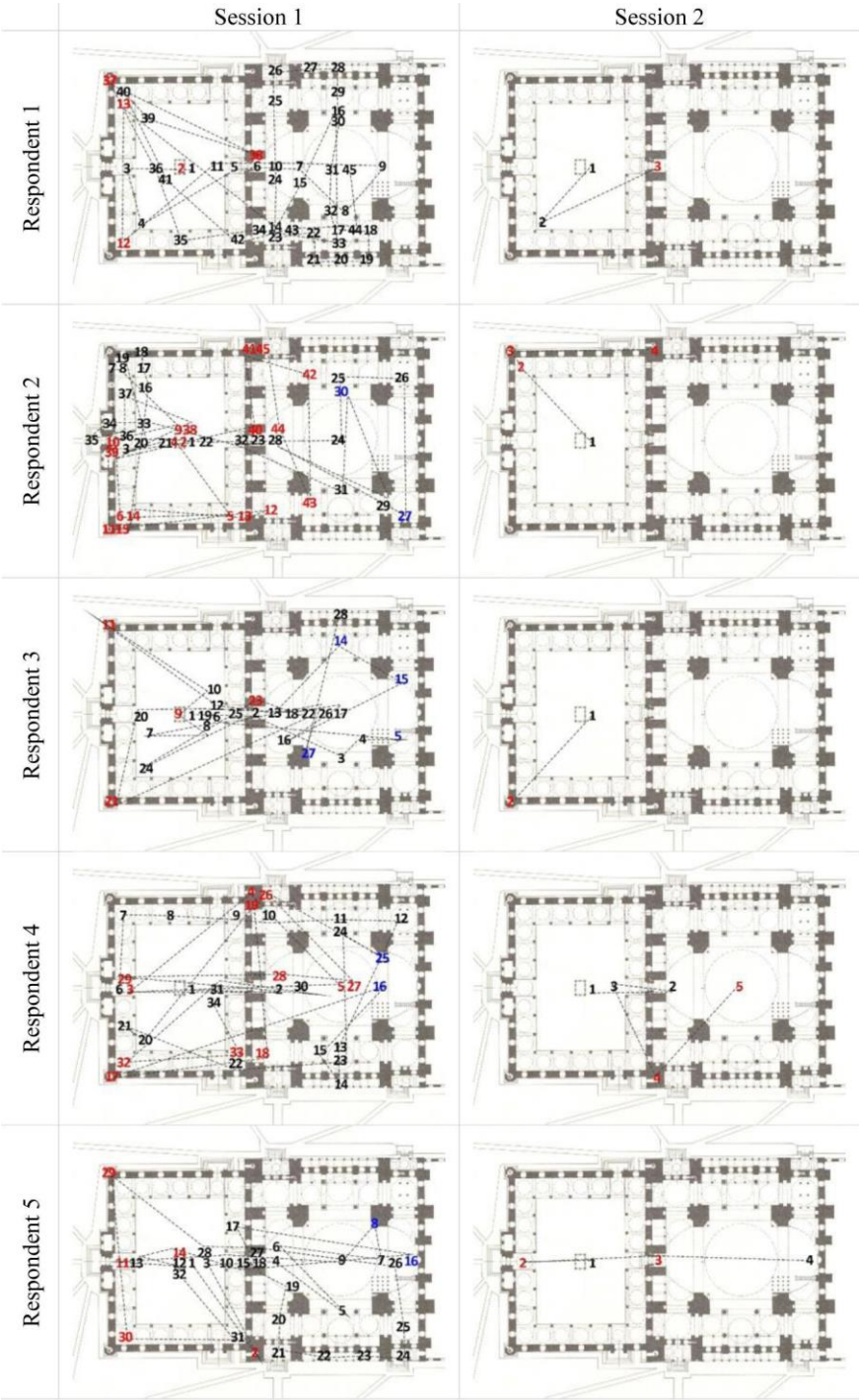

Figure 5. Route extraction from the VR experiment of the respondents (continues).

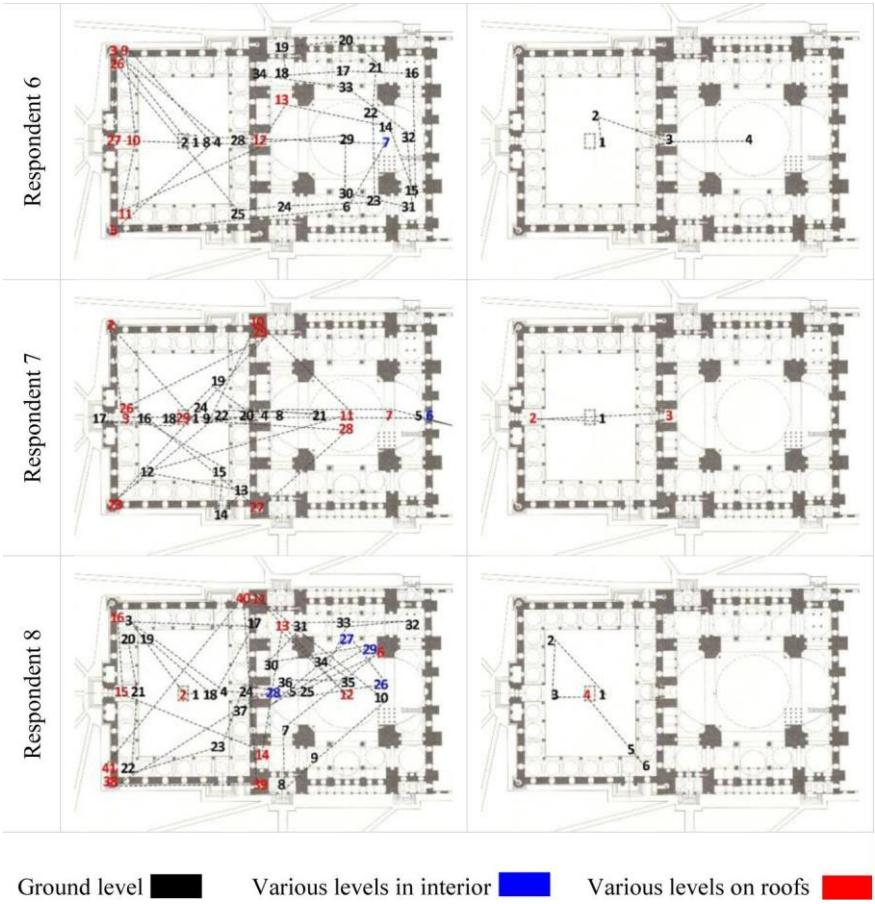

Figure 6. Route extraction from the VR experiment of the respondents.

The results of the sketching phases were also similar to the results of the interviews. Respondents' sketches in the first session were primarily concerned with the experience and atmosphere. In contrast, in the second session, they concentrated on the quantitative aspects of architectural elements (Table 8).

TABLE 2. Responses to survey question 1.

Respondents	Sessions	Observed architectural elements														
		Arch	Buttress	Column	Crown Gate	Dome	Dome Drum	Door	Facade	Half Dome	Mihrab	Minaret	Shadirvan	Shadow	Stoa (Revak)	Window
1	Session 1			●		●						●	●			
	Session 2			●		●			●			●				●
2	Session 1	●				●								●		●
	Session 2	●				●							●			
3	Session 1			●								●				
	Session 2					●										
4	Session 1			●		●	●									●
	Session 2			●		●										
5	Session 1	●		●		●	●	●				●	●		●	●
	Session 2					●					●					●
6	Session 1					●						●				
	Session 2					●						●				
7	Session 1			●	●	●						●	●		●	
	Session 2		●	●		●				●		●	●		●	●
8	Session 1					●						●				●
	Session 2			●											●	

TABLE 3. Responses to survey question 2.

Respondents	Sessions	Visited spaces						
		Courtyard	Dome	Emptiness	Interior	Minaret	Shadirvan	Stoa (Revak)
1	Session 1	●	●		●	●		
	Session 2	●				●		
2	Session 1	●	●		●			
	Session 2		●			●		
3	Session 1	●			●			
	Session 2					●		
4	Session 1	●			●	●	●	
	Session 2	●	●	●	●	●		
5	Session 1	●	●		●	●		
	Session 2	●	●		●			●
6	Session 1	●	●		●	●		
	Session 2	●			●			
7	Session 1	●	●		●	●	●	
	Session 2	●	●					
8	Session 1	●	●		●	●		
	Session 2	●						

TABLE 4. Responses to survey question 3.

Respondents	Sessions	Sizes of Spaces (1 Largest 4 Smallest)			
		Courtyard	Interior	Minaret	Shadirvan
1	Session 1	2	1	3	4
	Session 2				
2	Session 1	1	2		
	Session 2				3
3	Session 1	1	2		
	Session 2	2	1		
4	Session 1	1	2	4	3
	Session 2				
5	Session 1	2	1		
	Session 2				
6	Session 1	1	1		
	Session 2	2			
7	Session 1	1	1		2
	Session 2	2			
8	Session 1	2	1		
	Session 2				

TABLE 5. Responses to survey question 4.

Respondents	Sessions	Brightest/most luminous space(s)	
		Courtyard	Interior
1	Session 1		●
	Session 2	●	
2	Session 1	●	
	Session 2	●	
3	Session 1		●
	Session 2	●	
4	Session 1		●
	Session 2		●
5	Session 1	●	
	Session 2	●	
6	Session 1		●
	Session 2	●	
7	Session 1	●	
	Session 2	●	
8	Session 1	●	
	Session 2		●

TABLE 6. Responses to survey question 5.

Respondents	Sessions	Repeatedly visited spaces					
		Courtyard	Dome	Ground	Interior	Minaret	Reason
1	Session 1		●				To observe the site better
	Session 2		●				
2	Session 1		●				To observe the site better
	Session 2					●	
3	Session 1				●		To experience being on a higher level/flying
	Session 2					●	To observe the site better
4	Session 1			●			To feel secure
	Session 2			●			
5	Session 1					●	To experience being on a higher level/flying
	Session 2		●				To observe the site better
6	Session 1					●	To observe the site better
	Session 2					●	
7	Session 1		●				To observe the site better
	Session 2		●				
8	Session 1				●		To find different views and perspectives
	Session 2	●					To focus interior space

TABLE 7. Responses to survey question 6.

Respondents	Sessions	Perceived architectural spaces/elements both from interior and exterior					
		Courtyard	Dome	Interior	Minaret	Shadirvan	Window
1	Session 1		●				
	Session 2		●				
2	Session 1	●					
	Session 2				●		
3	Session 1				●	●	●
	Session 2				●	●	●
4	Session 1		●				
	Session 2		●				
5	Session 1	●	●		●		
	Session 2						●
6	Session 1	●					
	Session 2			●			
7	Session 1		●				
	Session 2		●				
8	Session 1		●				
	Session 2		●				

TABLE 8. Sketch observations by the authors.

Respondents	Observations based on sketches
1 & 2	In both sessions, the first two respondents have similar sketches drawn from the top of the dome towards the courtyard. While the first sketch is less detailed, the second includes quantitative interpretations such as the numbers and heights of the domes that cover the stoa.
3	The respondent concentrated on the environment and experience during the first session. As a result, the first sketch includes atmospheric elements such as clouds, an image of the respondents' feet, and a portion of the minaret. In the second sketch, the respondent maintains the same viewpoint but depicts a greater number of architectural elements associated with the mosque, such as domes, şadrvan, and minarets.
4	The courtyard view from the top of the dome, including the handles, was sketched in the first session. The proportions and number of architectural elements were also considered as well. The second sketch included more architectural features than the first, as well as a plan of the mosque.
5	The first sketch, which shows the courtyard from a dome, emphasizes being above ground level. The courtyard was drawn from a high window in the second sketch, along with the quantitative aspects of architectural elements.
6	The respondent draws the mosque's central dome from the interior space in the first sketch and places a human figure to explain the scale of the central dome. The second sketch provides insights into the atmosphere while concentrating on the same architectural element. Furthermore, the light coming in through the windows and the shadows dropping on the dome are illustrated.
7	The courtyard view from the minaret was illustrated in the first sketch. Highlight signs and expressions that reveal the human scale's decrement were added. The second drawing shows a perspective view of the interior space from the dome pulley. The number of niche openings and their formal typologies were projected.
8	The first drawing is looking from the courtyard towards the mosque's front facade. The shape and number of openings were taken into account. The second illustration conveys a similar point of view, with a focus on the entrance facade. The details of columns and column capitals were added in the second drawing, in addition to the openings.

5. Discussion

This study presents the findings and outcomes of qualitative research to reveal differences in individuals' perception and memorability of spatial qualities in the VR environment. The qualitative method is based on Kaufmann's (1980) conception of imagery, but it is used to analyze the experience in the VR environment rather than problem-solving or creative processes. During the

experimental phase, the duration of the VR experience was examined at 10-minute and 1-minute intervals, but no significant difference was found between these two experiences. It was discovered that the order of the two sessions had a significant impact on the users' motivation to focus on quantitative aspects of the architectural space. In this sense, the duration and frequency of the experiments can be reconsidered in future studies to achieve better results.

To outline the study's limitations, experiments were carried out with a white solid digital model rather than a fully textured model due to the required permissions to document monuments such as the Süleymaniye Mosque. The presence of photorealistic textural details may have an effect on the overall experience. Furthermore, the contextual and environmental parameters are neglected. Without the limitations mentioned above, the study is expected to show more detailed results about perception and memorability in a VR environment in the following studies.

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URBAN DESIGN ANALYSIS OF NEW YORK CITY'S VIRTUAL MODEL

The case of Tom Clancy's The Division

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Abstract. People have started spending time with digital tools and virtual worlds to escape reality's horrors. However, designed spaces are more than the players' needs, especially those digital games that their stories involve urban environments. This inefficiency causes spending futile efforts both in time and cost for the digital games' productions; The urban environments in these digital games are replicas of real-world cities. Some companies use some techniques for downgrading replicas. Therefore, this study aims to uncover the used techniques for designing Tom Clancy's The Division (2016). By using reverse engineering methodology and qualitative comparative analysis, the in-game map compared with the real-world map. Based on the results, the used techniques allowed the designers to scale down the game environment to be 2.5 times smaller than the actual city. Rather, verisimilitude is achieved by combining sufficiently accurate elements to give the impression of complete accuracy. By implementing the results of this research, designers can develop smaller replicas to be perceived as more extensive.

Keywords: *Digital games, Metaverse, Virtual City, Virtual World, User Experience*

ملخص. بدأ الناس في قضاء الوقت مع الأدوات الرقمية والعوالم الافتراضية للهروب من أهوال الواقع. ومع ذلك، فإن الفراغات المصممة أكثر من احتياجات مستخدمي الألعاب خاصة تلك الألعاب الرقمية التي تتضمن قصصها البيئات الحضرية. وتؤدي عدم الكفاءة تلك إلى إنفاق جهود غير مجدية في كل من الوقت والتكلفة لإنتاج الألعاب الرقمية؛ فالبيئات الحضرية في هذه الألعاب الرقمية هي نسخ طبق الأصل من مدن العالم الحقيقي. وتستخدم بعض الشركات بعض التقنيات للخفض من تلك النسخ المتماثلة. ولذلك تهدف هذه الدراسة

إلى اكتشاف التقنيات المستخدمة لتصميم لعبة The Division لتوم كلانسى (٢٠١٦) باستخدام منهجية الهندسة العكسية والتحليل المقارن النوعى للخريطة داخل اللعبة مقارنة بخريطة العالم الحقيقي. وبناءً على النتائج ، سمحت التقنيات المستخدمة للمصممين بتصغير بيئة اللعبة لتصبح مرتين ونصف أصغر من المدينة الفعلية. وبدلاً من ذلك، تم تحقيق التوافق الفعلي من خلال الجمع بين عناصر كافية الدقة لإعطاء انطباع الدقة الكاملة. ومن خلال تنفيذ نتائج هذا البحث، يمكن للمصممين تطوير نسخ متماثلة أصغر حجمًا يُنظر إليها على أنها أكثر شمولاً.

الكلمات المفتاحية: *الألعاب الرقمية، الميتافيرس، المدينة الافتراضية، عالم افتراضى، تجربة المستخدم.*

1. Background

The COVID-19 pandemic drastically impacted human lifestyles, transforming every paradigm into various virtual ways. Universities, school classes, and offices started to be remote, and people started to spend time with digital tools and virtual worlds to escape reality's horrors (Zhilong Chen et al., 2021). In this regard, metaverses can solve multiple social problems that emerged from the COVID-19 pandemic (lin z et al., 2021). The term "Metaverse" consists of two distinctive parts: the "Meta" meaning beyond, and "verse" derived from the word "universe." It aspires to describe a synced, shared, and persistent simulated three-dimensional virtual world. Users are defined by their avatars, being able to navigate in an immersive manner and interact through their presence (Shah, 2021). As metaverses are a sort of virtual worlds, they must follow six requirements. According to Bartle (2020), a world should pass through six different filters to consider as virtual. It must possess a defined physics, the user or player must be represented as an individual avatar, the world cannot be a turned-off and turned-on type, the world must be either multiplayer or multi-user, the world must be persistent, and finally though it may seem evident that world must not be the reality (Bartle, 2020).

Designing replicas of the cities helps humans to shape their understanding of the concept of the metaverse. According to MacCormac (1995), metaphors help to describe and explain the unknowns; without them, it would become impossible. These replicas are metaphors created to reflect the physical world and its assets (Jones et al., 2020). These places can resemble the physical appearance while performing the functions and behaviors of the physical world assets.

According to A. El Saddik (2018), Knowing which physical world elements should be mapped to the replicas is essential (El Saddik, 2018). A virtual place is an example of places simultaneously everywhere and nowhere (Auge, 1995). However, these places are within the concrete and symbolic construction that can engage with the history and physical place's identity.

Moreover, replicated cities are the result of the architect and landscape architect designers' works (Van der Merwe, 2021). Therefore, they are the people who perceive virtual places differently from the programmers and UI designers (Kim, 2018).

On the other hand, architects and landscape architects are the designers who are trained to enhance the sense of place (Friedman, 2021), so based on their knowledge, metaverses are the new territories for them to redesign the virtual worlds stylishly to strengthen the sense of place. Hence, with the growing aspirations for metaverses and digital games, their infrastructure is tormented by the lack of design methods (Solman, 2022). According to Solman et al. (2022), the architecture industry plays a crucial role in articulating the virtual domain as replicas are the direct products of architects' decisions rather than duplicating the physical world. The decisions by landscape architects on whether to allow or disallow the components' presence in the digital environment directly affect the shape of the virtual worlds' outcome. The current metaverses are developed and designed by game designers. However, from architects' viewpoint, in the virtual domain, designers are free to design without any set of physical-world rules; in this regard, architects can develop these places in a stylized way that does not seem as the physical world.

2. Literature Review

Currently, the digital game industry has many limitations in terms of level designing. Creating a well-developed virtual world requires more time and effort, which is generally considered as a time-consuming task for game designers (Kim, 2018). Unlike other tasks in digital game design, such as user interface design, game rules, sound design, and character design, designing a virtual world for a digital game requires careful consideration. Although some digital games are designed brilliantly, they are the outcome of practice and experience over many years (Kim, 2018). According to Kim (2018), many textbooks have proposed various techniques and methods to design virtual worlds for digital games; however, they mainly focus on technical parts and do not provide practical design techniques for the designers. For instance, Huijser et al. (2010) presented a method for designing a natural landscape in a virtual world; however, it only covers specific landforms (Darken, 1993). Although scientific articles and textbooks cover all aspects of digital game design, their approaches to urban design are insufficient (Kim, 2018).

Due to the mentioned limitations and the close relationship between virtual and physical cities, game designers use the same techniques as architectural designers. Some game companies are trying to use the physical world's

cities for their game environments. These environments are similar to the physical world, including urban patterns, architectural styles, and landmarks (Morris and Hartas, 2004). Designers use architectural methods in AAA game companies (a type of game company with a high budget) (Rotzetter, 2017). In addition, some companies, such as Ubisoft, try to develop replicas of the physical cities for the digital games' environments by employing creative methods. Due to the similarities of the replicas with the real ones, such models increase the players' sense of immersion (Catros, 2021).

In the physical world, architects and landscape architects use spatial properties to make a space seem more extensive than the original scale. For instance, using optimal ratios for street width, the appropriate setbacks of buildings, and using proper trees, street lamps, and other design features to make vistas and manipulate the peoples' sense of scale (Friedman, 2021). Applying all those techniques for developing virtual worlds need much time and effort, and it does not fulfill the players' needs (Rotzetter, 2017). Reconstructing the virtual version of urban environments and cities carries a high value as they act as a vessel beholding human experiences between physical and virtual. However, it is vain to represent all the elements of the physical world in the virtual one because, cognitively, we are more comfortable with abstraction. By applying subtle changes to the replicas, players feel more comfortable and more immersed during playtime (Shields 2002).

Catros and Maxime (2021) mentioned in their recent research about re-constructive historic cities for digital games that Assassin's Creed III has achieved the feeling of authenticity. However, the modeled world is dissimilar to what the historical city looked like (Catros, 2021). Moreover, some researchers, such as Danilo Di Mascio (2017), analyzed the architectural and historical aspects of digital games, but the research only introduces general information to the designers and not any design techniques. Two factors led to these restrictions; firstly, most companies do not have precise techniques and methods. Secondly, if the company has a specific method or technique, they protect it. Hence, those techniques are industrial secrets companies do not want to expose; therefore, collecting any helpful references on this topic is challenging. In this regard, this research investigates how the game designers and artists abstracted their reconstructions, consequently evoking the city's image observer.

3. Methodology

3.1. CASE STUDY

Ubisoft published Tom Clancy's The Division (TD) in 2016. This game was a commercial success, and the reviews for this digital game were positive. According to Ubisoft, the game broke its own record for the most first-day sales (Ubisoft, 2016). This game fits the MR33FP category according to the standards for classifying digital games (Kim, 2016). The game has been studied and analyzed by several scholars who have focused on some technical parts and cultural effects; however, none of the researchers focused on the design process. The game is based on New York City, which means the player can freely explore and engage in various activities, from simple activities like walking around the city to fighting. The user can play the game from a third-person perspective, meaning that the avatar is visible (Gies, 2015). The designers modeled a small part of Brooklyn and nearly one-third of Manhattan, representing over 113 square kilometers. This paper uses reverse engineering methodology and qualitative comparative analysis to uncover the techniques used by designers of TD.

3.2. REVERSE ENGINEERING

Reverse engineering plays a dominant role in uncovering digital games' development techniques (Linhoff, 2004). The research started by searching for scholars about TD and the used techniques for downgrading the environment. However, there was no relevant scholar, but some users in the game forums identified what portion of New York was excluded, which were not valid. In this regard, research started by overlaying the in-game map with New York city's map to explore the excluded portion. Since the game gives measurement information, it is evident that the whole map is 2 kilometers in length and 2.8 kilometers across the width (Figure2). For studying a book, it is necessary to read it; to understand and analyze a digital game, it is essential to play it (Di Mascio, 2021). In this regard, the first five-levels of the game have been played to access the Chelsea map, and the methodology below is designed (Figure1).

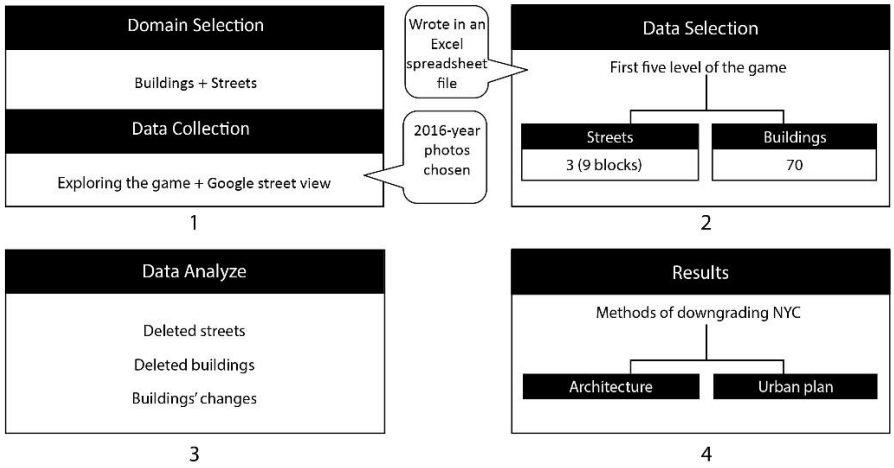

Figure 1. Methodology for analyzing the game

Streets and buildings are the major elements of a city (Lynch, 1984), so this research analyzed these two components. Since the study deals with the 3D representation of the cities in the digital games, the streets and the buildings of Chelsea compared with the Google Street View Map and all of the details written in an Excel spreadsheet file. To collect the exact shape of the urban environment in the game's production year, 2016-year photos have been chosen from the Google Street View map. The screenshots and the files are available in the author's archive. After the analysis, it was relevant to know how Ubisoft's designers approached the challenge of reconstructing a large environment as small as possible, and it is clear which part of New York was tried to recreate as a replica.

4. Results

Ubisoft's designers were able to create a replica of New York City, which is 2.5 times smaller than the physical one (Figure2). The designers used several ways for this challenge. For instance, they made the city aesthetically more intriguing by using symmetric scales and appropriate color palettes to support the gameplay's dynamics better. This research's outcome is a determination for knowing that the designers used techniques to develop a verisimilitude version for New York.

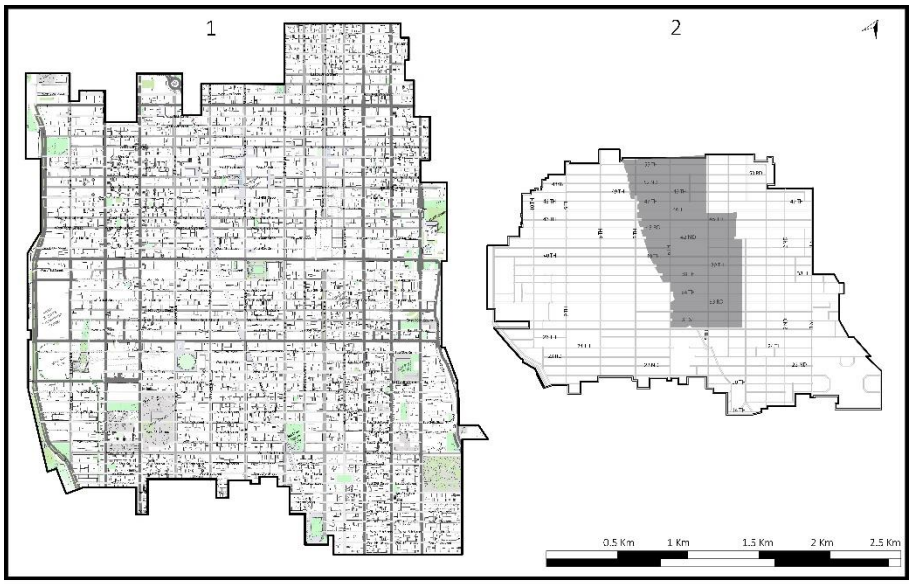

Figure 2. Designed parts of the New York City map for the game (1). In-game map (2).

4.1. ARCHITECTURAL DESIGN

The architectural style of this game is the same as the architectural styles in New York. Each district represents the same social and economic condition of the neighborhood. For instance, by using proper colors, fog effects, and decorating the buildings and streets, designers tried to reflect the luxurious lifestyle of the area. Furthermore, according to Lynch, landmarks are described as "point references" and have a significant role in a city's image (Lynch 1984). TD presents the landmarks visible from long distances and various locations in the game. The designers modeled the landmarks with a high level of detail. However, some landmarks, such as Penn South Plaza or London Terrace, are duplicated in two or more streets. On the other hand, some landmarks, such as Greenwich Savings Bank, have not appeared in the game. By exploring the online forums, we noticed that due to some buildings' duplication in the game environment, a range of players were more curious to explore the game environment. However, it disrupts the player's attention who lives in New York. For the next step, the research used qualitative comparative analysis proposed by Charles Ragin (Ragin 1987). The research compared 70 buildings on three streets to find the dissimilarities (Table 1). Yellow, brown, and red are the primary colors used for the buildings to communicate a warm feeling. For 61% of the buildings, colors and textures are identical; for 27 structures, colors and textures have been changed to synchronize them with the game's atmosphere. The research

could not measure the elevation and width of the buildings. In this regard, the number of windows rows', and columns have been compared. 45.7% of the buildings had the same number of window rows. For the other 54.3% of the buildings, designers increased or decreased the height of the buildings to make grand vistas. For comparing the width of the buildings, the number of window columns was counted one by one, and 14% had the same number of window columns. Furthermore, ten buildings of the mentioned three streets are excluded in the game. Instead, they are replaced with buildings from other streets, or in some cases, after excluding the buildings, vacant spaces are used as open urban areas. The research divided the used techniques into four different categories.

TABLE 1. Comparison of the physical buildings with the in-game buildings.

Charactrestics	Similar		Different		Total
	Quantity	Percentage	Quantity	Percentage	
Window's column	10	14.2%	60	85.8%	70
Window row	32	45.7%	38	54.3%	70
Color and texture	43	61.4%	27	38.6%	70
Buildings	60	85.8%	10	14.2%	70

4.2. TECHNIQUES

4.2.1. Technique 1

Ubisoft's designers excluded some buildings in three different styles. Buildings with the high level of details that do not count as landmarks have been excluded, or the level of the details has been decreased. For example, in figure 4, the designers excluded building B and widened building A to compensate for it. This technique was applied in multiple streets, which helped the designers to decrease the number of modeled buildings.

Figure 3. Screenshot of the Street View Map (left). Screenshot of the exact location in the game (right); It shows a sample of excluded buildings.

In New York City, one can find several buildings with similar façades constructed next to one another. However, for the virtual version of those

Figure 4. Screenshot of the Street View Map (left). Screenshot of the exact location in the game (right).

cases, designers can merge those buildings into one building and extend it. In TD, adjacent buildings with minimum details have been merged into one building. For instance, in Figure 4, instead of modeling buildings A and B, they merged them and modeled one structure. This approach of representing is applied in various game scenes. The technique consequently decreases the length of the streets and helps to downgrade the urban scale in a stylized way.

Moreover, using a metaphor is to digesting the concept and letting the user clearly understand the second object by representing minor elements (Dieberger, 1998). For instance, Ubisoft's game designers tried to show building C with fewer windows (Figure 4). This structure describes the style of the building to the players and lets them remember which building this is.

According to (Kim, 2018), the game's story is an essential part of designing a virtual environment, so designers should design the environment based on the game's story. In the TD game, the designers excluded some of the small buildings or shifted the buildings' lots in order to create their desired places where they needed more space. Figure (5. A) describes three applied techniques of shifting the building's lots, merging, and excluding the specific buildings.

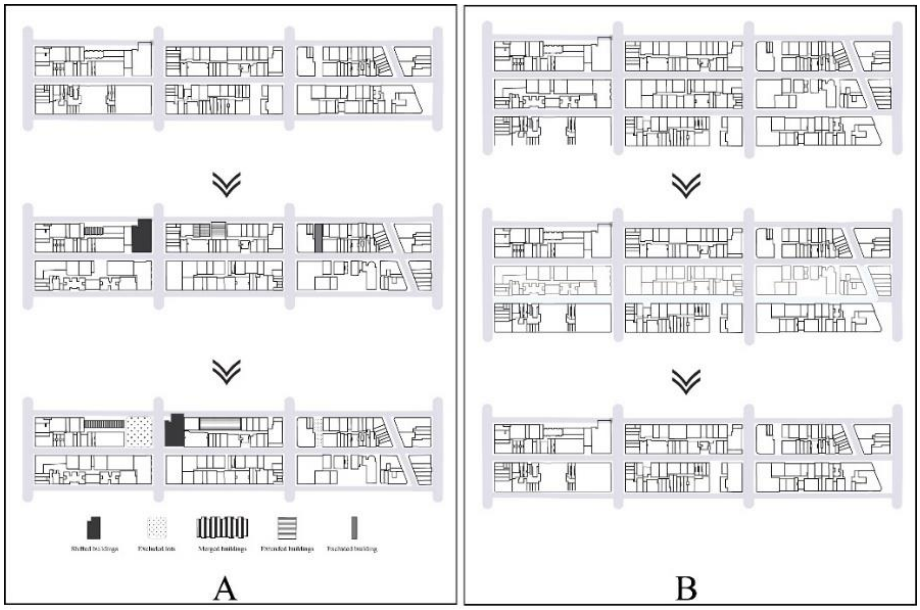

Figure 5. Diagram A (left) describes the techniques1, which relates to excluding and merging the buildings. Diagram B (right) describes the technique2, which relates to merging the streets.

4.2.2. Technique 2

As Kevin Lynch mentioned, districts are the elements that play the primary role in the image of a city (Lynch, 1984), so it is significant to let the players experience most parts of each district. Designing whole parts of each district considers lots of time and effort. In this regard, to minimize the replica's vastness and prevent developing unnecessary spaces, designers chose one row of the street and merged it with the next street row (Figure 5. B).

4.2.3. Technique 3

Vision is an essential sense of the human in both physical and virtual environments; however, most users focus on what attracts them more in virtual environments. For instance, during exploration in a virtual world, players do not focus on the whole travel experience as people usually do in the physical world. In addition, according to the story layer's significance in designing the game environment (Kim, 2018), the designer can exclude blocks of streets that do not involve the game's story. For those cases, Ubisoft's designers excluded the whole road in several places (Figure 7. A).

This technique, however, is different from the previous one, as the actual subject carries an attribute strange in appearance. A good example can be the architectural style of New York's some streets, where a block or a road is made up of a single building façade. In this game, the replica of these cases are excluded, and the whole street are designed with the same façade.

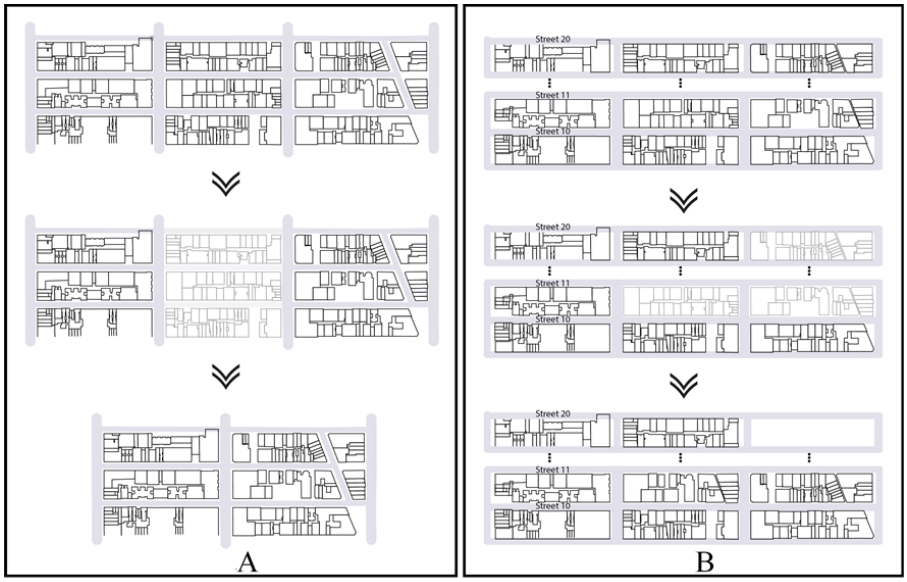

Figure 7. Diagram (A) describes the deleting streets with similar blocks. Diagram (B) describes the shifting blocks

4.2.4. Technique 4

As the person moves around the physical world, one perceives the environment subjectively and then creates a movie-like mental image through the encountered images. Primarily the person uses the landmarks to make that mental image. So, it is logical to decrease the length of the long streets or avenues by deleting the blocks that do not contain important buildings or landmarks. In addition, streets or avenues containing high buildings create grand vistas (Friedman 2021). For instance, if most buildings have ten floors and some have less than four floors in the middle of the streets, designers can cut those small buildings (Figure 7. B). On the other hand, most open-world games contain missions, and the player focuses on the close view, not the distant view, so it is possible to fool the player who knows the physical version of the city. Therefore, deleting blocks containing small buildings helps make a grand vista.

5. Conclusion

The digital game industry's economic importance means spending time on design research. Instead of trying to recreate all parts of an environment to look like reality or exclude some parts of the built environment, we need to collaborate across disciplines, which is more efficient in the design effort. TD analysis has identified several factors of interest, and the mentioned results are the techniques that can apply to virtual landscape designs. First, it revealed that senior designers in the AAA game companies are trying to interpret creative techniques for their designs to increase time and cost-efficiency. Demonstrating the techniques helps junior designers or people outside of the game industry learn these approaches in their designs or use the concepts to interpret more creative approaches. This research helps the players be aware of digital games' artistic qualities and pay more attention to the relevant aspect of digital games.

Furthermore, although the virtual world domain is not new, it has not been used much in our daily lives; However, nowadays, we need them more than before. For instance, due to COVID-19, we felt the importance of the concept of metaverses in our lives. Therefore, it requires lots of research and scholars. This domain will grow and become increasingly critical due to its usage in any virtual reality device. Let consider the virtual worlds as necessary as the physical world and understand the users' requirements. Our designs can raise the emotional senses of the users, as in the exploration of real cities. Investigating virtual worlds can trigger further research questions that have not previously been formulated. For the following research, we will analyze more digital games, and one of the future aims of this research is to use cognition science principles and find more efficient techniques to increase the efficiency of the designers and manipulate the players' sense of the place for designing the twins of the cities.

This paper has shown that in the game TD, New York City is dissimilar to what New York is in the physical world. We accurately compared the in-game map with the New York map, and many dis-similarities have been found. Probably Ubisoft purposed to reduce the city's travel time without teleporting. However, it can trouble players' perceptions, especially those living in New York. Searching on the game forums found that some players understood the excluded parts, which disturbed their sense of place.

The research highlighted that architecture and landscape architecture are essential in designing virtual worlds. For instance, landmarks are crucial cultural elements that players can communicate with and get historical information, making them curious to explore that area. It may be necessary to use these techniques in the development of games to enhance their playability. Therefore, as Lynch describes, to create a realistic city model, there must be enough accurate elements in the city.

As a result, by implementing the meaning and values symbolized by place features or place icons, architects and landscape architects can form new places that mimic reality. Results demonstrated some techniques to redesign the spatial layouts for designing the physical world's replicas.

It must be acknowledged that this study has limitations. The main limitation of this study is that only one digital game was studied as the case study; more digital games with different land uses should be examined. In addition, we should consider that every human being shares different procedures and priorities to recognize a space based on their experiences. Therefore, making a clear order for the spatial layout components will be challenging. Instead, this research will provide statistical results. However, this paper's methodology and logical procedure will be valuable for future developments related to designing replicas of the physical world.

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FROM PASSIVE TO IMMERSIVE: METAVERSE AS A PEDAGOGICAL APPROACH IN HISTORY CLASS

Presenting a Constant Reminder of Historical Remnants and a Customizable Reality for Future Preferences; Beirut as a Case Study

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Abstract. It is widely acknowledged that passive, non-immersive strategies of teaching adopted in history classes in Lebanon do not offer the right platform for knowledge retention in students. With that said, virtual reality and the use of Metaverse as a pedagogical approach is prophesied as the most apt to invoke a positive attitude from children towards the topic being studied, and thus, in this case, it increases their awareness of the existing built heritage they live amidst. This research sets out from a recent project implemented by Beirut Arab University, together with three UN agencies. The latter aimed for "developing children emotional attachment to the territory of Beirut Blast through activating their participation in the construction of cognitive maps by playing with spatial maps strategically designed in a game environment". A thorough assessment of the outcomes of the activities implemented throughout the project, including the executed physical models and game boards that simulate myriad neighborhoods in Beirut, is carried out, followed by an analytical comparison of these outcomes with those from using the proposed innovative digital tools. A pilot study is conducted on Martyr's square to assess how virtual tools can enhance the sensory experience and perception of the built space, making youth active learners rather than passive. It illustrates how introducing children to educating architecture from a young age not only nurtures their awareness of their local neighborhoods, but also generates responsible citizens. The outcome of this study can be divided over a timeline of past, present, and future. The virtual recreation of old Beirut aims to enhance the virtual learning experience as opposed to that from books and chalkboards. Children are expected to formulate a better understanding of their heritage, become more attached to the

remnants of the latter, and set out to customize the reality to their preferences or vision of how a better, sustainable Beirut looks like.

Keywords: *Metaverse, Pedagogy, History, Heritage, Beirut.*

ملخص. من المسلم به على نطاق واسع أن استراتيجيات التدريس السلبية وغير التفاعلية المعتمدة في تدريس التاريخ في لبنان لا توفر المنصة المناسبة للاحتفاظ بالمعرفة لدى الطلاب. وفى هذا الإطار، يعتقد أن الواقع الافتراضي واستخدام الميتافرس يمكن اعتمادهما كنهج تربوي باعتبارهما الأكثر ملاءمة لاستحضار موقف إيجابي لدى الأطفال تجاه الموضوع قيد الدراسة، وبالتالي في هذه الحالة ، فإنه يزيد من وعيهم بالتراث المبني الحالي يعيشون فيه. ينطلق هذا البحث من مشروع حديث نفذته جامعة بيروت العربية بالاشتراك مع ثلاث وكالات تابعة للأمم المتحدة. وقد هدفت الوكالات إلى "تنمية ارتباط الأطفال العاطفي بإقليم انفجار بيروت من خلال تفعيل مشاركتهم في بناء الخرائط المعرفية من خلال اللعب بالخرائط المكانية المصممة بشكل استراتيجي في بيئة ألعاب". تم إجراء تقييم شامل لنتائج الأنشطة المنفذة خلال المشروع، بما في ذلك النماذج المادية المنفذة ولوحات الألعاب التي تحاكي عددًا لا يحصى من الأحياء في بيروت، تلتها مقارنة تحليلية لهذه النتائج مع تلك الناتجة عن استخدام الأدوات الرقمية المبتكرة المقترحة. تم إجراء دراسة تجريبية في ساحة الشهيد لتقييم كيف يمكن للأدوات الافتراضية تعزيز التجربة الحسية وإدراك الفراغ المبني، مما يجعل الشباب المتعلمين نشطين بدلاً من متعلمين سلبيين. وضحت الدراسة كيف أن تعريف الأطفال بتعليم العمارة منذ الصغر لا ينمي وعيهم بأحيائهم المحلية فحسب، بل يولد أيضًا مواطنين مسؤولين. يمكن تقسيم نتائج هذه الدراسة على جدول زمني يشمل كلا من الماضي والحاضر والمستقبل. وقد هدفت عملية إعادة التصور الافتراضي لبيروت القديمة إلى تعزيز تجربة التعلم الافتراضي بدلاً من تجربة الكتب والسبورات التقليدية. يُتوقع من الأطفال صياغة فهم أفضل لتراثهم، وأن يصبحوا أكثر ارتباطًا ببقايا هذا الأخير، ويشرعوا في تخصيص الواقع وفقًا لتفضيلاتهم أو رؤيتهم لكيفية ظهور بيروت بشكل أفضل ومستدام.

الكلمات المفتاحية: *الميتافرس، علم أصول التدريس، التاريخ، التراث، بيروت.*

1. Introduction

Every single event that has led up to the present day gradually builds, brick upon brick, the people and the culture that currently exist. Just like past ancestors enrich their history, in return the history itself enriches the generations to come. With that said, Lebanon, the land that has been traversed by myriad cultures, momentous events, and significant periods, bares a profound historical background worth imparting. The latter entails stories that date back to the Canaanites, Phoenicians, and Romans, all the way to the Mamluks, Ottomans, and the French mandate. The timeline of the country intersected with several eras, leaving a trace of heritage and monuments that formulate footprints, each one of the latter connecting to the other to form a timeline of events, of which disclosing has become an obligation. (Barnett and Ochsenwald, 2022).

This paper tackles the effect of rebuilding Beirut in history classes, not as a bombardment of factual information, but as an immersive, non-passive environment. For that, the results of a project were Beirut was recreated in the form of 3D models were analyzed. The success of the latter allows for a theoretical assumption: the use of Metaverse (immersive 3D realities) as a pedagogy to educate children on their history will render positive results. A child's ability to understand heritage, make the necessary decisions in the present, and create the "better" future is assessed.

2. BACKGROUND: CULTURAL HERITAGE, HISTORICAL AND CIVIC EDUCATION

There must exist a strong relationship between this cultural heritage and historical and civic education. Historical teachings should perform their "civic and moral functions" (Peters, 2008), by formulating a collective memory of these past events and passing them on to the younger generations, molding them into the responsible citizens they ought to be. The importance of these teachings lies in three different categories: on the level of the self and the others, on the level of the nation, and on the heritage level.

2.1. THE SELF AND ITS RELATIONS TO THE OTHERS:

In each community, there is a certain culture that must be studied to identify what makes them Lebanese at core. Such a search for identity requires an understanding of self as well as of the other. The former brings the myriad divisions of a nation as small as Beirut to meet a certain standard of acceptance and perspective, indispensable for the coexistence of these groups. For the difficulty of targeting the adults whose viewpoints are built hardcore into their belief system, it is only logical that these classes are to be specifically introduced to the younger generations, whose opinions can somewhat still be molded and transformed to build a set of beliefs that include the importance of accepting the "different" other. The preceding actions will therefore affect the community as a whole, and the positive effects will be prevalent on a national scale.

2.2. THE NATION

Understanding that there exists a history shared by the nation, in both its treacheries and success, its wars and prosperities, would contribute to forming the identity by which this nation identifies. Identity, by definition, is an intersectional self-recognition by one-self of certain characteristics that

qualities to him/her with the recognition by a second party of the same characteristics, and thus, when a group of Lebanese people believe that certain attributes belong to them and disclose this unified vision so that others believe likewise, the two parties together create the identity of the country. In addition, teaching history should be presented in critical and analytical frameworks so that students think beyond their current frame of reference and drift away from present-day conceptions.

2.3. HERITAGE

Hundreds and thousands of years of different cultures traversing the land have left behind monuments and historical buildings worth preserving, like the Roman Baths, Martyr's Square, Beirut Souks, and Gemmayzeh Street. What is left of Berytus in the form of Beirut can only be preserved if the coming generations are aware of the vitality of the conservation of these buildings and the stories their walls disclose, and thus, this requires a cooperation in the preservation of part of what makes up the Lebanese identity.

3. Materials and Methods

This study employs several tools and techniques to fulfill the research objectives. An in-depth analysis was first conducted to identify the levels of teaching history linking the way of teaching with the memory of the students and the cultivation of critical and analytical skills. Moreover, the outcome of the activities of the project entitled "Youth-led rehabilitation efforts to support local communities affected by the Beirut blast", implemented by BAU Urban Lab in partnership with UNESCO, UNFPA, and UNODC Offices in Lebanon to develop children's emotional attachment to the territory of Beirut Blast, were used as an application methodology in this study. Considering the lack of database of the barely standing and demolished historical buildings in Lebanon post-explosion period, including drawings such as plans and elevations, we used in this research old and existing photos to create the 3D physicals and virtual models. Martyrs Square is finally taken as a pilot study to apply 3D virtual tools.

4. Development of Teaching History

4.1. TELL THEM AND THEY'LL FORGET…

"I've memorized a myriad of historical data, causes, and effects then wrote them down on exam paper in order to get the "good" grade."-Zeena Amkieh-

It is quite futile to take an initiative in critiquing the history material lectured from the textbooks. The content provides coverage for a wide range of topics, from different periods of time. However, it does not provide the framework for analytical or critical thinking.
A typical history class setting consists of a teacher reading from a textbook and explaining the content in a structured, organized manner as to depict the sequence of events in a comprehensible, easy-to-grasp method (Figure 1). The information retained, however, is most apt to be a short-term, temporary memory of the content. Students have become "passive" memorizers and no skills are cultivated or constructed in this process of learning. (Amkieh, 2015).

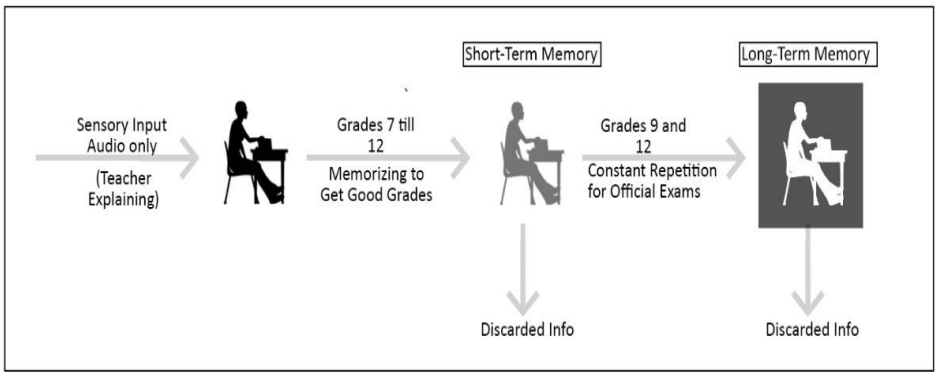

Figure 1. discloses the flow of information in a typical classroom setting.
Most of the information is discarded as it is rarely used in our daily lives.
Retaining this information remains important until the day of the exam. (The Author).

4.2. SHOW THEM AND THEY MAY REMEMBER…

More developed countries have presented history classes and lessons as an instructional model that turns the students into active learners, capable of resolving any form of historical inquiry, and relating events and settings in a visual timeframe and setting (Figure 2). This pedagogy followed promotes the importance of citizenship and the participation in decision-making processes. These skills are inevitably indispensable, specifically in Lebanon where involvement in the community and social cohesion are notions that must be enhanced. Some schools that are monetarily capable have started taking individual acts to better advance the teaching systems apart from any governmental decisions or imposed obligations. A number of them are now equipped with LCD projectors that are used to display documentaries and visuals from various media platforms, precisely YouTube. These movies

allow a better comprehension of the setting and the succession of events that have befallen in the past.

However, COVID-19 has accelerated the necessity of transforming any 2D learning environment to one that lies way beyond watching YouTube videos. Online learning became a mainstream as attendance-based classes were disrupted in the break of the pandemic. The 2D environment could have been either synchronous or asynchronous. A synchronous learning environment requires the instructor and the receiver to both be on display simultaneously via web conferencing platforms like Zoom, Microsoft Teams, WebEx, and Skype. An asynchronous learning environment is implemented through learning management systems, LMS, via platforms like Moodle and Blackboard. Contrary to synchronous e-learning, this does not require both parties to be present concurrently (Synchronous and Asynchronous Learning, 2021). Although online-based learning was merely an adaptation strategy to a grim reality, it reverberates myriad repercussions and limitations (Tamm, 2022):

- The overuse or extended use of synchronous web-based platforms will stretch their limitations and inefficiencies, often revealing the inadequacies of these means of communication as lag and fatigue take over the latter.
- Most of the developing countries are not qualified for internet-based learning as the electricity is still not supplied 24/7 and glitches every now and then when it is available. Similarly, the internet is not stable on the scale of the country as a whole.
- Online-learning does not help in comprehending the emotional stress a student might be going through, and thus the way a student is addressed does not always hit the right strings. This delays knowledge retention or sometimes hinders it.
- Students are troubled with a low perception of their other classmates or of their relation with those with whom communication had been once natural.
- Distractions and losing focus become a norm when information is confined to a mere screen.

A new pedagogy, using the Metaverse, can resolve the dilemmas mentioned above.

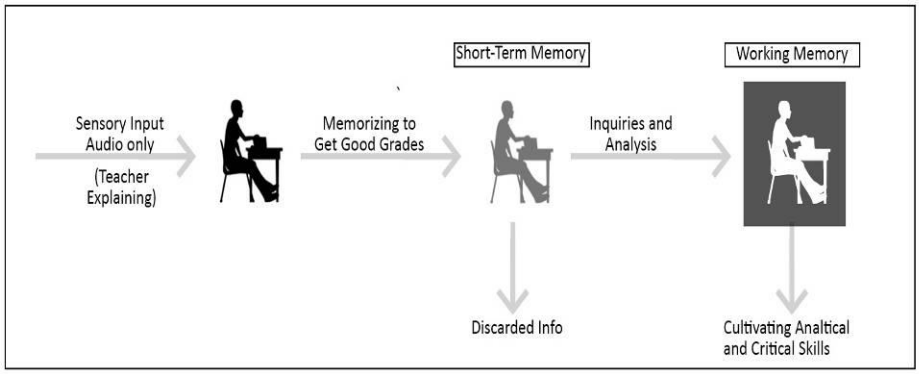

Figure 2 discloses the flow of information in a typical classroom setting that has incorporated a more analytical and critical approach that develops the skills of its students, (The Author).

4.3. INVOLVE THEM AND THEY'LL LEARN…

Extended reality is the umbrella beneath which lies augmented reality (AR), virtual reality (VR), and mixed reality (MR). It is the combination between the physical reality (human) and a virtual reality (computer generated graphics), and the resultant human-machine interaction (CARVALHO et. al, 2020).

VR is a synthetic, completely separate digital world. The user is utterly teleported to a world that is distinct from the physical reality using VR headsets, omnidirectional treadmills, and immersion helmets. This experience can be intensified by making it multisensory, targeting sound, sight, touch and any interaction with the virtually-created objects.

AR uses a different approach. It embodies virtual objects, directions, or even information into the real world. This is the literal meaning of combining the virtual and the physical worlds. The end result is a transparent layer of a number of virtual artifacts overlapping reality. This process is achieved through tablets, contact lenses, phones, glasses, or even VR headsets (Virtual Reality, 2022).

MR combines between elements of VR and AR (Figure 3). It enables the user interaction with both elements from VR and from AR. For instance, a virtual avatar or character presented by the MR facets and hardware would be able to recognize the physical world surroundings and react accordingly, sitting on a real-world chair to waving to someone passing by.

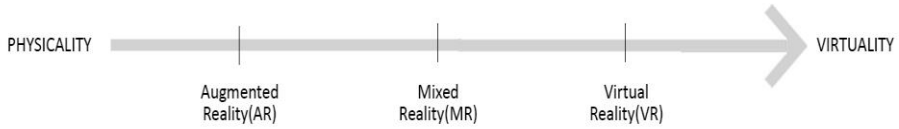

Figure 3 displays the branches of extended reality on a scale that defines the physicality and virtuality of each one with respect to the other, (The Author).

Metaverse is still in the prototype stage, and yet, it was capable of harnessing itself some significant notoriety. The Metaverse provides an immersive, interactive experience in a virtual, connected world. It is an incessant multiuser environment that relies on developing technologies, like VR and AR that allow a multisensory interaction with a virtual environment and all that it contains from objects to people or avatars. Similar to the "Internet" or the "Web", there is only one "Metaverse". It describes a complete interconnected web of immersive environments that are available on a multitude of multiuser platforms (Speicher et. al, 2019).

The main purposes for using VR in education which is location-based such as in classrooms and labs are as follows (Kundalakesi, et. al, 2017):

- The hardware allows the students to be involved in practices that are not readily available for them to rehearse such as piloting an airplane, driving a car, conducting surgeries, or even imitating ancient cultures and their lifestyles in history classes.
- This technology helps recreate an inconvenient situation such as the Lebanese Civil War where students can understand the gravity of the realities their parents had to endure. Using the VR, students can be taken on field trips that are considered quite impossible, such as visiting the current remnants of the Greek or Roman civilizations.

The level of immersion presented by the VR technology varies on four stages:

- The first stage is using VR to create a multimodal 360-degree YouTube VR.
- The second stage allows students to have an impact on the flow of the virtual display.

More autonomy is achieved in the third stage where they can navigate the Virtual world in a manner similar to navigating Google Earth VR.

The most immersive state is where students feel like they are actually present in the virtual world through a complete multisensory experience (Figure 4).

Pertaining to the aptitudes of the Metaverse in capturing 360-degree panoramic view or volumetric spherical videos, it can allow an entire mass of students to be educated about a certain era or culture and provide complete immersion in the events that occurred then. Moreover, new implementations and prophesies for the Metaverse in e-learning transcend that of 2D e-learning. Students hold one of the greatest impacts on the virtual curricula, personalizing it, and taking advantage of the hybrid learning experience where they are not limited to the interaction with a screen, but rather can see an entire hologram or representative avatar of a real-time figure (Mystakidis, 2022).

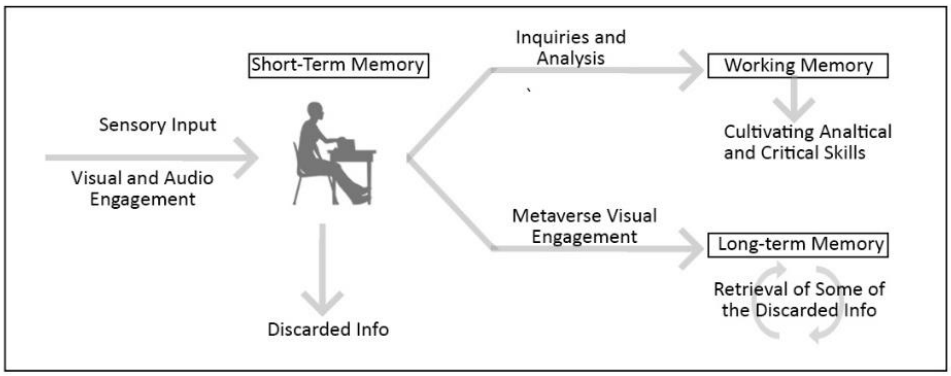

Figure 4 discloses the flow of information when VR compensates for the information lost after a critical, analytical teaching class. The sensory experience helps retain a wider scale of comprehension, (The Author).

5. Application of immersive techniques in the case of Beirut City

5.1. FROM 2D TO 3D USING PHYSICAL MODELS

The explosion in Beirut, ranked as the sixth most destructive accidental and non-nuclear man-made explosion to be adopted by history. It scarred not only the city in its buildings and infrastructure, but also in its people. The project targets the population that has been mildly affected by the Beirut blast. It was carried out on three stages: inviting children to test the game boards in BAU, participate in activities arranged in Karantina neighborhood, and attend a miniature exhibition of Beirut in St Nicholas Stairs at Gemmayzeh neighborhood. This initiative thus offers an alternative for the 2D pictures and images of the pre-explosion state of Beirut neighborhoods by presenting them to the participants as part of a miniature of Beirut, and giving them the opportunity to design their own neighborhood.

5.1.1. Preparatory Procedures

The staff of the Beirut Arab University, in cooperation with its students, employed their technical, creative, and communication skills in BAU Urban Lab in order to achieve results that comply with the main initiative of the project (Figure 5). The props designed include a large-scale physical model (1/800) of the region affected by the blast, close-up models of some landmark architectural buildings present in the miniature model of Beirut, along with their representative QR codes, and the game boards that enhance the engagement of children.

Figure 5 displays images from the workshop when students were working on bringing the models together. (BAU Urban Lab, 2021).

5.1.2. Miniature Model

Through a process that transitions from brainstorming to conceptual thinking to synthesizing an adequate visual presentation, a cognitive map of the city was drawn in the form of a large-scale model that contributes in registering the cognitive abilities of the participating children. The softscape adhering to the buildings map the greenery present in the real world. This serves to make the children more aware of the natural environment in their capital city. Nevertheless, the high-level of compatibility of this model with the real world allows the passers-by to identify what they see with the image of the neighborhood they have already registered in their minds.

5.1.3. Close-up Models

Some buildings are marked in the large-scale model and further brought to life using intricate details, balustrades, and facades that were mapped, printed, and then assembled together into a realistic miniature of the real building (Figure 6). These models are endorsed with QR codes that direct the users to a site disclosing the historical and cultural values of the building modelled, by presenting the series of events and the architectural aspects that render it worth preserving.

Figure 6 displays images showing the intricacy of the close-up models from the final exhibition held in Gemmayzeh (BAU Urban Lab, 2021).

5.1.4. Game Boards

Finally, after the children have explored the image of pre-explosion and accumulated within themselves feelings of nostalgia, the team decided to create a plan that engages the children in creating the image of their city and thus, turning them into active citizens that take part in communal decisions. The idea of the game board was then created, as close as a physical 3D could adhere to a 3D virtual model. The game board includes unassembled pieces of a city that are flexible in their assembly and allow for myriad variations of neighborhoods to match the preference of different children. These pieces include buildings, roads, and vegetation, as well as coloring tools and glue.

Unfortunately, the pandemic hindered the possibility of holding several activities and events. These were then compensated with a virtual application

of the procedure and concluded with a video that sums up the results of the myriad neighborhoods created by the imaginations and the preferences of each child alone.

5.1.5. Webinar

In an attempt to train teachers of Art, Geography, and Civic engagement on the importance of educating architecture at early ages, as well as how to use the newly designed maps and models as a new pedagogical method that integrates spatial thinking, an online event was held with a total of 225 attendees participating in this capacity building workshop.

5.1.6. Beirut Arab University Workshops

Children were invited to a tour in the faculty Lab where they explored previously executed models. They were then taken to the Model Making Lab where the game boards were distributed and tested for the first time. Children were also walked through the process of creating a large-scale model, and they helped allocate some of the buildings on the map. Finally, a huge roll sheet was laid on the floor outdoors where students, hand in hand, drew what they imagined their city of preference would look like. The result was a large rolled-up sheet of all the parks, entertainment areas, and activities children were deprived of in Lebanon

- *The Karantina Neighborhood Workshop*

The Karantina neighborhood, one of the settings that were severely damaged by the explosion, held the second workshop for face-to-face interactions. Karantina Is one of the low-income marginalized neighborhoods that is in proximity to the location of the explosion. Thirty children attended the workshop, explored the large-scale model created of the affected regions of Beirut, and set off creating a neighborhood of their own design using the game boards prepared by the students and staff of Beirut Arab University. The game board pedagogy was presented as a successful means for children to explain the experiences they lack without having to express in speech.

5.1.7. Beirut Miniature Model Art Exhibition to Introduce Cultural Heritage to Children

The exhibition that took place in Gemmayzeh aims to present the 3d physical models of particular historical neighborhoods in Beirut brought together by the staff and students of Beirut Arab University. It concludes the project with a 3-day event summing up and celebrating the different activities and outcomes obtained. School teachers, children, parents, university students, and reporters were attracted to the exhibition, exploring nooks and crannies of the large-scale physical model and the close-up models of the most important

heritage buildings. People enjoyed the ornamentations on façades, balustrades and arabesque patterns, domes and minarets. The depth of the generated physical models made them easily identifiable and profoundly captivating. Further information can be gained by scanning the QR codes of the larger scale buildings where people can learn and read more about the history of the building, its cultural and historical values, and the importance of conserving it.

5.2. FROM 3D PHYSICAL TO 3D VIRTUAL

Martyr's square or "Sahat el Chouhada" has witnessed myriad disruptions over the years, transforming it to one of the main public spaces of downtown Beirut. It is now deemed as the "heart" of the city.
The experiment carried out aims to study the engagement of students with a virtual world of Martyrs' Square created using physical data that can be obtained from the site and its history. Three important settings are chosen to summarize the timeline of events, in an attempt to bring the students to visualize and live the era in its every aspect. The first is a simulation of year 1950, which gathers the accumulating events from the very initiation point until the demolition of the Little Saray. The second setting is defined as the period after the demolition and the resultant construction of cinema Rivoli. The final setting is the current state of the square and the effects of the revolution on how this public space is used. The significance of these dates will be discussed in direct relation to the set of events from which they are extracted.

5.2.1. Martyr's Square as a pilot study

- Before 1950: Martyr's Square, a Symbol of Independence

Beirut occupying a strategic location on the Mediterranean Sea, has always been a point of interest of all the adjacent and distant civilizations since it first existed in 2800BC. Martyr's square emerged from the gardens of a palace. It went by "Square of the Canons" and "Hamidiye's square" before it became a symbol of revolution and public expression in what became known as the "Martyr's Square" in 1916. In 1888, the governor took position in the Little Saray. By the end of the French mandate, the square became a symbol of independence in 1943 and would host the National Independence celebrations. The Little Saray was later destroyed in the year 1950, with the intention of opening up the square to the sea. The eclectic building, however, was then replaced with the Regent Hotel and Rivola Cinema.
However, through the use of the Metaverse, the children will not only be introduced to the factual background of the time period. They will be able to walk through the streets of Beirut, experience how different events

successively left a mark on the area. Children will know what it felt like living in Beirut before the 50s, what it meant to march in mass demonstrations in fight for the Lebanese independence, how important it was to join the mass celebrations when the latter was achieved.
Aside from that, they will also become more attentive to how the architectural heritage developed over time. For example, the Little Saray shown in figure 7 establishes a good demonstration of the changes in style. The French mandate effect is prevalent in the eclectic style incorporated. A series of baroque architecture elements intertwines with more austere features that were mostly dominant during the Ottoman era. The building is elevated on a plinth, subtly allowing it to harness more power. Other features include an oblong façade decorated with neo-baroque windows, a crenelated cornice running along the roof, flanking corners, and a large gable. Children will also be able to notice how the presence of the Saray helped defined the confinement of the square within the realms of buildings. Opening the square to the sea reduced the definition of the area.

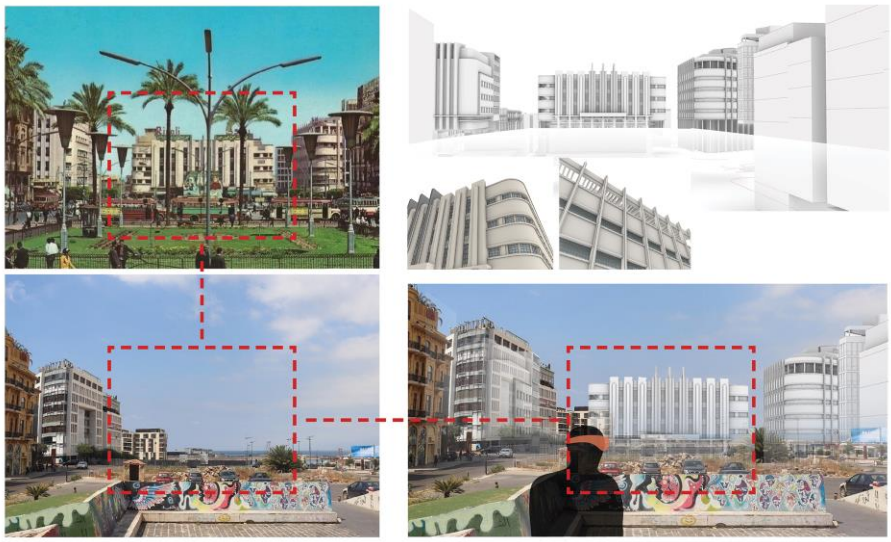

Figure 7 demonstrates how the Little Saray can be depicted in a virtual reality by using modelling software (The Authors).

- After 1950: Martyr's Square, Transportation and Cultural Hub

A newly elected president presented development plans designed by a French architect and urban planner. These eventually faced strong political opposition and halted when the Civil War broke (1975-1990). The division of Beirut into East and West during the beginning of the Civil War reflected on the Square

with a demarcation line, “Green Line”, which was a North-South axis that winded up at Martyr’s Square.

By integrating virtual realities to the education system, students will be able to navigate through the 50s and witness the square as a leisure and cultural centre, with families walking in and out of theatres, cinemas, and hotels before the war. One of these buildings would include the Rivoli Cinema built in the 60s and depicted in figure 8. Beirut will be experienced as a safe city again, with its congested streets, vibrant people, and neoclassic buildings. The Metaverse will enrich children with the feeling of peace and security, feelings our current generation currently lack due to incessant turmoil and turbulence.

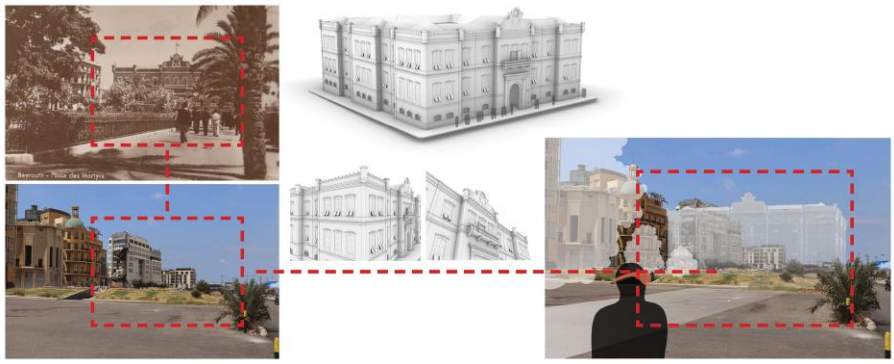

Figure 8 displays images showing how the 3D virtual tools can bring Cinema Rivoli back to Martyr’s square (The Authors).

By 1993, 80% of the buildings that were previously listed as historical landmarks got destroyed due to the war. Among them is the police station in Martyr’s Square. Children will be able to go back to that time period and identify what architectural elements making up that building have remained to exist in current constructions such as the arches, the concept of a grand entrance decorated with Greek columns, intricate rooftop cornice patterns, and crafted balustrades. They can also take part in the marches or strikes as demonstrated in figure 9 and learn what it means to be a responsible citizen that fights for a nation as a whole through previous event occurrences. This is a direct response to the message, “*Involve them and they’ll learn*”.

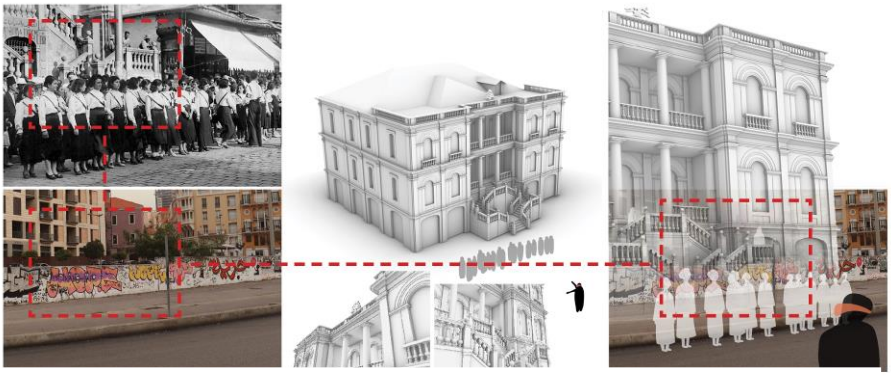

Figure 9 displays images showing how the 3D virtual tools can bring Police Station back to Martyr's square (The Authors).

- 17th October 2019: Martyr's Square Reclaimed, a Symbol of Cooperation

Martyr's Square reclaimed its symbolism as a platform to voice out the citizens needs for liberty and change when protestors gathered to injustice. Citizens have claimed these privatized spaces using several means: physical, intellectual, symbolic, artistic, etc., thus changing the image of the area from a symbol of political divisions to a representation of the cooperation of the people (Figure 10).

- Physical Reclamation:

People created from the space what urban planners and organizations failed to provide. Reshaping the square took many forms. Furniture and tents were distributed in order to mark spaces and zones for public discussions and political debates. Street food and small businesses installed stands with affordable prices, in order to provide the protestors with essentials of a day of protest. Spontaneous patterns of interaction were recreated between the people, and thus creating a new collective memory to replace the void. The circulation of the images after that between people led to the rebirth of the space as one for the people, a square of revolution. #ReclaimYourPublicSpace (Salame, 2022).

- Intellectual and Artistic Reclamation:

The intellectual aspect is disclosed through open and free debates that occurred in the streets, as an attempt to educate the citizens and make them more aware of their rights. The artistic aspect also occurred simultaneously where lots of young artists emerged expressing themselves with graffiti on the walls and floors. They are, as well, contributors in the historical and cultural aspects of the country.

Although these events only happened recently, a future method for engaging children in this period is to recreate the art pieces left behind, the spaces as divided by the citizens, including the discussion areas and the business stands. How a diverse country united to stand up to injustice defines how a certain heritage provided ground for people to identify as one nation and build tolerance towards the "different" other.

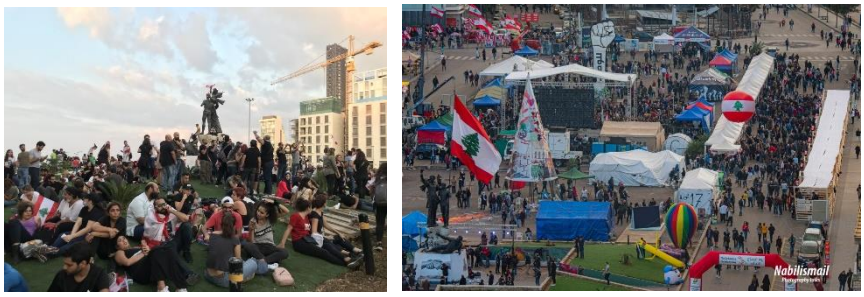

Figure 10 Different ways of occupation of Martyr's Square during the revolution

6. Conclusions

Lebanon is at crossroads. The country can either have a new start, or it can go back to the same unrest it has been going through for years, and perhaps educating children at a young age to understand the value of their heritage, the uniting foundation transcending their diversity, and the vitality of preserving the culture is the most effective means to build a generation that aims to unify amidst this diversity. Although shifting to a completely immersive reality remains theoretical for now, transforming towards educating architecture using 3D models rather than 2D pictures and factual lectures has proven to be a success in the project carried out by BAU students.

Whether the propensities offer a partly or fully engaging learning atmosphere, immersion increases knowledge retention in students and allows them to synthesize, relate, and criticize.

Involve them and they'll learn, so that the next brick laid in Lebanese history restores our cultural heritage and rebuilds our lost serenity.

Acknowledgements

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DAY 1 - PARALLEL SESSION 4

TOPIC 1 - ARTIFICIAL INTELLIGENCE

GETTING A HANDLE ON FLOOR PLAN ANALYSIS

Door classification in floor plans and a survey on existing datasets

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Abstract. Floor plan interpretation and reconstruction is crucial to enable the transformation of drawings to 3D models or different digital formats. It has recently taken advantage of neural-based architectures, especially in the semantic segmentation field. These techniques perform better than traditional methods, but the results depend mainly on the data used to train the networks, which is often crafted for the specific task being performed, making it hard to reuse for different purposes. In this paper, we conduct a literature survey on the existing datasets for floor plan analysis, and we explore how information regarding door placement and orientation can be recovered without having to change the initial data or model. We propose a two-step recognition method based on image segmentation followed by classification of cropped zones to allow data augmentation during training. In the process, we generate a dataset consisting of 35000 annotated door images extracted from an existing dataset.

Keywords: *Floor Plan Analysis, Data Engineering, Machine Learning, Neural Networks, Dataset Survey.*

ملخص. يعد تفسير وإعادة بناء المخططات والمساقط الأفقية أمرًا بالغ الأهمية لتمكين تحويل الرسومات إلى نماذج ثلاثية الأبعاد أو تنسيقات رقمية مختلفة. وقد استفادت هذه التقنيات مؤخرًا من البنى القائمة على العصبية، خاصة في مجال التجزئة الدلالي. تؤدي هذه التقنيات أداءً أفضل من الطرق التقليدية، لكن النتائج تعتمد بشكل أساسي على البيانات المستخدمة لتدريب الشبكات، والتي غالبًا ما يتم تصميمها للمهمة المحددة التي يتم تنفيذها، مما يجعل من الصعب إعادة استخدامها لأغراض مختلفة. في هذه الورقة البحثية، نجري مسحًا أدبيًا حول مجموعات البيانات الحالية لتحليل المخططات والمساقط الأفقية، ونستكشف كيف يمكن استرداد المعلومات المتعلقة بوضع واتجاه الأبواب فى المسقط الأفقى دون الحاجة إلى تغيير

البيانات الأولية أو نموذج المبنى. نقترح منهج للتعرف الآلى على خطوتين بناءً على تجزئة الصورة متبوعة بتصنيف المناطق التي تم اقتصاصها للسماح بزيادة البيانات أثناء التدريب. في هذه العملية، نقوم بإنشاء مجموعة بيانات تتكون من ٣٥٠٠٠ صورة باب مشروحة مستخرجة من مجموعة بيانات موجودة.

الكلمات المفتاحية: *تحليل المساقط الأفقية، هندسة البيانات، التعلم الآلى، الشبكات العصبية، مسح لمجموعات البيانات.*

1. Introduction

Floor plan interpretation and reconstruction have been a field of research for many years. Often, the goal was to enable the conversion of hand-made floor plan drawings to modern formats used in Computer-Aided Design (CAD). Compared to the traditional paper-based practices, having these models in digital formats is advantageous in terms of storage and sustainability. Furthermore, the conversion also enables the creation of 3D models from existing floor plans, making it possible to bring existing building designs into digital spaces such as the metaverse.

Initially, floor plan interpretation was performed using low-level image processing techniques and hand-crafted rules. By taking advantage of design conventions that dictate how floor plans should be represented, e.g., using thick lines for walls and thin lines for other elements, a common approach was to take an input image and separate the elements depending on line thickness (Dosch et al., 2000; Macé et al., 2020; Ahmed et al., 2012). Other image processing techniques were also used, such as the employment of the Hough Transform (Macé et al. 2010) to extract lines from the drawings. Then, symbols could be recognized using traditional recognition methods, such as, subgraph isomorphism (Llados, Marti and Villanueva, 2001).

More recently, image classification and segmentation have been dominated by deep-learning-based approaches, especially with Convolutional Neural Networks and Vision Transformers. These methods have been shown to perform and generalize better than traditional approaches based on hand-crafted rules. However, they also have disadvantages. The first drawback is the large amount of annotated data necessary to train a deep-learning model. As the performance of these models depends mainly on the data that are fed onto them, the data must be carefully annotated in large quantities, which is time consuming. Unfortunately, floor plan data is not as widely available as data for other tasks such as image classification, which has well-established benchmarking datasets, e.g., ImageNet (Deng et al., 2009). Not only is there a lack of benchmarking datasets for floor plan interpretation, but the available datasets also do not follow consistent annotation conventions. The annotations come as a necessity for each individual task, instead of a generalized

description of the images. For example, door annotations usually only comprise an opening instead of the whole door symbol, as authors usually only target structural reconstruction. This can be seen in Figure 1.

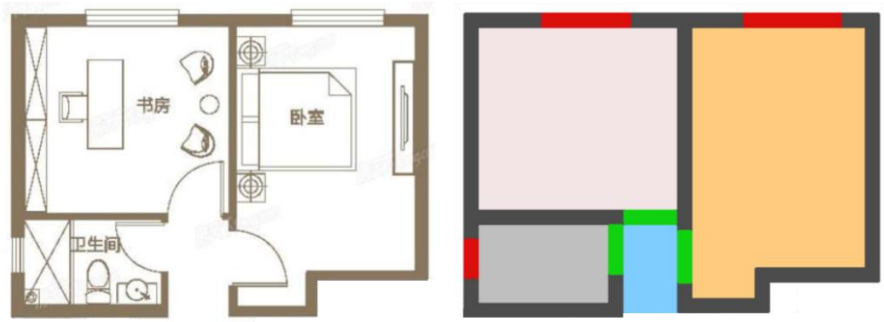

Figure 1. Ground truth annotation of a floor plan image. The annotation of the doors does not include the door swing area. Example adapted from (Lv et al., 2021).

More recent works (Fan et al., 2021; Simonsen et al., 2021; Song and Yu, 2021) have also explored the use of Graph Neural Networks (GNNs) for the classification of floor plan images or CAD drawings. These, unlike raster-based methods, can retrieve the segments that make up each component without the loss of information caused by methods based on convolution and pooling. Nonetheless, GNNs are often more resource intensive than raster-based methods.

In this paper, we focus on recovering the door type information lost after applying segmentation models. Due to the importance of data on these methods, in the next section we present a literature survey on the available datasets. Given that door classification depends on orientation, we propose a method that is invariant to geometric transformations, and we create a dataset consisting of 35000 annotated door symbols extracted from CubiCasa5K (Karlevo et al., 2019). Our code, in the form of a CubiCasa5K GitHub fork, is made publicly available to serve as a basis for future developments.[1]

2. Literature Review on Available Datasets

Deep learning techniques require large amounts of data to perform well. In this section, we present a literature review on the most relevant floor plan datasets, which are summarized in Table 1.

The CVC-FP (Heras et al., 2015) is one of the first datasets of floor plans. It consists of 122 real floor plan images divided into 4 categories depending

[1] https://github.com/joaocmd/CubiCasa5k

on their origin and style. The elements are encoded with polygons in SVG format, which include walls, doors, windows, parking doors, and separations. Besides the visual elements, relationships between objects are also encoded, such as neighboring rooms and incident elements.

With the objective of aligning floor plans with in-house photos, Liu et al. (2015) introduce Rent3D, consisting of 215 floor plans and 1570 photos. The floor plans contain an annotated real-world scale, rooms and their respective types, walls, doors, windows, axis-aligned bounding boxes for icons, and relationships between rooms. For the image alignment task, the photos are each assigned to room elements. This dataset was recently extended by Vidanapathirana et al. (2021), creating the Rent3D++ dataset. This version does not add any images, but fixes and adds some categories and relationships between elements. The annotations are encoded in JSON files describing the different elements and CSV files containing the assignment of photos to rooms. Furthermore, the authors also introduce a dataset of room surface textures.

Dodge, Xu and Stenger (2017) introduce the R-FP dataset.[2] This dataset consists of 500 floorplan images. The ground truth only includes the wall segmentation, but a subset was annotated to perform object detection.

Liu et al. (2017), in their research, collected and annotated 870 images from the LIFEFULL HOME'S dataset.[3] The ground truths are encoded in text files describing the rooms, walls, doors, and some objects, which are all described by rectangles. While rooms are classified depending on their type, this dataset makes no distinction between doors and windows, which are distinguished later using hand-crafted rules. However, only the annotations are available.

Zeng et al. (2019) introduce two datasets, R2V and R3D, for floor plan image recognition using deep learning. The R2V dataset consists of the pixel-wise annotation of 815 images from the dataset in Raster-to-Vector (Liu et al., 2017). Similarly, R3D is the pixel-wise annotation of the Rent3D (Liu et al., 2015) dataset with 18 additional images. The pixel-wise classifications include wall, door, window, and room-type segmentation.

H. Kim, S. Kim and Yu (2021) propose a method for recovering spatial information in large floor plan images. The authors introduce a dataset consisting of 230 floor plan images from the Seoul National University (SNU). For the annotations, they use polygon boundaries for walls, doors, windows, staircases, and elevators. The dataset is available upon request to the corresponding author.

Wu et al. (2019) focus on generating house interior plans given a building boundary. They introduce the RPLAN dataset consisting of over 80000 pixel-

[2] https://rit.rakuten.com/data_release/, 2022/04/03.
[3] https://www.nii.ac.jp/dsc/idr/en/lifull/, 2022/04/03.

annotated images from real houses. The annotations include room types and distinguishes between interior and exterior walls as well as between main door and remaining doors. The authors also provide a toolbox to interact with the dataset; however, the original images are not publicly available.

CubiCasa5K (Karlevo et al., 2019) is a publicly available dataset, containing 5000 annotated floor plan images. Each raster image is associated with an SVG file that contains the geometric and semantic annotations of more than 80 object classes. The images are divided into 3 categories depending on their style, but there is a large amount of variation even within each category.

Lu et al. (2021) introduce RuralHomeData, which they use for floor plan understanding. This dataset includes the segmentation of 800 real-world floor plans of rural homes. Lv et al. (2021) also propose a system for converting raster floor plan images to a vector format, using their RFP (Residential Floor Plan) dataset, which is made up of 7000 images retrieved from the Internet. The annotations contain the segmentation of walls, doors, windows, and room types. Objects, scales, and text elements are also annotated, as well as doors and window openings. As far as we know, these two last datasets are not publicly available.

Simonsen et al. (2021) follow the newer graph-based approaches and propose a method to recognize doors in plans directly in DXF files. The authors introduce the Repository of Unique Buildings (RUB), collecting 81 floor plans in the DXF format. The files are used to generate two datasets, an image-based one containing the bounding box of the door elements and a graph-based one with node-wise classification.

The FloorPlanCAD (Fan et al., 2021) is another dataset of vector CAD drawings. As of May 2022, it contains 15663 drawings. The drawings are provided in SVG and PNG formats, where the elements are segmented and classified primitive-wise into 60 classes. However, private information that could identify the buildings was removed from the floor plans, and the plans are cut into squared blocks, where only 50% of them are kept. This is not a serious limitation as research have shown that good model results can be achieved with partitioned inputs (Lu et al., 2021).

The Systems Evaluation Synthetic Documents (SESYD) (Delalandre et al., 2010) is a public database with 1000 synthetic vector floor plans. Although the floor plans do not correspond to real-world buildings, their style is consistent with floor plan images of other datasets. The annotations are encoded in XML files with axis-aligned bounding boxes identifying the symbols, as well as some information regarding their orientation. The symbols include common objects, doors, and windows.

The FPLAN-POLY (Rusiñol, Borràs and Lladós, 2010) dataset contains 42 floor plans in the DXF format that have been vectorized from raster images. The dataset is public and aims to provide a framework for evaluating symbol

spotting. Thus, the annotations correspond to labels assigned to the convex hull of the symbols.

The Repository of Building Plans (ROBIN) (Sharma et al., 2017) is a public dataset developed for floor plan retrieval tasks. It contains 510 floor plan images, each classified by its number of rooms and overall building shape. Another version called ROBIN++ is also available, consisting of the same floor plans but in a roughly sketched style.

The Building Plan Repository for Image Description Generation (BRIDGE) (Goyal et al., 2019) contains over 13000 floor plan images, including some that are present in other public datasets such as SESYD (Delalandre et al., 2010) and ROBIN (Sharma et al., 2017). The dataset aims to support tasks such as symbol spotting, caption generation, and description synthesis. As such, the annotations include bounding boxes and labels for the symbols, and free-text captions for parts of the images.

As we have seen in most of the datasets, the annotations vary largely, which is a challenge for accurate and complete reconstruction. Specifically, we explore the problem of correctly identifying door types and their orientation, which is often disregarded in the annotated data. In the next section, we cover how we define a convention for door classification and how we can make use of the available datasets to build a classifier.

TABLE 1. Summary of datasets covered in Section 2. ✓* indicates that the dataset is available through an application and ✓** that only the annotations are available.

Dataset	Size	Content	Public
CVC-FP (Heras et al., 2015)	122	Objects, structural elements, relationships	✓
Rent3D++ (Vidanapathirana et al., 2021)	215	Objects, structural elements, images, textures	✓*
R-FP (Dodge, Xu and Stenger, 2017)	500	Wall pixel segmentation, objects	✓*
Raster-to-Vector (Liu et al., 2017)	870	Room type, walls, openings, objects	✓**
R2V (Zeng et al., 2019)	815	Room type, walls, openings pixel segmentation	✓**
R3D (Zeng et al., 2019)	232	Room type, walls, openings pixel segmentation	✓
SNU (H. Kim, S. Kim and Yu, 2021)	230	Walls, doors, windows, stairs, elevators	✓**
RPLAN (Wu et al., 2019)	80000+	Room type, walls, openings pixel segmentation	✓**

CubiCasa5K (Kalervo et al., 2019)	5000	Objects, structural elements, room types	✓
RuralHomeData (Lu et al., 2021)	800	Room type, walls, openings pixel segmentation	✗
RFP (Lv et al., 2021)	7000	Room type, walls, doors, windows, objects, scales, text	✗
RUB (Simonsen et al., 2021)	81	Labeled CAD doors	✓
FloorPlanCAD (Fan et al., 2021)	15663	CAD primitive-wise segmentation	✓
SESYD (Delalandre et al., 2010)	1000	Objects, windows, doors	✓
FPLAN-POLY (Rusiñol, Borràs and Lladós, 2010)	42	Annotated objects' convex hulls	✓
ROBIN (Sharma et al., 2017)	1020	Floor plan shape/type classification	✓
BRIDGE (Goyal et al., 2019)	13000+	Objects, room and building captions	✓

3. Describing Doors

Finding a method to describe doors is a challenging problem as it depends on orientation and, thus, on the point of view of the observer. In this section, we propose a solution to that problem.

First, we observe how every door can be defined by its two endpoints: S and E (*Start* and *End*). Then, the door symbols are described according to the position of the door axis relative to these two points. Visually, this can be thought of as moving the door so that it sits on top of the x axis on the Cartesian plane with S to the left of the y axis and E to the right of it. Then, the *Left*, *Right*, *Forward*, and *Reverse* labels depend on which quadrant the door opens to. This rationale is illustrated in Figure 2.

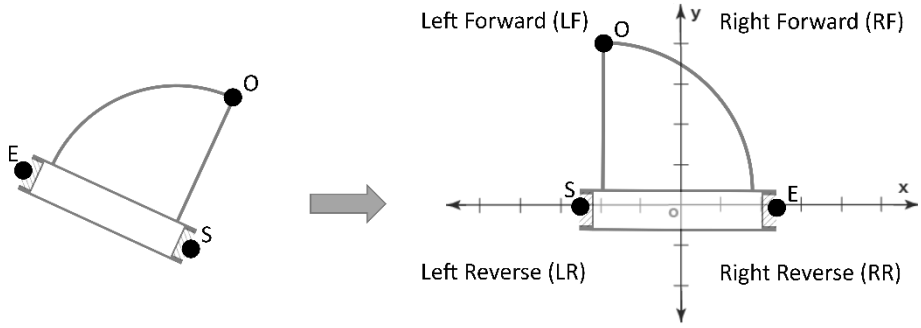

Figure 2. Process to describe a door symbol. S and E are placed on top of the x axis so that S is on the left. The quadrant of point O determines the door classification. This example corresponds to a *Left-Forward (LF)* door.

In addition to normal swing doors, we also describe other related symbols. Some swing doors can open in both directions and, sometimes, the door axis changes depending on the opening direction. For that reason, we define two door axes for these doors, one for each direction. Double doors consist of two swing doors that open in a single direction, where one has an axis on the left and the other on the right. Thus, these doors are described by their opening direction. Other types of doors such as sliding doors and roll up doors are also given a label, but we do not assign any specific information regarding opening direction. Nonetheless, the same ideas can be applied to classify them if that information is needed, as well as to classify other elements such as windows.

The following sections use these concepts to create a dataset and build a classifier capable of identifying door types in floor plan images.

4. Dataset Description and Generation

To address the problem of recovering door information using the available data of previous works, we created a dataset based on the label description elaborated in the previous section. The resulting dataset consists of **35000** door images, varying in resolution and aspect ratio.

To abide by the previous description, we first define a total ordering of all coordinates, from the bottom left corner to the upper right corner. If two points are at the same value on the *x* axis, the first point is the one with the smallest *y* value. That is, let $P_1 = (x_1, y_1)$ and $P_2 = (x_2, y_2)$ then:

$$P_1 < P_2 \Leftrightarrow x_1 < x_2 \vee (x_1 = x_2 \wedge y_1 < y_2) \quad (1)$$

We use this total order to define each door by its two endpoints: S and E (start and end), where $S < E$. The imposed order is not necessary to describe a door symbol, but it is necessary to guarantee consistency in annotation across all symbols and images.

By applying this total order, we get the final labels which are illustrated in Figure 3. However, when we consider how the images are labeled, the dependency on a total order introduces a problem. Notice how, if point 7 moved right under point 6, their order would change and so would the classification of the doors between them, as the segment would be like the leftmost case. For this reason, these labels cannot be used if the input images are to be rotated during the training process, which is a common data augmentation technique. As a solution, the doors can be given a general class during segmentation and the specific class can be retrieved later by running a classifier on each isolated door symbol. This is our rationale for performing door orientation classification after segmentation, instead of trying to perform both at once during the segmentation.

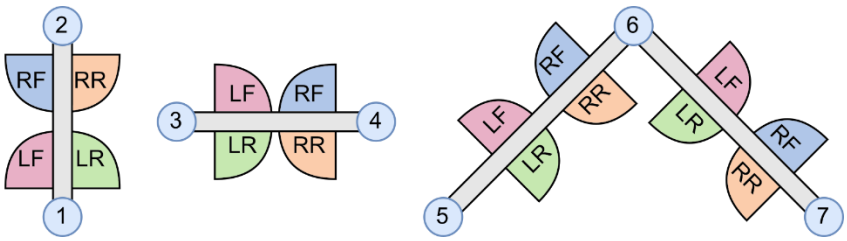

Figure 3. Door labels in different orientations. The characters mean "*(L)eft*", "*(R)ight*", "*(F)orward*", "*(R)everse*", and are combined to form 4 different classes. The numbers in the points correspond to their index considering the ordering criteria introduced in this section.

To create our data, we apply this process to the images in the CubiCasa5K (Karlevo et al., 2019) dataset. In that dataset, the annotations are encoded in SVG files, which were explored to extract the new images. The authors of CubiCasa5K use the SVG *id* attribute to classify each element; however, they included additional information in other fields. Namely, the *class* attribute identifies the type of door, of which we found: *Swing Beside*, *Swing Opposite*, *Slide*, *ParallelSlide*, *RollUp*, *Zfold*, and *None*.

The *Swing Beside* class is used for normal swing doors. We extract S and E, the start and end points, respectively, from the SVG element. The points are sorted according to the previously defined criteria, attending to the fact that image coordinates on the y axis are reversed. The representation of swing doors in the SVG files includes an arc, which we use to find the point reached by the door when fully open, which we will refer to as O. By calculating the

distance between O and S and between O and E, we assign the label "L*(eft)*" if O is closest to S, and "*R(ight)*" otherwise. To assign the label "*F(orward)*" or "*R(everse)*", we must find if O sits above or below the $\overline{SE}$ segment, which can be done through the cross product between $\overrightarrow{SE}$ and $\overrightarrow{SO}$, after setting the z value of both vectors to zero, and then looking at the sign of the resulting z component to identify the door facing direction. The four possible scenarios are shown in Figure 4.

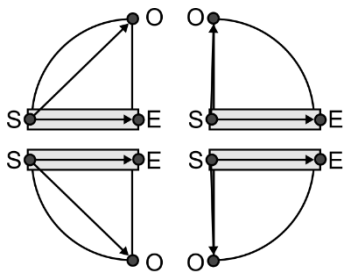

Figure 4. Possible scenarios for forward/reverse classification. The sign of the cross product is positive on the two top examples and negative on the bottom examples.

The other classifications build on the same concepts. Double doors are also annotated as *Swing Beside*, but have two arcs instead of one. In that case, we perform the forward/reverse classification on one of the arcs and classify them as double doors with the given direction.

The *Swing Opposite* doors consist of single doors that swing in both directions. For these, we perform left/right classification for both arcs. To guarantee consistency, we start by labeling the forward arc and only then the reverse one. Figures 5c and 5d show two examples of such classes. As we have a defined order for classifying this type of doors, we can, for example, abbreviate "*RF-LR"* into "*RL*" and "*LF-LR*" into "*LL*".

Finally, for the remaining classes, we just use the *class* attribute directly. The final images are extracted by rotating the original images so that their corresponding walls are horizontal and then cropped to our region of interest.

We have, until this point, described how the data is extracted. We now focus on how the data is grouped and augmented. The data is split into a train set, a validation set, and a test set, according to the original floor plan images dataset. The images on each set correspond to the door symbols extracted from the corresponding floor plan images. As the floor plans in CubiCasa5K (Karlevo et al., 2019) are varied in style, the resulting dataset shares that same feature, and the images correspond to elements found in real floor plans with different surrounding contexts and noise.

Our defined classes allow us to use the same image for different classes. For example, a normal swing door with the label "*LF*" can be mirrored horizontally to create an "*RF*" image, mirrored vertically to create a "*LR*" image, and mirrored in both directions to create a "*RR*" image. The same is applicable to *Swing Opposite* doors, where "*LL*" can be transformed into an "*RR*" image, and "*LR*" into an "*RL*" image. Furthermore, by vertically mirroring an "*LL*" example, a different "*LL*" example is created, doubling the number of examples. For the other classes in which we did not consider any orientation, those can be mirrored four times to generate examples with a slightly different appearance. This, in turn, can be used to balance the number of examples for each class.

Example images can be seen in Figure 5. Dataset statistics are summarized in Figure 6, where we can see that single doors are the most common by a large margin, and folding doors are rarely used.

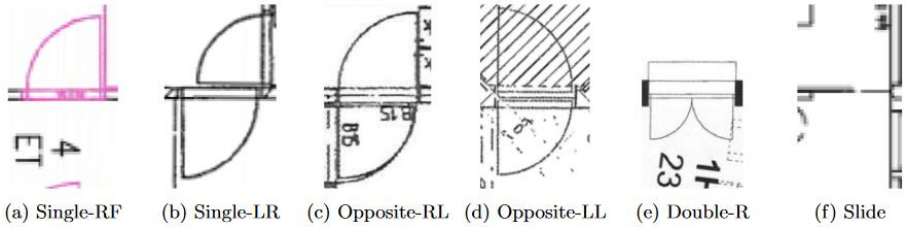

Figure 5. Examples of our labeled images. Each caption corresponds to the given image class.

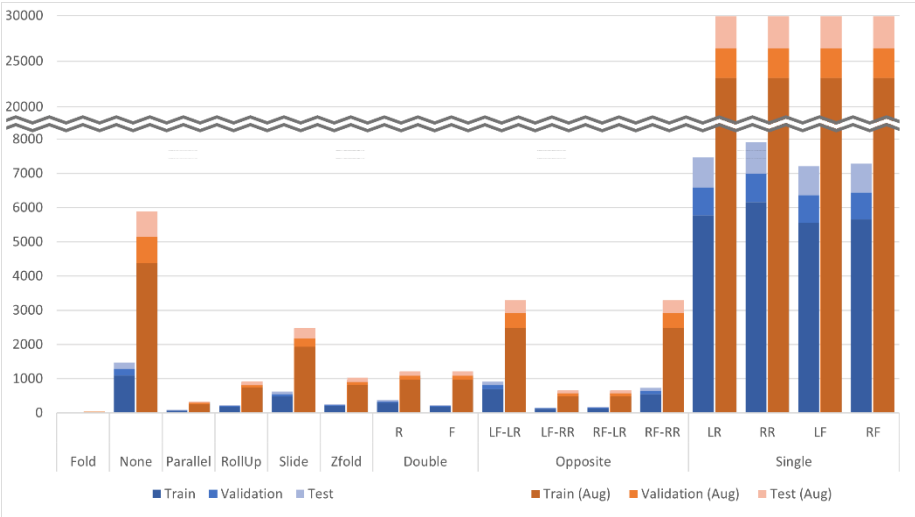

Figure 6. Number of examples for each label on the original and augmented datasets.

5. Application and Evaluation

The approach described in the previous section was developed to allow us to train a classifier for door symbols, as that information is lost during the segmentation process. In this section, we describe how we can combine both the segmentation and the classification processes.

We use the data generated in the previous section, augmenting all but the single swing doors as those largely overwhelm the other classes, and group all sliding doors into a single class. For our classifier, we chose to use a pre-trained ConvNeXt-Tiny (Liu et al., 2022) due to its small size, simple architecture, and good performance. We perform transfer learning on the generated data, using normal data augmentation techniques such as color shifting and geometric transformations.

The model achieves 90.7% overall accuracy on the test set. As we can see from Figure 7, it struggles with the distinction of the *slide* and *none* classes, having achieved only 66.8% accuracy on the *none* class by wrongly classifying most of the remaining as *slide*. However, we observe that these examples are also hard for a human to categorize, as the *none* class was used for wall openings, but other strange cases are present, such as crossed-out symbols or symbols with no clear category that could be easily confused. In most buildings, simple swing doors are used, and the model achieves excellent results for those, with an average of 97.7% accuracy and 94.6% precision for these classes.

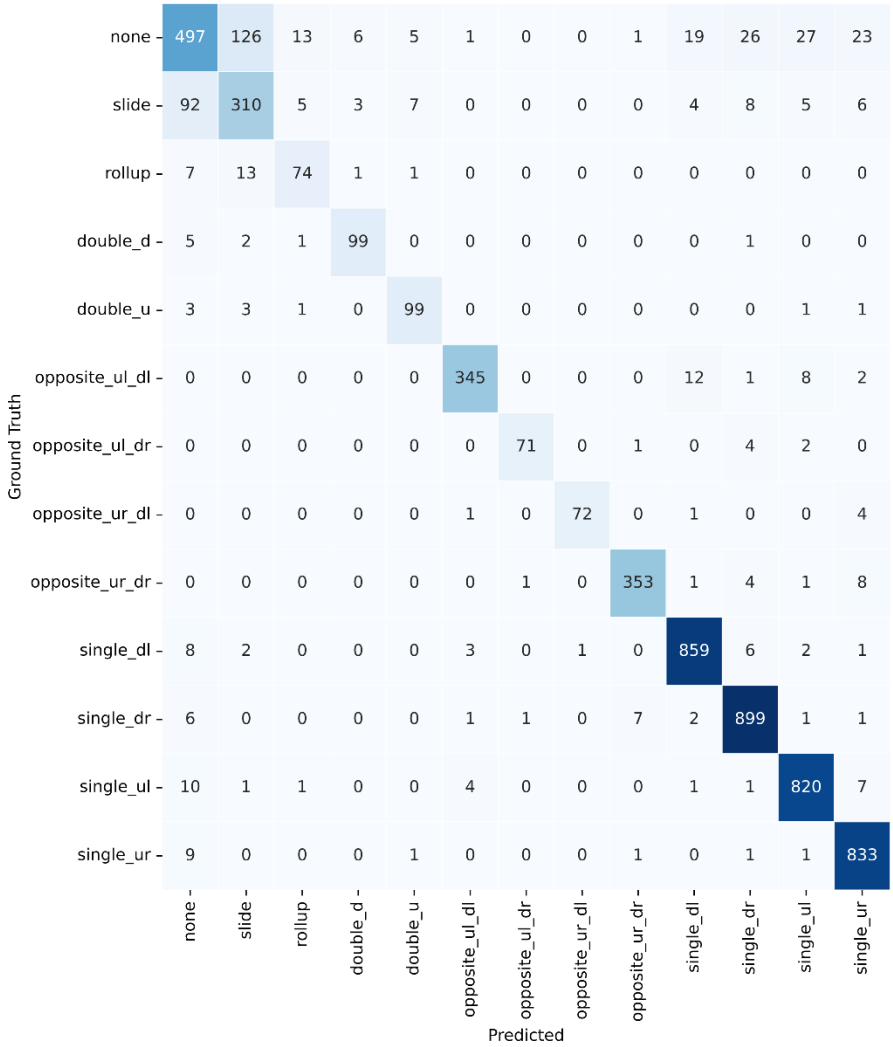

Figure 7. Confusion matrix of the trained model on the augmented test set.

We then integrate our classifier into a general recognition process, which is shown in Figure 8. Starting with the original image, we extract a pixel-wise segmentation. We use the model provided in the CubiCasa5K repository. The doors can be retrieved by finding the contours of the wall openings and approximating them with a rotated rectangle, then the rectangle is expanded so that it is able to fit any type of door. The start and endpoints are extracted from the rectangles by considering their longest sides. Then, similarly to the dataset generation, the points are ordered to maintain consistency in the image classes.

Figure 8. General process for door classification. The doors are recognized during segmentation, but the semantics are lost. We extract the zone where the door might be and use a classifier to recover that information. Floor plan image adapted from Lv et al.'s (2021) work.

In Figure 9, we see an example of our recognition process in an image from the CubiCasa5K (Karlevo et al., 2019) dataset. The image is part of the dataset's test set and, as such, the door symbols in the image were not used during the door classifier training. From the image, we can see that the only misclassified element was due to a segmentation error which considered only one door instead of two. Right above the misclassified door is a correctly classified element, as the smaller door was not detected by the segmentation network. For reference, we used the model proposed by Karlevo et al. (2019). Considering the segmentation error, the door classification model makes a reasonable prediction.

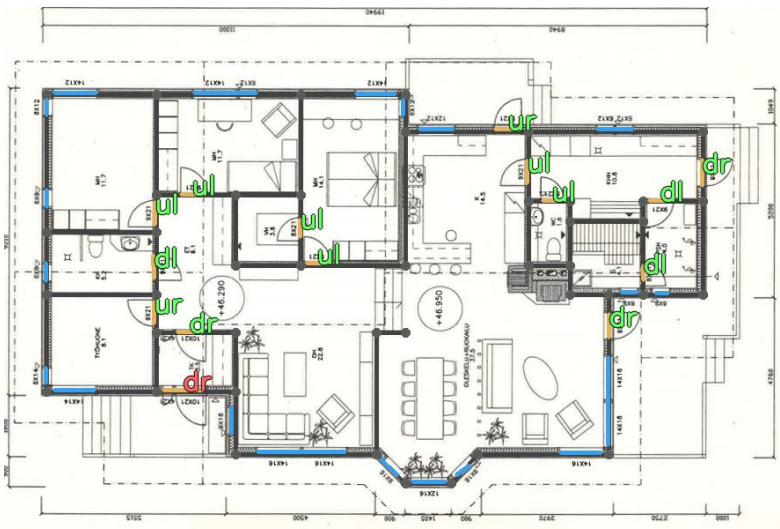

Figure 9. Door recognition results on an example image. In red, a misclassified door.

6. **Conclusion and Future Work**

In this paper, we identified a drawback of the use of pixel-segmentation approaches in the analysis of floor plan images, namely, the information loss that happens regarding door placement and orientation. We proposed a method to classify doors present in floor plans, and a method to gather the necessary data to do so. To support this task, we performed a survey of the datasets that have been used for floor plan analysis.

One drawback of our approach is the need for a two-step classification process. It can be of interest to pursue a classification that can be inferred directly during the semantic segmentation process while still allowing data augmentation techniques to be used during model training. In this paper, we focused on the extraction of semantic content for swinging doors. For future work, we plan to apply the same approaches to the recognition of other elements such as sliding doors, roll up doors, and windows.

Acknowledgements

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TOWARDS INFORMED DESIGN DECISION SUPPORT OF ADDITIVE MANUFACTURING IN CONSTRUCTION

The use of integrated knowledge in BIM-based architectural design

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Abstract. Additive Manufacturing (AM) technologies have great potential to promote sustainable development in the architecture, engineering, and construction (AEC) domain. But the inherent complexity of AM and lack of domain knowledge hinder decisions about appropriate construction methods. With state-of-the-art Semantic Web technologies, a knowledge base regarding AM technologies can be formalized and integrated into the Building Information Modeling (BIM) methodology. To this end, this paper demonstrates how a Design Decision Support System (DDSS) utilizes formal knowledge to assist architects in choosing the appropriate AM method by assessing the manufacturability of individual building components. By following and refining the essential activities described, we aim to provide architects with informed decision support, thus facilitating the versatile use of AM technologies in the AEC domain.

Keywords: *Building Information Modelling, Decisions Support System, Additive Manufacturing in Construction.*

ملخص. تتمتع تقنيات التصنيع التجميعى بإمكانات كبيرة لتعزيز التنمية المستدامة في مجال العمارة والهندسة والبناء. ولكن التعقيد المتأصل في التصنيع التجميعى ونقص المعرفة بالمجال يعيقان القرارات المتعلقة بأساليب البناء المناسبة. باستخدام أحدث تقنيات شبكات الانترنت الدلالية، يمكن إضفاء الطابع الرسمي على قاعدة المعرفة المتعلقة بتقنيات التصنيع التجميعى ودمجها في منهجية نمذجة معلومات البناء. وتحقيقًا لهذه الغاية، توضح هذه الورقة البحثية كيف يستخدم نظام دعم قرار التصميم المعرفة المرتبطة بالشكل لمساعدة المعماريين في اختيار طريقة التصنيع التجميعى المناسبة من خلال تقييم قابلية تصنيع مكونات المبنى الفردية. ومن خلال متابعة الأنشطة الأساسية الموضحة وتحسينها، نهدف إلى تزويد

المعماريين بدعم قرار مستنير، وبالتالي تسهيل الاستخدام المتنوع لتقنيات التصنيع التجميعى في مجال العمارة والهندسة والبناء.

الكلمات المفتاحية: *نمذجة معلومات البناء، نظام دعم القرارات، التصنيع التجميعى فى الإنشاء.*

1. Introduction

Additive Manufacturing (AM) technologies have been increasingly studied to mitigate the environmental impact of the building industry. More sustainable building materials (Liu *et al.*, 2022), material and energy-efficient design (Dielemans *et al.*, 2021), life-cycle analysis from the process control (Kuzmenko *et al.*, 2022), etc., have demonstrated the potential of AM technologies for sustainable development in the AEC domain. The multitude of innovative 3D Concrete Printing (3DCP) methods could be classified as particle-bed binding, material extrusion, and material jetting (Buswell *et al.*, 2020), while each method presents individual strengths and constraints on the printed building components. Considering the practical application of AM technologies in construction, the architects and engineers have to explore feasible AM method(s) in the exponential portfolio of processes, materials, machine systems, applicational contexts, and requirements (Dörfler *et al.*, 2022). It is known that early design stages account for essential decisions for upcoming planning and construction phases, however, a lack of domain knowledge primarily makes the decision-making of AM methods intractable (Zeiler, Savanovic and Quanjel, 2007).

Previous studies have advocated formalizing AM ontologies for design support, mainly addressing the manufacturability problems for particular geometry features (Dinar and Rosen, 2017; Kim *et al.*, 2019). Regarding BIM-based prefabrication and planning, Cao et al. proved that formal knowledge helped to reduce design iterations by proactively validating conformities between product features and manufacturing capabilities (2022).

The achievements of leveraging domain-specific ontologies have led to the effort of integrating a formalized AMC (*About AMC TRR 277 - Additive Manufacturing in Construction*) knowledge base into the BIM methodology for design decision support. Accordingly, Li and Petzold proposed a Design Decision Support System (DDSS) using Semantic Web technologies and Multi-Criteria-Decision-Making (MCDM) methods to assist architects in choosing feasible AM methods for the BIM-based architectural design (2021). As an update, this paper introduced the essential activities evaluating building components' manufacturability, followed by the implementation details of a technical framework. Expanding on this work could provide

more comprehensive decision support, thus bringing AMC technology to the forefront of novel architectural design.

2. Background

2.1. EXPLICIT KNOWLEDGE AND SEMANTIC WEB TECHNOLOGIES

In order to identify suitable formalization techniques for the AMC knowledge base, we first study the data-information-knowledge-wisdom (DIKW) hierarchy and disambiguate different terms of knowledge. According to Rowley (2007), data is unprocessed input that needs to be structured and formatted to be part of the information, whereas knowledge derives from the synthesis of information and can be put to productive use. Wisdom is built upon accumulated knowledge with the exclusive capability of visioning foresight even in new situations or problems.

Polanyi further distinguished knowledge as tacit or explicit (2009). While tacit knowledge remains subjective in peoples' ability, values, experience, etc., explicit knowledge can be objectively articulated and codified. Using machine learning techniques such as Convolutional Neural Networks (CNN) and Case-Based Reasoning (CBR), tacit knowledge can be captured and served in specialties such as architectural design and medicine (Roith, Langenhan and Petzold, 2017; Alzubaidi *et al.*, 2021). Knowledge representation (KR) techniques, on the other hand, are able to encode knowledge in formalisms such as semantic networks, production rules, and monotonic or non-monotonic logic (Russell and Norvig, 2016). With KR techniques, explicit domain knowledge can be formalized as domain-specific knowledge bases consisting of logic-based ontology and rules. As to the expressive description logic (DL), the ontology is further anatomized as terminologies (TBox), roles (RBox), and assertions (ABox) (Rudolph, 2011).

Semantic Web technology provides a standard set of languages for building knowledge bases. World Wide Web Consortium (W3C) has recommended the Web Ontology Language (*OWL - Semantic Web Standards*), SPARQL query language (*SPARQL 1.1*), SHACL (*Shapes Constraint Language (SHACL)*) for ontology-making, query, and validation. Additionally, SWRL (*SWRL: A Semantic Web Rule Language Combining OWL and RuleML*) and nominal schemas are often applied to strengthen the expressivity of OWL in rule-making (Krisnadhi, Maier and Hitzler, 2011). Notably, a distinguishing feature of the Semantic Web technology is the Open-World Assumption (OWA) – one cannot state false for the sake of missing knowledge as it might be found somewhere else, as opposed to the Closed-World

Assumption (CWA) for database-like information systems or logic programming adopting the presumption of Negation-as-Failure (NAF) (Rudolph, 2011).

2.2. IMPACTS OF AM METHODS ON ARCHITECTURAL DESIGN SPACE

The entanglement and interaction of material, machinery, and process account for AM methods' varying capabilities and constraints for architectural design. Apparently, materials used for printing and their properties in a hardened state should comply with design intent and regulations. Further, as to extrusion-based AM methods, fresh material's properties such as buildability and open time, are critical to a collapse-free print as well as sufficient layer-wise bonding strengths that influence mechanical performances of the building component. Therefore, cycle time derived from toolpath and printing speed should be coherent to extruded material's fresh state properties. In this sense, building components' dimensions are constrained by fresh state properties, planned toolpath, and printing speed.

Dörfler *et al.* (2022) illustrated that the architectural design space was constrained by the Crane system from WASP (*Stampante 3D per case*). Indeed, the workspace of a machine system envelopes the printed components at their largest scale. Without extra operations, such as repositioning and reorientation of the machine system, the geometry of printed components must be confined to the workspace. Moreover, slicing or printing directions also impact the design space: functional workspaces of an articulated robot with 6 degrees of freedom (DOF) is a proper subset of its maximum workspace (Gudla, 2012). Consequently, many processes that deploy 6-DOF articulated robots but only print vertically are mechanically subject to additional geometric constraints. Knowing constraints of such a kind in the early design stages could reduce the time-consuming iterations from design to construction.

Many AM processes have promised greater design freedom in geometry (Paolini, Kollmannsberger and Rank, 2019). Nonetheless, careful considerations are required to ensure manufacturability. Particle-bed methods can print complex overhanging structures; however, they cannot realize a closed volume with any internal cavity (Lowke *et al.*, 2018). Conversely, the maximum degrees of overhang for extrusion-based methods are usually determined by concrete's fresh state as well as planning of the print path, whereas cavities are less problematic (Carneau *et al.*, 2020). In order to seize the opportunities brought by AM technologies and reduce time-demanding design iterations, it is worth formalizing AM processes'

geometric boundary conditions and making them accessible during the early stages of architectural design.

3. Design Decision Support System for AMC

3.1. CONCEPT

The design decision support system, or DDSS, aims to assist architects and engineers in choosing appropriate AM method(s) for BIM-based architectural design. It addresses the decision-making problem by integrating the AMC knowledge into the BIM methodology, by which multiple design criteria can be evaluated to make sound decisions (Figure 1).

The AMC knowledge includes, but is not restricted to, process workflow, machine system, material, quantitative description of geometry freedom and function, as well as information about the assembly. The availability of such knowledge is enabled by *knowledge formalization*. Baumeister et al. (2009) pointed out a formalization continuum from unstructured images to logic and rule - the latter constitute an AMC knowledge base in the context of this DDSS. By demand, this knowledge base could be accessible to relevant BIM practitioners through specific SPARQL queries.

Such a DDSS is able to assess the manufacturability for a BIM-based architectural design, and a different attitude, when compared to other works, e.g., from Cao *et al.* (2022), has been held for interactive and informative decision support. Non-manufacturable geometry features, e.g., overhangs that exceed the upper bound of individual AM methods, are visualized in the BIM model as a reference for design adaptations. The MCDM algorithms would adaptively compute the ranking of applicable AM methods based on architects' preferences. Furthermore, the system is built on a closed-loop information flow. After each decision on the appropriate AM method, the relevant information is applied to the BIM model for semantic and geometry enrichment.

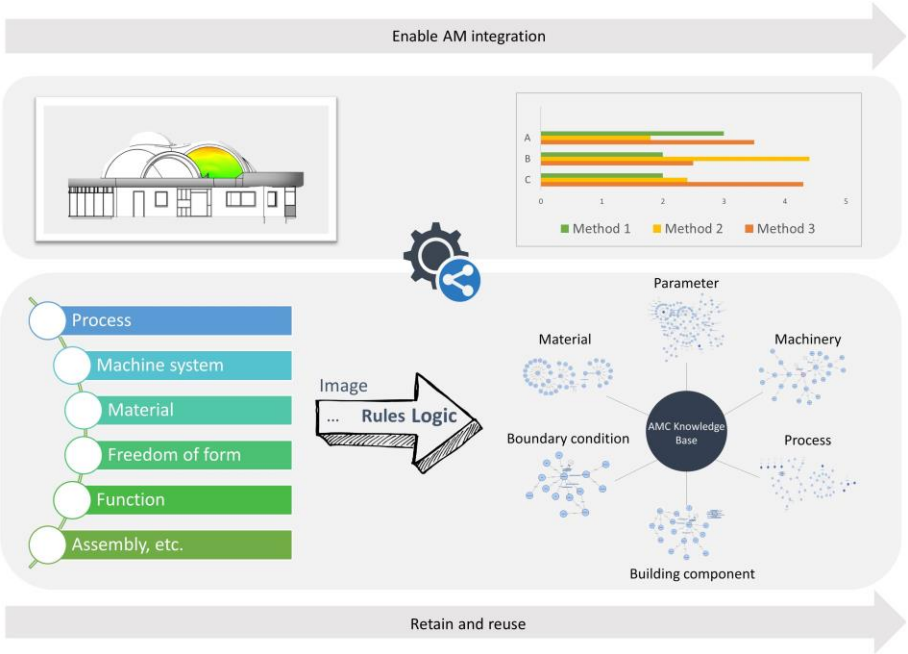

Figure 1. Schematic of Design Decision Support System

3.2. OVERVIEW OF AMC KNOWLEDGE BASE

As an integral part of the knowledge base, the AMC ontology is formalized through the processes of specification, knowledge acquisition, conceptualization, formalization, and validation (Pinto and Martins, 2004). The module dependency and concept hierarchy of the current AMC knowledge base are shown in Figure 2.

The module dependency on the left illustrates four tiers of imports from the *Parameter* module to the AMC knowledge base. The *Parameter* module arranges concepts that are used to describe different aspects of an object subjectively. These concepts are defined based on perspective or use cases rather than realism. This module consists of process parameters, e.g., layer height, water jet pressure, etc., manufacturing-feature parameters for overhang and bounding box, and material parameters ranging from mass density to mechanical strength, to name just a few. Importing this module as a backbone, properties of the material and machine systems and quantized in the second tier. Next, the *AMC Method* module incorporates the second tier for descriptions in the process-resource pattern, and *Designed Building Component* module solely imports the *Material* to reflect the design intent. All the modules are finally integrated to form the AMC ontology.

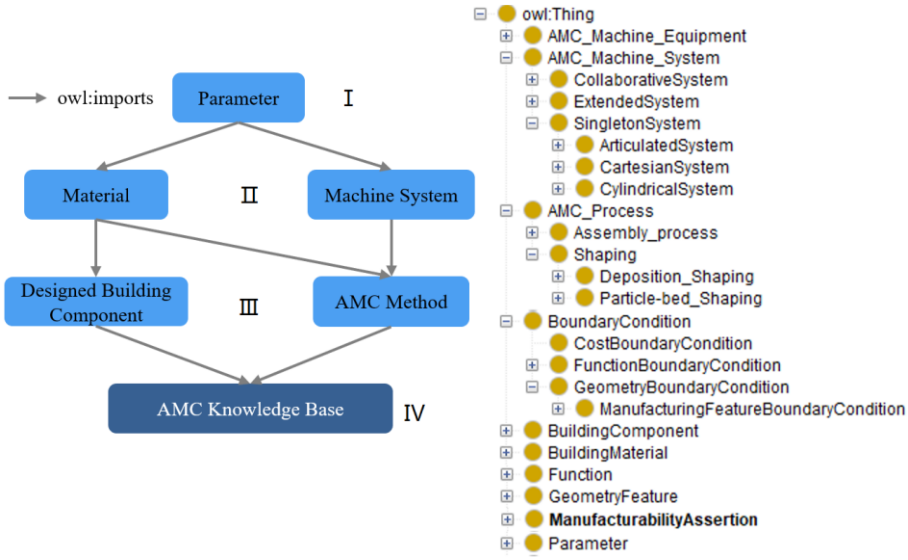

Figure 2. Dependency and Class Overview of AMC Knowledge Base

On top of the aggregated, application-level AMC ontology, restrictive design rules are made regarding the geometry, material, and functional conformities of the designed building components. As shown in the class hierarchy on the right, we formalized different boundary conditions for AM methods in terms of cost, function, geometry, etc. The designed building components will be connected to these boundary conditions through SWRL rules (see Section 3.3.3). By comparing extracted information from the BIM model against these boundary conditions, manufacturability can be asserted via the *ManufacturabilityAssertion* entity. This way, conformities of specific AM methods are attributed to individual features from the design perspective.

3.3. ACTIVITIES FOR MANUFACTURABILITY ASSESSMENT

To determine the building component's manufacturability regarding a given AM method, a list of essential activities in the DDSS has been identified: *1) extraction, 2) statement of facts, 3) reasoning, and 4) feedback.* The *extraction* activity provides semantics as well as quantized manufacturing features, which are translated into an ad-hoc data schema bridging the BIM authoring tool and the DDSS integrating a local copy of the AMC knowledge base. After that, facts are stated upon this knowledge base, followed by the *reasoning* process of AM methods' conformities. Last but not least, the deduced facts about conformities are presented on the DDSS and can be selectively visualized in the BIM environment.

3.3.1. Extraction

A BIM model embodies both geometry and semantic information. In the scope of this work, the building component's manufacturing features, material, and function information need to be retrieved or computed for further analysis. In both closed and open BIM environments, access to material and functional information via dedicated application programming interfaces (APIs) for proprietary and IFC (Industry Foundation Classes) models is relatively straightforward. Manufacturing feature extraction from geometry, however, is a synthetic problem of modeling techniques, geometry representations, algorithms in computational geometry, etc. Even more, process and machinery parameters are also input to the precise calculation of manufacturing features. For instance, the calculation of overhang degree has to consider layer height, nozzle size, and printing direction. A comprehensive study of manufacturing feature recognition is beyond the scope of this work. In the previous stage of our research, we opted to fast and trivial approximations of two manufacturing features: overhang and Oriented Bounding Box (OBB).

During the approximation of the overhang degree, we disregarded the process and machinery parameters and defined the overhang degree as a *down-sink angle per face*. From this, the solid model is triangulated into meshes and then evaluated for the overhang degrees based on individual normal directions of these faces. To track the manufacturability of these overhangs, each can be assigned a unique identifier and visualized according to their deviations from the maximum overhang value.

As to the OBB feature, the entity provided in the IFC data schema essentially represents the Axis Aligned Bounding Box (AABB), which does not necessarily fit the building component tightly (*IfcBoundingBox*) tightly, thus possibly leading to manufacturability misjudgments about dimensions. Considering the structural functions and inherent mechanical anisotropy for many AM processes, in actual cases, the prefabricated building components are rarely re-oriented from the build-up direction during assembly. To this, the OBB feature can be computed efficiently: first, all vertices of the triangulated solid are projected on the horizontal plane; afterward, the minimum-area enclosing rectangle is derived using the algorithm of *Rotating Calipers* (Toussaint, 2014); at last, such a 2D rectangle is erected to the vertical extent of the building component. By demand of the actual 3D OBB feature, one could refer to a variety of methods reviewed by Chang *et al.* (2011).

3.3.2. Statement of Facts

Facts, or assertions relating to individuals constitute the ABox of the AMC knowledge base. The original AMC knowledge base, however, does not hold

assertions for individual building components. Thinking on the frequent geometry adaptations during early design stages, neither should the knowledge base expand after each manufacturability assessment. In other words, extracted information from the BIM model should be updated in the knowledge base during assertion activity, accessed during reasoning activity, and removed after the feedback activity. These Create, Read, Update and Delete (CRUD) operations are enabled by open access APIs, e.g., OWL API (*OWLAPI - Semantic Web Standards*).

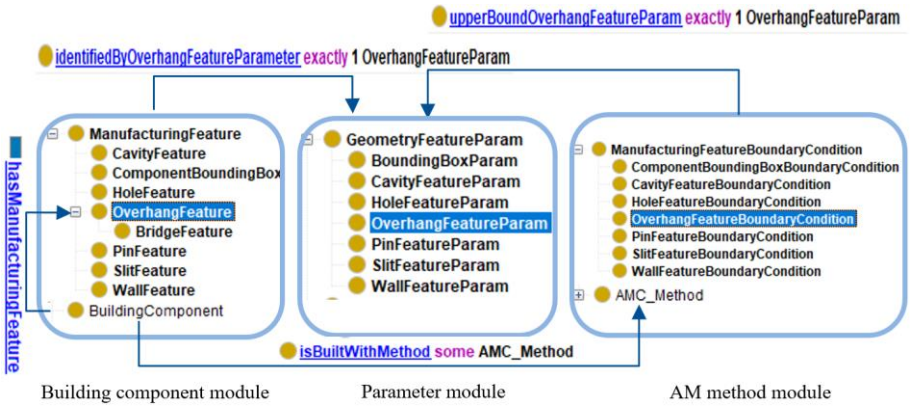

Figure 3. Classes and Object Properties for Manufacturability

There are three groups of assertions in OWL 2: class and individual assertion, object property assertion, and data property assertion (*OWL 2 Web Ontology Language*). See in Figure 3, each building component has some manufacturing features which are identified by corresponding parameters via a specific object property; further, these parameters are constrained by AM methods' boundary conditions. In each assessment, individuals for *OverhangFeature* and *OverhangFeatureParam* classes need to be created and specified (class assertion); afterward, the object property of *hasManufacturingFeature and identifiedByOverhangFeatureParameter* should associate the two newly created individuals (object property assertion). Although not shown in the figure, related data properties should assign numeric values to *OverhangFeatureParam* as well (data property assertion). Similar procedures apply to the material and function information.

3.3.3. Reasoning

Reasoning is an integrated part of Knowledge Representation and Reasoning (KR & R) to infer implicit knowledge from an explicitly defined knowledge base. To foster a practical and full-fledged decision support system, we have

ported a reasoner for manufacturability inference and future explanation functionalities.

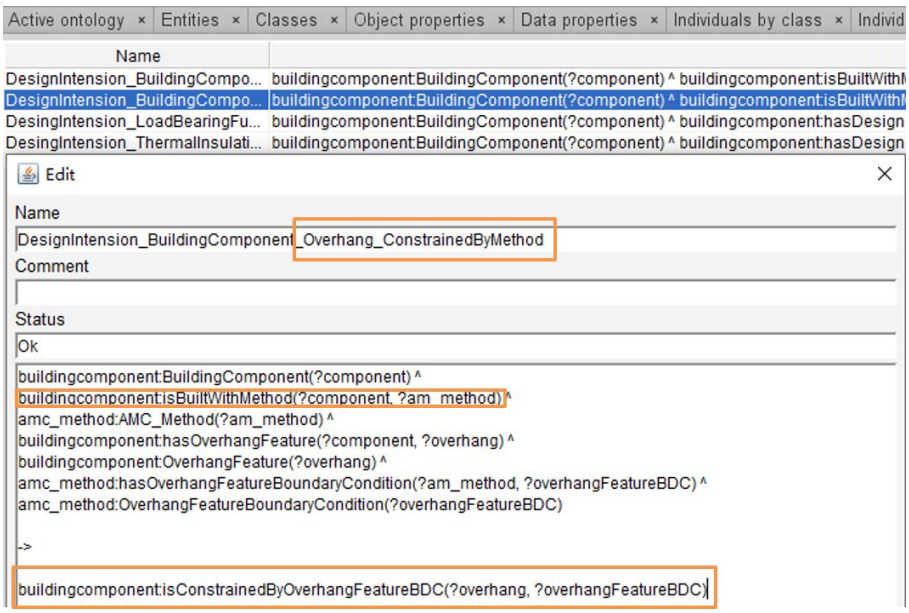

Figure 4. SWRL Rule to Apply Boundary Condition on Building Components

Khamparia and Pandey (2017) provided a comprehensive analysis of a variety of DL reasoners from multiple perspectives. On this basis, we adopted *Pellet* (*Pellet - Semantic Web Standards*) as the reasoner used by DDSS, considering technical aspects such as the expected DL expressivity (SROIQ(D)), rule-making language (SWRL) support, reasonable response time, justification capability, etc., as well as non-technical ones including availability and licensing.

On top of the updated geometry and semantic information from previous activities, the *Pellet* reasoner will apply the declared SWRL rules to relate AM methods to the building component and deduce manufacturability assertions accordingly. A designed building component is not direct output from any conceptualized AM processes; still, it can be virtually constrained and evaluated: Figure 4 demonstrates an SWRL rule that connects the overhang boundary condition of AM methods to the evaluated building component(s). Once a building component is associated with a specific AM method through the *isBuiltWithMethod* object property, the *Pellet* reasoner will be triggered, to first apply AM method's intrinsic boundary conditions on the building component, then deduce the manufacturability through numeric or type comparisons.

3.2.4. Feedback

In this activity, the DDSS should present textural and visual feedback for informed design adaptations. Inconformity between design and AM methods will be represented to both architects and domain experts during the iterative processes of architectural design. Notably, in the current stage of our research, the system only aims to facilitate rational design for AM rather than automating the design processes. To frame the design development with multiple actors, Zahedi and Petzold (2019) proposed BIM-based, minimized communication protocol and visualization tools.

As a proof-of-concept, this paper demonstrates how the manufacturability is presented on the DDSS portal and fed visually back to the BIM authoring system so that architects can reference for design adaptations.

4. Technical Framework and Use Case

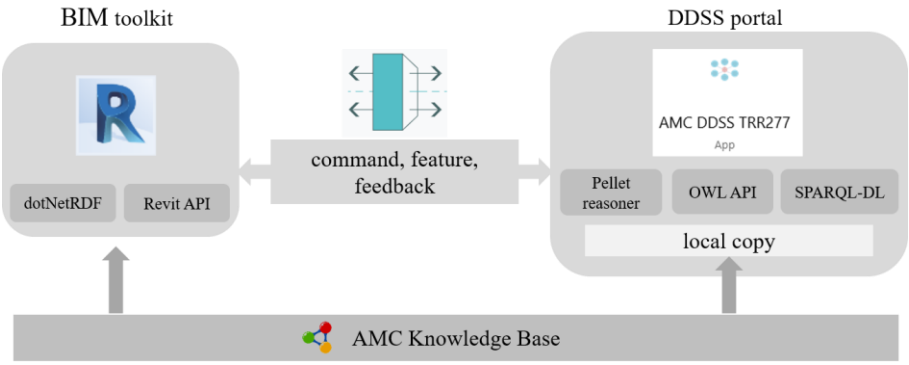

Figure 5. Technical Framework of DDSS

Figure 5 illustrates the framework of DDSS from a technical view. Basically, two functional parts - DDSS portal and BIM toolkit, are separated to deal with prescribed activities while the formalized AMC knowledge base keeps intact as a shared knowledge pool. A local copy of the knowledge base must be streamed and stored in the DDSS portal for facts assertion and reasoning activities, while the BIM toolkit is responsible for feature extraction and visualization.

To meet scalability, the DDSS portal is built as standalone software while communicating with the BIM toolkit. More in detail, the DDSS portal has ported the necessary libraries, including Pellet reasoner (*Pellet - Semantic Web Standards*), OWL API (*OWLAPI - Semantic Web Standards*), SPARQL-DL (*SPARQL-DL - Semantic Web Standards*), etc., and is deployed as an application on the Universal Windows Platform (UWP). In

addition to Revit API, BIM toolkit also integrates dotNetRDF (*DotNetRDF - Semantic Web Standards*) to retrieve parameters for feature extraction (see Section 3.3.1). The communications between the DDSS portal and BIM toolkit are enabled by remote procedure calls (*gRPC*).

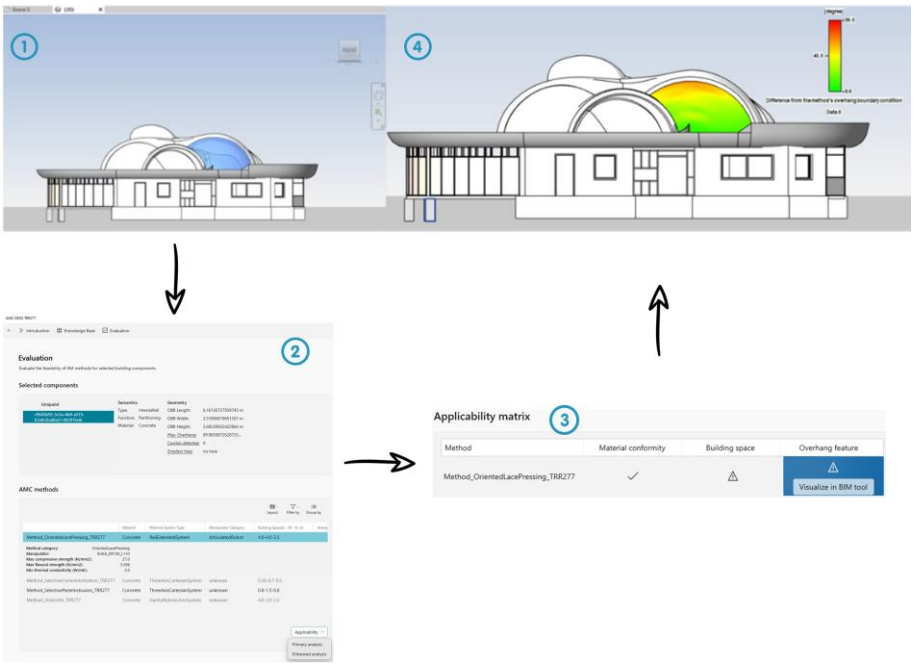

Figure 6. Building Component Manufacturability Evaluation

For BIM-based architectural design, a use case is defined as follows: an architect is about to complete the preliminary design, corresponding to the Level of Development 200 (LOD 200). At this point, the architect would like to be informed of appropriate AM methods for further analysis about cost, performance, etc. Current design may be adapted, provided that quantitative or qualitative opportunities are given.

As illustrated in Figure 6, the first step in this workflow is to select building components in the BIM authoring tool (Revit); afterward, material information and manufacturing features are retrieved and computed by the BIM toolkit, then transferred to and illustrated on the DDSS portal. The DDSS portal, meanwhile, provides a structured view of AM method's information, including material, maximum workspace, mechanical strength, etc. By choosing and evaluating a specific AM method, more features such as overhang are computed and asserted into the localized AMC knowledge base. Accordingly, the building component's manufacturability is inferred

and presented on the portal. Last but not least, visual representation of manufacturability is triggered and overlaid in the BIM model. Till now, the manufacturability of the building component is evaluated and visualized according to boundary conditions of specific AM method, and the architects are informed of visual references for design adaptation.

5. Discussion

It is worth noting that although we focused on formalizing, refining and utilizing the formal knowledge in the current stage, there is no doubt that the organization of different participants and heterogeneous digital resources contributes to better decision support in the long term. This has been discussed both in both AEC domain and other industries (Carrillo and Anumba, 2002) (Fakhar Manesh *et al.*, 2021).

Regarding the ontology structures shown in Figure 2, one might question why the AM method module (named as *AMC Method)* does not import the building component module (*Designed Building Component)* as product in the prevailing resource-process-product pattern followed by other ontologies (Cao, Zanni-Merk and Reich, 2019). We defense from two aspects: first, till now, BIM-based design is not yet able to embrace the fabrication information from different AM methods. In this regard, we look forward to filling this gap through the fabrication information model which is now under research (Slepicka, Vilgertshofer and Borrmann, 2021); second, as mentioned in Section 2.2., architectural design space is influenced by many intra- and inter-process uncertainties in both time and spatial regions. Without aligning to one of the so-called upper ontologies it would be inefficient and error-prone to enhance the current knowledge base to a more comprehensive level (Ocker, Paredis and Vogel-Heuser, 2019). Currently, such an alignment is still under work.

6. Conclusion

This paper introduces the concept of the DDSS that utilizes formal AMC knowledge to foster a manufacturing-aware architectural design. In particular, it depicts the holistic workflow for manufacturability evaluation from feature extraction to visualization. We believe that this work will be the foundation of future extensions, including MCDM approaches, simulation tools and feedback mechanism on a communication basis.

We are aware that formal knowledge is only capable to embody explicit rather than tacit knowledge which is pervasive during the design stages. In

the future, we will envision a knowledge management system that integrates different knowledge types and heterogeneous digital resources to greatly improve the design decision support for AM technologies, thus promoting sustainable development in the AEC domain.

Acknowledgements

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A HYBRID APPROACH BASED ON BUILDING PHYSICS AND MACHINE LEARNING FOR THERMAL COMFORT PREDICTION IN SMART BUILDINGS

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Abstract. One of the most important challenges facing the world is the application of modern technology in order to create smart buildings that achieve sustainable development goals (SDGs). Thermal comfort and reduction of energy consumption in buildings are considered important factors which, in turn, are reflected in creating a healthy environment and improving human productivity. Internet of Things (IoT) provides an ideal solution for collecting real-time data on the factors affecting indoor thermal comfort and energy consumption. However, comfort level is subjective and depends on many factors, which may not be learned by conventional models, an integrated model depending on thermal comfort factors is needed. In this work, a hybrid physics-based model incorporated with machine learning techniques is used for the prediction of thermal comfort inside buildings. XGBoost (eXtreme Gradient Boost) algorithm method was used due to its abilities to handle complex problems. A calculated dataset was extracted from the physics-based model gathered with the environmental variables data such as humidity, moisture, temperature, and air velocity collected from IoT devices. The results show an improvement in the prediction of the thermal comfort approach as compared with the conventional models. The XGBoost algorithm can exhibit an effective solution for eliminating deficiencies of traditional models and can be used when designing smart buildings, simulating, and evaluating the designed buildings, controlling energy consumption, and achieving thermal comfort.

A HYBRID APPROACH BASED ON BUILDING PHYSICS AND MACHINE LEARNING FOR THERMAL COMFORT PREDICTION IN SMART BUILDINGS

Keywords: *Thermal comfort, machine learning XGBoost, Smart buildings, building physics, IoT.*

ملخص. من أهم التحديات التي تواجه العالم تطبيق التكنولوجيا الحديثة من أجل إنشاء مبانٍ ذكية تحقق أهداف التنمية المستدامة. وتعتبر الراحة الحرارية وتقليل استهلاك الطاقة في المباني من العوامل المهمة التي تنعكس بدورها على خلق بيئة صحية وعلى تحسين إنتاجية الإنسان. يوفر إنترنت الأشياء (IoT) حلاً مثاليًا لجمع البيانات بطريقة متزامنة حول العوامل التي تؤثر على الراحة الحرارية الداخلية واستهلاك الطاقة. ولكن مستويات الراحة لا تقاس بشكل موضوعى وتعتمد على العديد من العوامل، والتي قد لا تتعلمها بالضرورة النماذج الحوسبية التقليدية. ولذا تظهر هنا الحاجة إلى نموذج متكامل يعتمد على عوامل الراحة الحرارية. تم فى هذا البحث استخدام نموذج هجين قائم على الفيزياء مدمج مع تقنيات التعلم الآلي للتنبؤ بالراحة الحرارية داخل المباني. تم استخدام طريقة خوارزمية XGBoost (eXtreme Gradient Boost) نظرًا لقدرتها على التعامل مع المشكلات المعقدة. تم استخراج مجموعة بيانات محسوبة من النموذج القائم على الفيزياء التي تم جمعها مع بيانات المتغيرات البيئية مثل الرطوبة ودرجة الحرارة وسرعة الهواء والتي تم جمعها عن طريق أجهزة إنترنت الأشياء. تظهر النتائج تحسنا في التنبؤ بنهج الراحة الحرارية مقارنة بالنماذج التقليدية. يمكن أن تعرض خوارزمية XGBoost حلاً فعالاً لإزالة أوجه القصور في النماذج التقليدية ويمكن استخدامها عند تصميم المباني الذكية ومحاكاة وتقييم المباني المصممة والتحكم في استهلاك الطاقة وتحقيق الراحة الحرارية.

الكلمات المفتاحية: *الراحة الحرارية، التعلم الآلى XGBoost، المبانى الذكية، فيزياء المبانى، انترنت الأشياء.*

1. Introduction

One of the challenges facing creating smart buildings with respect to climate change that prevails in the world is achieving thermal comfort inside the building in addition to conserving energy during use (Calama-González, León-Rodríguez and Suárez, 2022). Smart educational buildings are considered one of the most construction systems that need thermal comfort during the presence of workers and students, which helps to study and focus better (Balbis-Morejon and Noya-Sambrano, 2020).

These smart buildings need advanced systems to monitor the change in the physical properties that affect the thermal comfort inside the buildings. Physical properties such as temperature, humidity, air flow velocity, and carbon dioxide ratio are among the most important factors that affect thermal comfort and energy conservation in smart buildings (Majewski et al., 2020).

The use of IoT devices which is already supported by sensors to measure changes in these factors inside buildings has become a necessity, as it can collect a lot of information throughout the day and during periods of temperature and energy usage peak (Zang, Xing and Tan, 2019). Managing this huge amount of data is one of the most important requirements in order to reach the optimal use of energy and achieve thermal comfort within smart buildings.

Physics-based modeling algorithms require significant computing resources and are not suitable for fast predictions. Machine learning is

considered as one of the best ways to manage complex processes and link different physical variables in order to help make a decision to achieve indoor thermal comfort (Qavidel Fard, Zomorodian and Korsavi, 2022).

Different Techniques such as Support Vector Machine (SVM), Artificial Neural Network (ANN), and random forests (RF), decision trees (DT), genetic and Logistic Regression method (LoR), Gradient boosting (GB) and eXtreme Gradient boosting (XGBoost) are used due to their abilities to handle complex problems.

Machine learning models could generate linear equations, and with the reduced number of attributes, the predictive ability will only decline. At the same time, XGBoost, method could potentially be improved with parameter tuning. And so, this study focuses on design an optimised thermal comfort model in educational buildings based on IoT monitoring sensors and hybrid parameters of the physics based and XGBoost machine learning model. The physics-based part can make estimate thermal comfort based on physics equations that builds forecasting to map the parameters that affect the thermal comfort in buildings. XGBoost Algorithm was ran using Mathematica wolfram 13.1 software which can make a correlation between theses parameters and provide a time conserved solution during these complex processes.

2. Method

2.1. OVERALL STRUCTURE OF THE MODEL

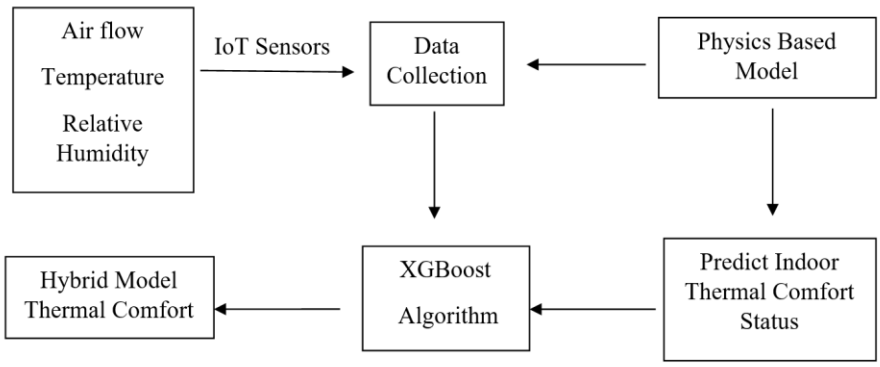

Figure 1. The hybrid physics-based/ML model.

The hybrid model consists of the physics based and ML part. By integrating these two parts, the developed model can take both advantages of the physics-based method and ML method.

2.1.1 Data set

The studied data set was taken from the indoor monitoring system containing IoT sensors. The system offers an inexpensive way of monitoring the indoor environment with wifi sensors able to make real time monitoring of temperature, humidity, CO2, air flow velocity, room occupancy and light levels. The data set collected every minute during the educational day in 8 hours for three selected variables. The monitoring system was installed in the walls of the classroom. The duplicates were first isolated from the dataset. The procedure of duplicates removal was performed with the use of Python 3.10.5.

2.1.2 IoT System

The 9-wall mounted IoT devices are used to provide a real time information about different parameters that affect indoor thermal comfort in educational building Fig 2. The Data process are gathered through three layers as follow:

1. Perception layer: In this layer the IoT sensors can record the information about indoor humidity, temperature, and air velocity.
2. Network layer: The gateway devices are responsible for data routing from the previous layer.
3. Cloud layer: In this layer the data was collected, and the analysis would take place. The aggregated data that stored in this layer is a real time monitoring data. The visualization and statistics would help in taking the best decision through the statistics provided from this layer.

Figure 2. Educational classroom that used in this study

2.1.3 Extreme gradient boosting (XGBoost)

XGBoost is a type of machine learning algorithms that used as a supervised learning technique due to its efficiency and faster learning process through an ensemble algorithm based on gradient boosted trees (Chen and Guestrin, 2016).

The loss function related to XGBoost provides an additional regularization term that contributes to smoothing the final learning weights and reducing the probability of overfitting. It also considers gradients up to the second order to optimize the loss function. Additionally, in order to avoid overfitting problems, XGBoost also handles row and column sampling (Wang et al., 2021). The following paragraphs explain how this algorithm works.

XGBoost integrates predictions of "weak" classifiers (tree model) to achieve a "strong" classifier (tree model) via a serial training process. It can avoid over-fitting by adding a regularization term. Parallel and distributed computing makes the learning process faster to give a quicker modeling process. Figure 3 shows a schematic diagram of the computational process of XGBoost and y_i appeared in the process is calculated by Equation 1.

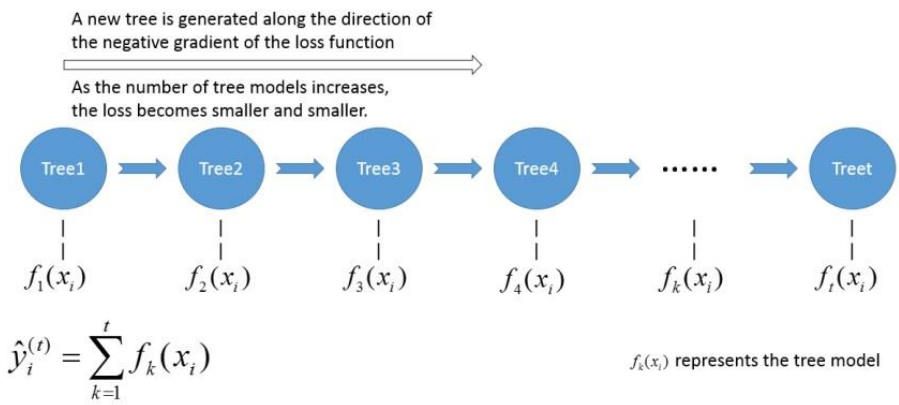

Figure 3. A schematic diagram of XGBoost computational Process

$$\hat{y}_i^{(t)} = \sum_{i=1}^{t} \boldsymbol{f_k(x_i)} = \hat{y}_i^{(t-1)} + \boldsymbol{f_t(x_i)} \quad (1)$$

where, $\hat{y}_i^{(t)}$ is the final tree model; $\hat{y}_i^{(t-1)}$ is the previously generated tree model; $\boldsymbol{f_t(x_i)}$ is the newly generated tree model, and *t* is the total number of base tree models. For the XGBoost algorithm, both depth and number of trees are important parameters. The problem of finding the optimal algorithm was

changed into finding a new classifier that can reduce the loss function, with the target loss function shown in Equation 2

$$Obj^t = \sum_{i=1}^{t} L(\, y_i, \hat{y}_i^{(t)}) + \sum_{i=1}^{t} \Omega(f_i) \qquad (2)$$

where, y_i is the actual value; $\hat{y}_i^{(t)}$ is the predicted value; $L(\, y_i, \hat{y}_i^{(t)})$ is the loss function and $\Omega(f_i)$ is the regularization term.

Substituting Equation 1 into Equation 2 and then following some deduction steps, Equation 3 could be obtained

$$Obj^t = \sum_{i=1}^{t} L(\, y_i, \hat{y}_i^{(t-1)} + \boldsymbol{f_t}(\boldsymbol{x_i})) + \Omega(f_t) + Constant \qquad (3)$$

The final target loss function was then converted into Equation 4, and the model was then trained according to this target loss function.

$$Obj^t = \sum_{i=1}^{t} [g_i \boldsymbol{f_t}(\boldsymbol{x_i}) + \frac{\mathbf{1}}{\mathbf{2}} \boldsymbol{h_i} \boldsymbol{f_t^2}(\boldsymbol{x_i})] \; + \Omega(f_t) \qquad (4)$$

Where $g_i = \partial_{y_i^{(t-1)}}\, l(\, y_i, y_i^{(t-1)})$, $h_i = \partial^2{}_{y_i^{(t-1)}}\, l(\, y_i, y_i^{(t-1)})$ are the first and second order gradient statistics on the loss function.

The regularization term $\Omega(f_t)$ is calculated by Equation 5 to reduce the model's complexity and also improve its usability to other datasets.

$$\Omega(f) = \boldsymbol{\gamma}\, \mathbf{T} + \frac{1}{2}\boldsymbol{\lambda} + \|\omega\|^2 \qquad (5)$$

where, T is the number of leaves; ω is the weight of the leaves; λ and γ are coefficients,
with default values set as λ=1, γ=0.
The XGBoost algorithm can accept both continues variables and discrete variables as inputs but the output variable has to be discrete, including binary variables. In this study, the XGBoost algorithm was ran in Mathematica wolfram 13.1 software. When using the XGBoost algorithm, Z-statistic is often used for testing the significance of each independent variable, with p-value given at 95% confidence interval. It is calculated and given by the computational package after running the XGBoost algorithm.

2.2. ERROR MEASUREMENTS

Normalised Mean Bias Error (NMBE) and the Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) are used as a validation metrics to evaluate the accuracy of the XGBoost model (Eguía-Oller *et al.*, 2021).

$$NMBE = 100 * \frac{\sum_{i=1}^{N}(y_i - \hat{y}_i^{(t)})}{\sum_{i=1}^{N}(y_i)} \quad (6)$$

$$\mathrm{CV(RMSE)} = 100 * \frac{SQRT(\sum_{i=1}^{N}(y_i - \hat{y}_i)^2)}{\sum_{i=1}^{N}(y_i)} \quad (7)$$

3. Results

Figure 4 shows the change in indoor temperature and relative humidity during the period between March 2021 and October 2021 in the educational building. The temperature increases and reach the maximum level at summer.

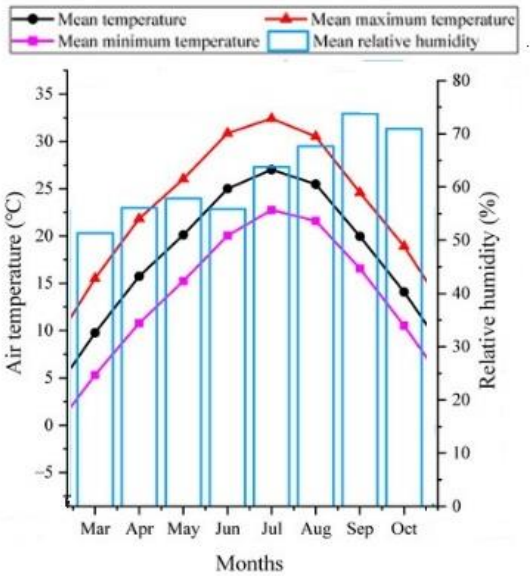

Figure 4. Temperature and relative humidity as measured inside the classroom

The XGBoost model consists of a lot of parameters that must be taken into consideration. These parameters are

● "n_estimators": the number of base tree models, the higher the number of iterations, the higher the value;

● “max_depth”: the maximum depth of the base tree model, with a higher value for more complex base tree models;
● ‘gamma”: the minimum loss reduction required to divide further on the leaf nodes of the tree, with higher values for more conservative models;
● “subsample”: the subsample rate of the training instances.
In Table 1 the tuned parameters and evaluation metrics from the XGBoost model are presented after construction.

TABLE 1. The mean NMBE, CV(RMSE), standard deviations (SDs). and computation time (in seconds), needed to train each of the models

Model	Variables	Regression trees	NMBE [%]	SD	CV(RMSE) [%]	SD	Computational time [sec]	R^2
Physics based	Air Velocity	120	-2.185	7.61	10.43	4.68	2.02	0.93
	Temperature	400	-1.09	2.81	4.57	1.59	5.21	0.91
	Relative humidity	440	0.075	4.52	5.98	2.76	7.31	0.92
Hybrid	Air velocity	120	-2.20	7.33	8.74	4.44	0.91	0.99
	Temperature	400	0.163	3.78	4.47	1.66	0.81	0.99
	Relative humidity	440	0.88	4.37	5.66	3.14	0.92	0.99

According to the results shown in the table and Figure 5, the hybrid model maintains a relative reduction in errors with a slight change in the results between the two models, in a faster processing time for arithmetic operations than the traditional model

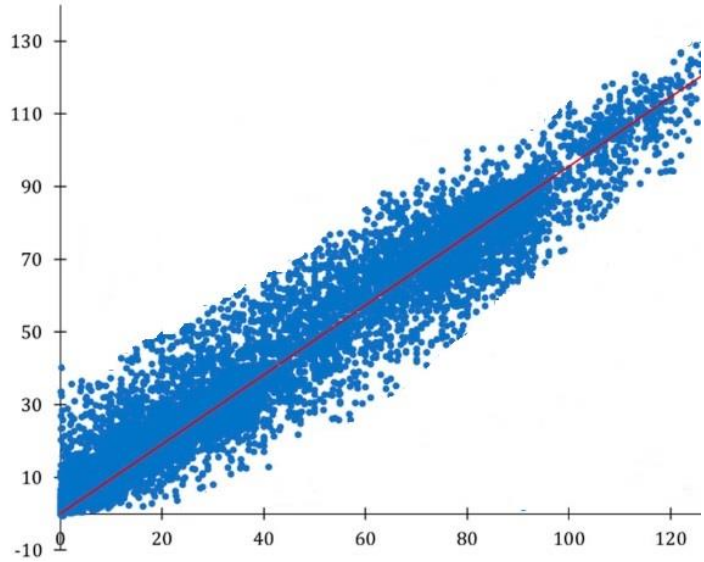

Figure 5. True value (x-axis) vs. predicted value (y-axis) plot for optimized XGBoost

4. Conclusions

An optimized model consists of two sections, an application of physics-based model for prediction of thermal comfort and a hybrid integrated model for thermal comfort real time calculation using IoT devices within an educational building using XGBoost algortithm can monitor the indoor thermal comfort variables. The results show that the model can accurately predict the indoor environmental parameters. The Error measurements in the three variables was below 5% for temperature, below 6% for relative humidity and below 9% for air flow with very low computational times. This indicate that the hybrid model could be an effective one to help the end user in decision making.

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URBAN MAP GENERATION IN ARTIST'S STYLE USING GENERATIVE ADVERSARIAL NETWORKS (GAN)

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Abstract. Artificial Intelligence is a field that is able to learn from existing data to synthesize new ones using deep learning methods. Using Artificial Neural Networks that process big datasets, complex tasks and challenges become easily resolved. As the zeitgeist suggests, it is possible to produce novel outcomes for future projections by applying various machine learning algorithms on the generated data sets. In that context, the focus of this research is exploring the reinterpretation of 21st century urban plans with familiar artist styles using different subtypes of deep-learning-based generative adversarial networks (GAN) algorithms. In order to explore the capabilities of urban map transformation with machine learning approaches, two different GAN algorithms which are cycleGAN and styleGAN have been applied on the two main data sets. First data set, the urban data set, contains 50 cities urban plans in .jpeg format collected according to the diversity of the urban morphologies. Whereas the second data set is composed of four well-known artist's paintings, that belong to various artistic movements. As a result of training the same data sets with different GAN algorithms and epoch values were compared and evaluated. In this respect, the study not only investigates the reinterpretation of stylistic urban maps and shows the discoverability of new representation techniques, but also offers a comparison of the use of different image to image translation GAN algorithms.

URBAN MAP GENERATION IN ARTIST'S STYLE USING GENERATIVE ADVERSARIAL NETWORKS (GAN)

Keywords: *Urban Map, Style Transferring, Generative Adversarial Networks, CycleGAN, StyleGAN.*

ملخص. يعتبر الذكاء الاصطناعي مجالا قادرا على التعلم من البيانات الموجودة لتجميع بيانات جديدة باستخدام أساليب التعلم العميق. ويمكن حل المهام والتحديات المعقدة بسهولة باستخدام الشبكات العصبية الاصطناعية التي تعالج مجموعات البيانات الكبيرة. كما تقترح روح العصر، من الممكن إنتاج نتائج جديدة للتوقعات المستقبلية من خلال تطبيق خوارزميات التعلم الآلي المختلفة على مجموعات البيانات التي تم إنشاؤها. في هذا السياق، ينصب تركيز هذا البحث على استكشاف إعادة تفسير المخططات الحضرية للقرن الحادي والعشرين بأساليب فنية مألوفة باستخدام أنواع فرعية مختلفة من خوارزميات شبكات الخصومة التوليدية القائمة على التعلم العميق (GAN). من أجل استكشاف إمكانات تحويل الخرائط الحضرية باستخدام مناهج التعلم الآلي، تم تطبيق خوارزميتين مختلفتين من GAN وهما cycleGAN و styleGAN على مجموعتي البيانات الرئيسيتين. تحتوي مجموعة البيانات الأولى، وهى مجموعة البيانات الحضرية ، على ٥٠ مخططًا حضريًا لمدن فى ملفات jpeg تم جمعها وفقًا لتنوع الأشكال الحضرية. بينما تكونت مجموعة البيانات الثانية من أربع لوحات لفنانين مشهورين تنتمي إلى حركات فنية مختلفة. نتيجة لتدريب نفس مجموعات البيانات مع خوارزميات GAN المختلفة وقيم العصر تمت مجموعة من المقارنات والتقييمات. وفي هذا الصدد، لا تبحث الدراسة فقط في إعادة تفسير الخرائط الحضرية الأسلوبية وتظهر قابلية اكتشاف تقنيات التمثيل الجديدة، ولكنها تقدم أيضًا مقارنة بين استخدام خوارزميات GAN لترجمة الصور المختلفة.

الكلمات المفتاحية: *الخرائط الحضرية، نقل الأنماط، شبكات الخصومة التوليدية، الشبكات التوليدية القائمة على الدورات، الشبكات التوليدية القائمة على الأنماط.*

1. Introduction

The mass of information brought by the development of information and communication technologies can be easily processed and manipulated with artificial intelligence (Boden and Edmonds,2009). In this way, data can be used as design input, and unexpected situations and new forms of representation can arise. This paper presents an approach that uses Generative Adversarial Networks (GAN) algorithms to generate and transfer artist style to interpreted urban maps as a generative representation method.

Artists produce artworks in many corners of the cities they live in, or they visit. However, many of them have not found a chance to express the plan of that city with their own style. One aspect of this work within the scope of the machine learning exploration is to show what a city plan would look like if it were tried to be represented in the style of an artist. Since besides the conventional visualization tools, machine learning has a great potential to be used in the research area of cultural and architectural heritage for understanding the built environment in the digital realm with the idea of inserting new interpretations to the existing urban map characteristics

(Tamke et al, 2018). However, it significantly important to highlight the limits of the scope of the research in terms of as generation method of the visual mediums, to avoid any misinterpretations and speculations that might be associated urban morphological and planning studies, which requires broad investigations to make a statement.

As presented in the future sections of the paper, the proposed method of machine learning explorations has clear boundaries for to create a digital map collection of contemporary urban plans in the styles of the well-known artists from variety of artistic movements. Thus, it could be further used in multi-media environments as a dataset collection to identify and highlight various urban features and characteristics through various styles of the artists. Although it is possible to see such studies in this field in the literature of architectural visualization and representation, there is no precedent study on the urban map generation in the styles of various artistic movement through the exploration of machine learning methods and tools.

Another aspect of this study is to emphasize and explore the diversity that occurs when different image2image translation GAN algorithms. Different epoch and batch values have been tested in this exploration for the representation. All machine learning models have been trained on the Google Colab, thanks to the availability of a higher Graphics Processing Unit (GPU) as an advantage of cloud computing. Generative adversarial network (GAN) model framework has been selected as the generation method for this research since it is designed to learn and generate image data, that neural networks may produce fictitious and high-quality data (Goodfellow et al. 2014). In GAN, one algorithm generates, the other evaluates, and the cycle continues until the discriminator no longer distinguishes the image that can be produced by Generator as real or fake. In this research, two different GAN algorithms of of cycleGAN and styleGAN have been trained with five different data sets to evaluate their potentials for stylistic urban map projections. In order to increase the diversity of the work, 4 different artist's data sets were generated. The dataset belonging to the urban maps was obtained manually from the Snazzy Maps platform, and the other four datasets belonging to the artists were taken from the data provided by Berkeley AI Research as open source (Berkeley AI Research, 2022). The results of running the same data sets with different GAN algorithms and epoch values were compared and evaluated. In this respect, the study not only shows the discoverability of new representation forms but also offers a comparison of the use of different algorithms. The discussion includes generative adversarial networks, dataset creation, and results.

1.1. ABOUT THE GENERATIVE ADVERSARIAL NETWORKS

A Convolutional Neural Network (CNN) is a Deep Learning system that can take an input image, assign relevance such as learnable weights, biases, and etc. to various aspects/objects in the image, and distinguish between them (Saha, 2018). When compared to other classification methods, the amount of pre-processing required by a CNN is significantly less. Through the application of suitable filters, a CNN is able to capture the spatial and temporal dependencies in an image (Saha, 2018). Because of the reduced number of parameters involved and the reusability of weights, the architecture performs superior fitting to the picture dataset. To put it another way, the network can be trained to recognize the image's sophistication. When Convolutional Neural Networks are trained on object recognition, they build an image representation that becomes increasingly explicit as the processing hierarchy progresses (Gatys et al 2015). As a result, as the network's processing hierarchy progresses, the input image is transformed into representations that care more about the image's real content than its exact pixel values.

In machine learning, generative modeling is an unsupervised learning task that entails automatically detecting and learning regularities or patterns in input data so that the model may be used to produce or output new examples that could have been drawn from the original dataset (Brownlee, 2019). . These GANs generate new images using image inputs rather than a random data distribution as a source. Style transfer, colorizing, in painting, super resolution, future state prediction, object transfiguration, photo editing, enhancement, pose morphing, data augmentation, and many more areas of machine learning and computer vision can all be addressed by image-to-image GANs (Saxena and Teli, 2021). The GAN model architecture involves two sub-models: a generator model for generating new examples and a discriminator model for classifying whether generated examples are real, from the domain, or fake, generated by the generator model (Hui et al, 2018). The CycleGAN is an extension of the GAN architecture that involves the simultaneous training of two generator models and two discriminator models. The first generator receives photos from the first domain and creates images for the second domain, while the second generator takes photographs from the second domain and generates images for the first domain (Brownlee, 2019). The generator models are then updated using discriminator models to judge how realistic the generated images are.

The StyleGAN's GAN architecture differs from the CycleGAN by the inherent generator model. The generators implemented in the styleGAN architecture uses a mapping network to map points in latent space to an intermediate latent space. Thus, the intermediate one can control the

generated style at each point, and it introduces the noise as a source of variation at each point as well in the generator model (Amirian et.al. ,2021).

2. Collecting and Processing the Datasets

For the purposes of this research, two different types of data sets have been collected: First the urban data set that consists of manually collected 1000 map images from 50 cities. Secondly, the artists' paintings data sets that have been separately constituted for the training process of the algorithms in terms of Van Gogh, Cézanne, Monet, and Ukiyoe from the CycleGan data repository.

2.1. URBAN DATASET

For the Urban dataset generation, the base map template had been created using the Snazzy Maps website, which allows user to define their own style for the maps, by using the Google Maps data. From the interface, 1000 map images have been collected without labels or signs and have low contrast and saturation values. The location of each map was chosen from different characterized urban morphologies on purpose, to see variety of urban characters under various artist styles. Therefore, we have manually collected 20 map images from 10 countries' 5 most populated cities, from Europe, Asia, North and South America (Table 1). The original images were 1920*1080 pixels, therefore a batch resizing and cropping processing operations have been applied. In order to maintain the images into 256*256 pixel sizes by keeping the aspect ratio, which approximately shows a 10,2 km2 area, by Python code using Numpy and PIL libraries. In the end, we have generated an urban dataset that contains 1000 images in suitable pixel size, RGBA color mode, and .png format. Examples of this data set (2%) can be seen from Figure 1 (Fig.1). The data have separated into train_urban and test_urban folders that the train_urban folder contains 80% of the total data, whereas test_urban has %20 which equals 200 map images.

TABLE 1. *The location of the map images that constitutes the urban dataset*.

Country	Cities
Turkey	Istanbul, Ankara, İzmir, Bursa, Antalya
Germany	Berlin, Hamburg, Cologne, Munich, Stuttgart
Italy	Florence, Genova, Milan, Naples, Rome
Spain	Barcelona, Bilbao, Madrid, Sevilla, Valencia
Netherlands	Amsterdam, Eindhoven, Maastricht, Rotterdam, Utrecht
Brazil	Brasilia, Fortaleza, Rio de Janeiro, Salvador, Sao Paulo
Japan	Hiroshima, Kyoto, Nagasaki, Osaka, Tokyo
Russia	Kazan, Moscow, Novosibirsk, Samara, St. Petersburg
U.S.A	Boston, Chicago, Los Angeles, Miami, New York City
Egypt	Alexandria, Aswan, Cairo, Luxor, Sharm El-Sheikh

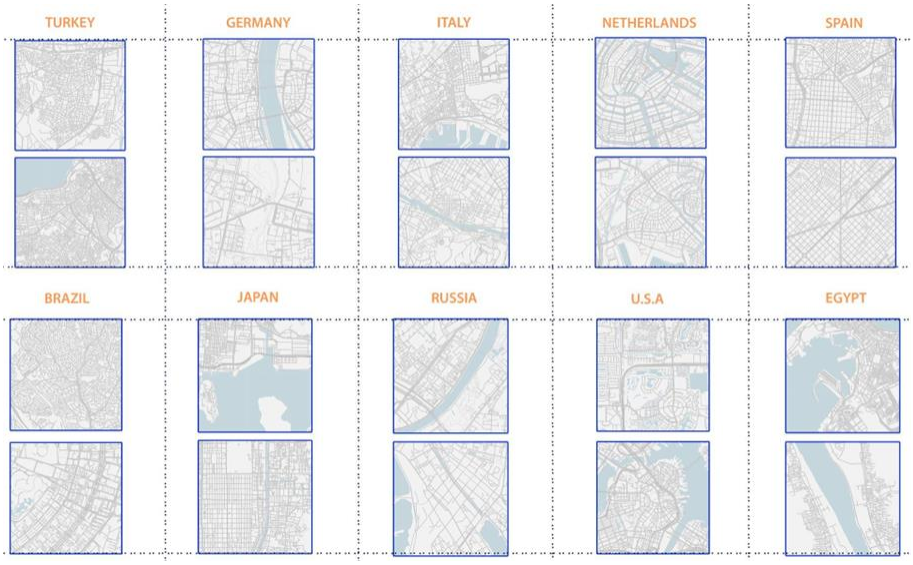


Figure 1. Urban Dataset example map images from 10 different countries

2.2. ARTIST PAINTINGS DATASET

In order to apply different artist styles to urban layouts, we collected datasets from the CycleGAN repository. The selection criteria for the artist's painting besides the availability issue of the data was the artistic movements that they are belong in to.

The art works of well-known pioneer artist of the Impressionism, who were Van Gogh, Monet, Cezanne, has been included in the data sets; whereas Ukiyo-e's paintings has been consciously added to data set from the Japonisme style, which has strong connections and influence on

impressionism, in order to embrace the complexity within the dataset. The selection of the impressionist artworks was critical at that point of the research, since the movement pioneers generally depicts the landscape and the contemporary life by capturing the rapid pace of contemporary life and the fleeting conditions of light (Nesic, 2022). Thus, that kind of constant transformation represented on the artworks has been elaborated conceptually as in a similar manner of the urban fabric, which is constantly subjected to the alterations within different time frames.

All painting dataset containing the artworks of the artists mentioned above have been subjected to a series of batch image processing operations, to maintain 256*256 pixels, in RGB color mode, jpg formatted images. Each of the datasets had been separated into train and test folders likewise the urban dataset. The examples from the artists' datasets can be seen in Figure 2 (Fig.2).

Figure 2. Artist dataset examples and the total number of images contained in each dataset

3. Training the GAN Models: CycleGAN & StyleGAN

3.1. CYCLEGAN

The CycleGAN is a technique that involves the automatic training of image-to-image translation models without paired examples and unsupervised learning is used to train the models using a set of images from the source and target domains that can be unrelated (Brownlee, 2019). The system can learn to capture features of one image collection and find

methods to translate these features to other image collection in the absence of paired training examples (Chen et al., 2019). Cycle consistency is a further feature to the architecture that is used by the CycleGAN which is the idea that an image produced by the first generator may be utilized as the input for the second generator, whose output must resemble the original image and the output of the second generator may be fed into the first generator as input, and the output should equal the second generator's input (Zhu, et al., 2020). By including an extra loss to calculate the difference between the output of the second generator and the original image, and vice versa, the CycleGAN promotes cycle consistency. As a result, the generator models are regularized, directing image production in the new domain in the direction of image translation (Brownlee, 2019).

3.1.1. Van Gogh to Map & Map to Van Gogh

To test the model, the model initially trained with 60 epochs on the Google Colab platform. After the generation of first sample images and plotting the discriminator losses on the chart (Figure 3), the application continued by training it with 6000 epochs values.

For both applications the hyper parameters had been set the same as LR (Learning Rate) = 0.0002; Batch Size =16, except the epoch number. However, while training the model with 6000 epochs, we faced an interruption in the 5560th epoch due to the working time issue of Google Colab. The total, discriminator, and generator loss values, in the 10th and 5560th epochs of the application, are:

Epoch [10/ 6000] | d_X_loss: 0.4649 | d_Y_loss: 0.5561 | **g_total_loss: 10.3906**

Epoch [5560/ 6000] | d_X_loss: 0.1041 | d_Y_loss: 0.1751 | **g_total_loss: 3.6625**

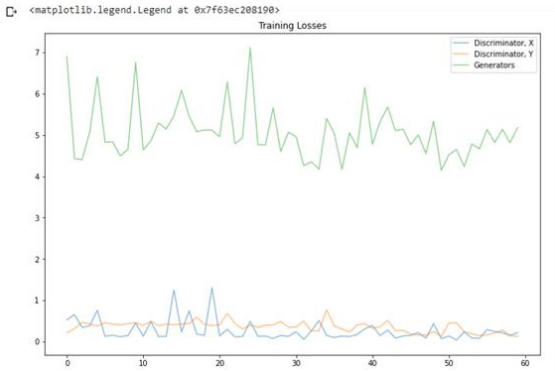


Figure 3: Training Losses with 60 epochs

The outputs of the training with 100th epoch and 5500th epoch can be seen below for both maps to painting (Figure 4 a & b), and paintings to map (Figure 5 a & b) applications.

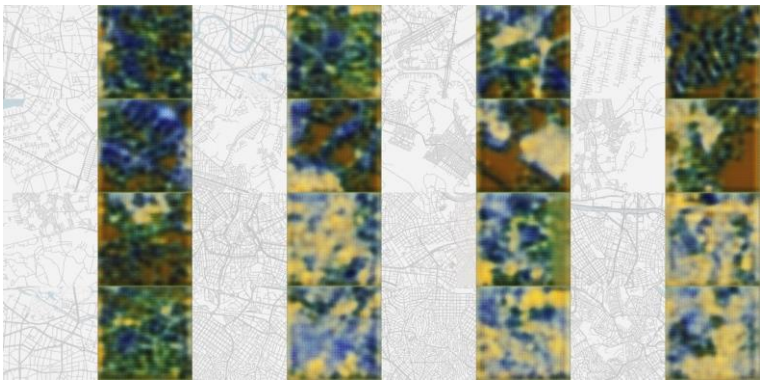


Figure 4 (a): Map to Van Gogh Painting 100th epoch

Figure 4 (b) : Map to Van Gogh Painting 5560th epoch

Figure 5(a): Van Gogh Painting to Map 100th epoch

Figure 5(b): Van Gogh Painting to Map 5560th epoch

3.1.2. Monet to Map & Map to Monet

Likewise, in Van Gogh's paintings application, the model was first trained with 100 epochs for the first trial. Then we have trained our model using the same hyper parameters as the previous application, but this time with a smaller number of epochs of 4000, to see the difference in between. The discriminator and total losses of the 10th and 4000th are:

Epoch [10/ 4000] | d_X_loss: 0.0395 | d_Y_loss: 0.4869 | **g_total_loss: 5.2189**
Epoch [4000/ 4000] | d_X_loss: 0.2004 | d_Y_loss: 0.2249 | **g_total_loss: 3.2786**

The output images for both Monet map to painting (Figure 6 a & b) , and painting to map (Figure 7 a & b) can be seen from as well as the loss chart in Figure 8.

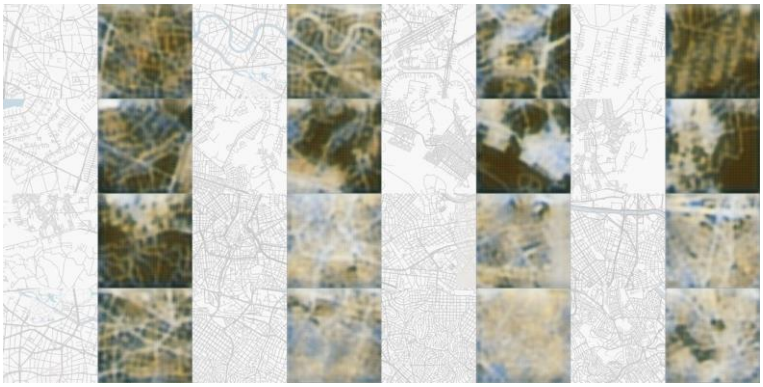


Figure 6(a): Map to Monet Painting 100th epoch

Figure 6(b): Map to Monet Painting 4000th epoch

Figure 7(a): Monet Painting to Map 100th epoch

Figure 7(b): Monet Painting to Map 4000th epoch

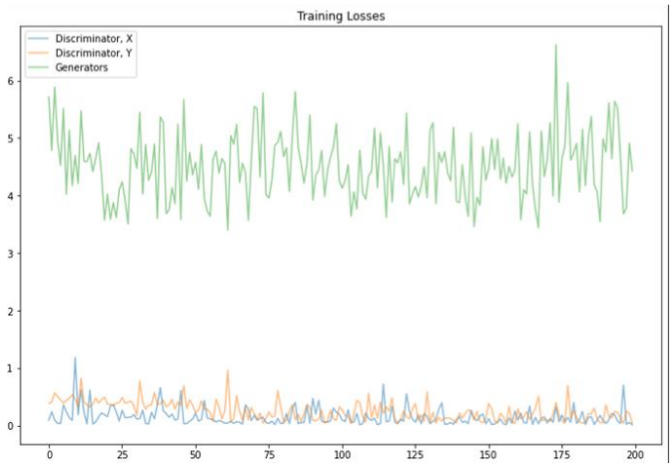


Figure 8: Training Losses of Monet to Map & Map to Monet application

3.1.3 Evaluation of the Outputs

When we try to evaluate the outputs of CycleGAN models on the same urban data set applied with two different sets of Van Gogh and Monet paintings, it is possible to say that the map to painting conversion had provided better results in terms of legibility of urban characteristics. As well as it can be seen from Figure 4(b) and Figure 6(b) the urban features are so clear that they could be seen as an aerial image painted by Van Gogh's and Monet's style. But also painting to map conversions are still valuable in terms of creating an urban texture out of the original paintings Figure 5(b) and Figure 7(b). However, the produced maps are not so readable as in the case of the map to painting, for detecting the urban grid and natural elements.

Secondly, when we compare the difference between each application on different artists' paintings, we can say that due to the different number of epochs applied, the resolutions of the generated images are various. One might say that the Van Gogh applications results are more prominent than the Monet one, especially in the painting to map conversions. At that point, it is important to note that a smaller number of epochs might not be the only reason for it. The reason can also be interpreted as the artists' style is highly determinant for the legibility of the generated maps. Even if both artists are pioneers of the same artistic movement of impressionism, the personal style differences that can be seen clearly from their masterpieces have also been projected on this research's outputs.

3.2. STYLEGAN

The StyleGAN is a GAN extension that proposes significant changes to the generator model. These changes include the use of a mapping network to map points in latent space to an intermediate latent space, the use of the intermediate latent space to control style at each point in the generator model, and the addition of noise as a source of variation at each point in the generator model (Brownlee, 2019). In the styleGAN algorithm, a feature space that was initially created to capture texture information to get a representation of the style of an input image is employed (Gatys, Ecker, & Bethge, 2015). The filter responses in each layer of the network are used to create this feature space. It consists of the correlations between the various filter responses over the feature maps' spatial area. A stationary, multi-scale representation of the input image by adding the feature correlations of many layers, which captures the texture information but not the global layout is generated. In addition to producing stunningly photorealistic, high-quality images of faces, the resultant model also provides control over the style of the created picture at various degrees of detail by adjusting the style vectors and noise.

3.2.1 Cézanne to Map and Map to Cézanne

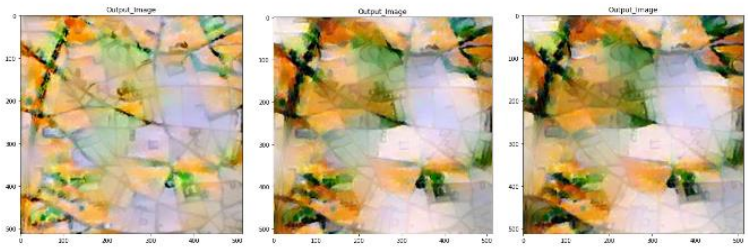
The StyleGAN model was trained with 10 epochs and 1000 iterations for each epoch. Losses in the first epoch and the last one was:

After epoch 1: Tot_loss: 6.7482, Sty_loss: 1.6912, Con_loss: 3.9273, Var_loss: 1.1297

After epoch 10: Tot_loss: 5.5615, Sty_loss: 0.9411, Con_loss: 3.4904, Var_loss: 1.13

The loss of the system has not changed drastically with different parameters; however, visual results seem promising and satisfying. The algorithm is run with painting to map transfer initially.

Figure 9: Style image and content image



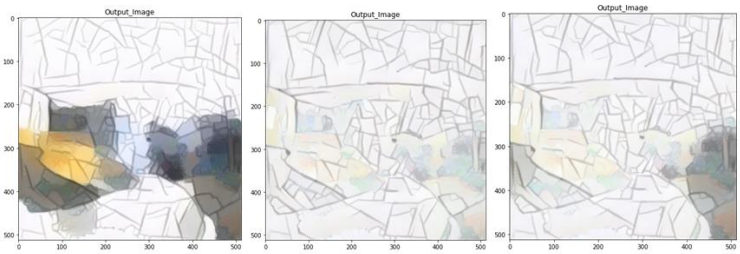
Epoch#1 Epoch#5 Epoch#10

Figure 10: Cézanne to Map transfer

After trying the painting to map, the algorithm has ran in the opposite direction and transfer the map to painting to see the results. Even the system loss has not changed significantly, the results can be evaluated as promising new stylistic map features.

After epoch 1: Tot_loss: 5.314, Sty_loss: 0.9266, Con_loss: 3.388, Var_loss: 0.9993

After epoch 10: Tot_loss: 5.2411, Sty_loss: 0.8976, Con_loss: 3.3408, Var_loss: 0.9944



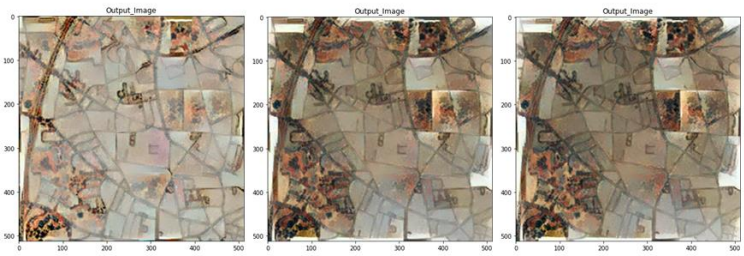
Epoch#1 Epoch#5 Epoch#10

Figure 11: Map to Cézanne transfer

3.2.2. Ukiyo-e to Map and Map to Ukiyo-e

The StyleGAN model was trained with 10 epochs and 1000 iterations for each epoch. The losses are plotted similarly to previous training sessions with different artists.
After epoch 1: Tot_loss: 7.16, Sty_loss: 1.74, Con_loss: 3.98, Var_loss: 1.43
After epoch 10: Tot_loss: 5.31, Sty_loss: 0.92, Con_loss: 3.38, Var_loss: 0.99

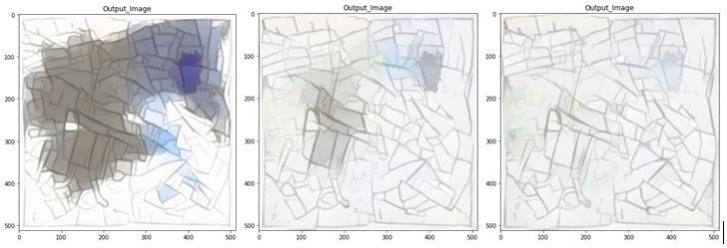
Figure 12: Style image and content image



Epoch#1 Epoch#5 Epoch#10

Figure 13: Ukiyo-e to Map transfer

Map to painting has run and the losses achieved like the Cézanne example.
After epoch 1: Tot_loss: 6.61, Sty_loss: 1.54, Con_loss: 3.74, Var_loss: 1.37
After epoch 10: Tot_loss: 4.98, Sty_loss: 0.86, Con_loss: 3.15, Var_loss: 0.82



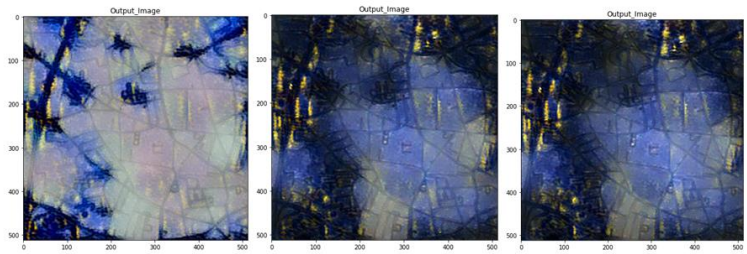
Epoch#1 Epoch#5 Epoch#10

Figure 14: Map to Ukiyo-e transfer

3.2.3. Van Gogh to Map and Map to Van Gogh

The last exploration was from Van Gogh dataset and the system loss results were like other attempts. The algorithm was run with 10 epochs and 1000 iterations for each epoch as previous attempts.
After epoch 1: Tot_loss: 8.34, Sty_loss: 1.72, Con_loss: 4.15, Var_loss: 1.78
After epoch 10: Tot_loss: 5.241, Sty_loss: 0.83, Con_loss: 3.481, Var_loss: 0.904

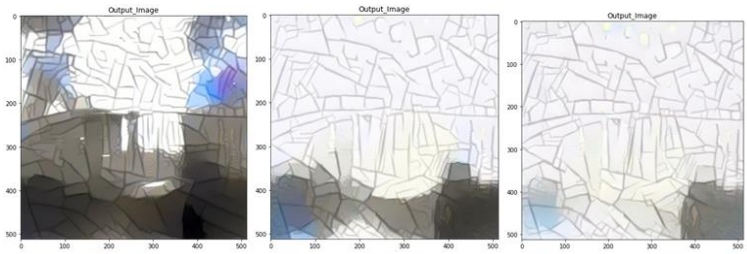
Figure 15: Style image and content image



Epoch#1 Epoch#5 Epoch#10

Figure 16: Van Gogh to Map transfer

Map to painting trial in Van Gogh dataset gave more promising results than other trials in the styleGAN algorithm. The losses are similar to previous attempts yet; visual results are more promising than Van Gogh to map attempt.
After epoch 1: Tot_loss: 7.267, Sty_loss: 1.902, Con_loss: 4.205, Var_loss: 1.612
After epoch 10: Tot_loss: 5.011, Sty_loss: 0.762, Con_loss: 3.338, Var_loss: 0.842



Epoch#1 Epoch#5 Epoch#10

Figure 17: Map to Van Gogh transfer

3.2.4. Evaluation of the Outputs

When we try to evaluate the outputs of StyleGAN models on the same urban map applied with three different paintings of Cézanne, Ukiyoe, and Van Gogh, the map to painting style transfer provided improved results in terms of legibility of urban morphology as in the CycleGAN models. The one disadvantage of the StyleGAN algorithm is that it works with image pairing which means it only transfers the one image style, not the whole artist style. However, the map to painting transfers gave promising results for urban map generating in artists' styles.

4. Results and Discussion

After many failed attempts, Generative Adversarial Networks successfully learn and generate urban plans with chosen artist's styles. By training datasets of different styles, various results have been achieved. In the context of the results, we believe that the model Map to Painting with cycleGAN algorithm is a more promising GAN model in terms of introducing a new type of representation, where you can see various artist's touch in today's modern urban plans. Therefore, it is possible to say that, it enables the user to generate map images that look like an aerial view, which are painted by an avant-garde artist, from basic figure ground maps of the cities.

Secondly, the painting to map outputs of the StyleGAN also values a lot, especially for the future research directions, in terms of generating new urban patterns in artists' style. However, in the styleGAN algorithm, the system does not train the whole paintings of the artists to apply the style to the map, it rather learns the style of the given painting and applies it to the map. So, rather than producing maps in an artist's style like in cycleGAN, it produces maps in paintings' style. As well as it can be seen from the outputs, the same content map image given to the algorithm produced various urban morphologies in various artistic styles depending on the used technique in the paintings. So, the generated painting to map images can provide a basis for further research agendas, which focus on the inquiry about the potentials and drawbacks of applying this methodology as a tool for urban planning applications.

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USING ARTIFICIAL NEURAL NETWORKS AND SPACE SYNTAX TECHNIQUES TO UNDERSTAND MASS HOUSING DESIGN PARAMETERS

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Abstract. The design of mass housing is a complex process that involves the use of a large number of components and parameters. The field of design has unavoidably been changed by the impact of digitalization, which has resulted in the proliferation of computational design models, data structures, artificial intelligence, and an algorithmic way of thinking. Artificial neural networks, space syntax methodologies, predefined rules will help shape the steps of the schematic design process and establish certain limitations. Within the confines of this research, predefined guidelines were used to bring about geometric variances in the design of mass houses. Both traditional and digital instruments were utilized in the process. Methodologies based on artificial neural network models and space syntax techniques were utilized to investigate case studies and develop prototypes. The artificial neural network model is designed to understand the factors affecting mass housing design parameters. The importance percentages of the parameters were determined according to the outputs of this model. Besides, methodologies based on space syntax have had a significant impact, both on decision-making processes and on feedback-based design. In this study, several digital tools were used to analyze such as visibility graph analyzes, node-based techniques, and isovist analysis. In the section devoted to the conclusion, the comparison of the various prototypes that were obtained, the findings of the space syntax analysis, and the various stages of model development are discussed.

Keywords: *Architectural Configuration, Artificial Neural Networks, Rule-based Design, Visibility Graph Analysis (VGA), Isovist Analysis*

ملخص: يعد تصميم مشاريع الإسكان الكبرى عملية معقدة تتضمن استخدام عدد كبير من المكونات والمتغيرات. وقد تغير مجال التصميم حتما بسبب تأثير الرقمنة، مما أدى إلى انتشار نماذج التصميم الحوسبية، وهياكل البيانات، والذكاء الصناعى، وطرق التفكير

الحوسبية. وتعتبر الشبكات العصبية الصناعية ومنهجيات بناء الفراغ والقواعد المحددة مسبقا من التقنيات التى ستساعد على تشكيل خطوات عملية التصميم المبدئى وإرساء بعض المحددات. وفى هذا البحث، تم استخدام إرشادات محددة مسبقا لإنشاء نماذج هندسية عديدة ومتباينة فى إطار عملية تصميم مشاريع الإسكان الكبرى، وذلك باستخدام أدوات تقليدية ورقمية. وقد تم استخدام منهجيات مبنية على الشبكات العصبية الصناعية ومنهجيات بناء الفراغ للتحقيق فى دراسات حالة وتطوير نماذج أولية. فقد تم تصميم نموذج شبكة عصبية صناعية بهدف فهم العوامل المؤثرة على المعايير والمتغيرات الخاصة بتصميم مشاريع الإسكان الكبرى. وتم تحديد النسب الهامة المتعلقة بتلك المعايير بناء على مخرجات النموذج. وقد كان لمنهجيات بناء الفراغ تأثير كبير على كل من عمليات صنع القرار والتصميم المبنى على التغذية المرتجعة. وفى هذه الدراسة، تم استخدام العديد من البرامج الرقمية التحليلية مثل تحليلات الرسم البيانى للرؤية والتقنيات المبنية على نقاط الالتقاء وتحليل برنامج الأيزوفست. وتخلص الورقة البحثية إلى استعراض لمقارنة بين كافة النماذج المطورة التى تم الحصول عليها بالإضافة إلى نتائج تحليلات منهجيات بناء الفراغ وكافة مراحل تطوير النماذج.

الكلمات المفتاحية: التكوين المعمارى، الشبكات العصبية الصناعية، التصميم المبنى على القواعد، تحليلات الرسم البيانى للرؤية، تحليل برنامج الأيزوفست.

1. Introduction

As the impact of digitalization and emerging form-finding tools increases, the roles and responsibilities of the modern designer are changing and transforming into new forms. Specifically, novel ways are used to develop and support design stages that transition from conventional to digital creative processes. Within this framework, the effect that the designer has throughout the process is rethought and explored in relation to the shifting conditions. The stages of the design action, which are expected to include creative thinking (Casakin et al., 2010) and iterative stages (Burry, 2004) by their nature, include the steps of developing and concretizing the original ideas proposed for the solution of the defined design problem. Artificial intelligence (AI) approaches, unique protocols, digital tools, and hybrid models (which combine digital and analog methods) are all viable options developing novel and innovative concepts in mass housing design. Furthermore, traditional approaches such as sketching, physical modeling, and diagramming may be used to construct a strategy that is based on potential outcomes and can be utilized in developing a representation for the initial design idea. According to Oxman (2006), the active involvement of the computer in solving the design problem is different from simply making digital drawings when considering the computational design stages. The emergence of computer-aided design (CAD) and building information modeling (BIM) technologies due to the impact of digitalization has resulted in creating new opportunities for designers. These opportunities may be summarized as follows: Computer-aided design technologies have the

potential to make a constructive contribution to the stages of the design process that include creative problem solving, early design phase, communication, and visualization (Robertson and Radcliffe, 2009). Besides, with the introduction of creative digital tools and advanced computational models, there is a greater demand to comprehend and control the design process.

Artificial intelligence approaches include efficient models for solving complex and non-linear problems. Artificial neural networks (ANNs), which are components of supervised machine learning approaches that mimic the brain (consisting of neurons), enable meaningful interpretations and inferences from the processed data. According to Tayfur (2020, p.4) “ANN is inspired from the information processing of biological nervous system, such as the brain”. The human brain, however, works entirely differently from a traditional digital computer and has always fueled the interest in studies of neural networks or somewhat artificial neural networks (Haykin, 1996). These models, by their nature, are very effective in revealing relationships and tacit knowledge that seem complex in terms of the number of inputs and advanced algorithms. Human intelligence is based on a serial system and deals with a complex data only through interpretive mechanisms. In contrast, AI, benefiting from parallel processing, could handle complex and large amounts of data. Computational learning algorithms and AI-based approaches, which have a sophisticated framework, make eloquent extrapolations by utilizing forecasting models and learning types (i.e., supervised learning, reinforcement learning, hybrid learning, unsupervised learning, etc.), and statistical analyzes of enriched data in various dimensions. These approaches can fulfill essential components of reasoning modules and learning types. The effects of these machine learning models are increasing not only in engineering but also on the designer’s tasks and design methods. Estimating the parameters and importance percentages that affect the design processes can be tested with machine learning approaches. Within the scope of this study, the parameters affecting the mass housing design were tried to be estimated according to the artificial intelligence model. As a result of the development of the multi-layer perceptron model, also known as MLP, it is now much simpler to conduct an analysis of many design parameters' variables, which in turn grants the designer increased control over the process. Combinations are constructed by adhering to a set of criteria and presumptions that are specific (based on equations). The rules that influence the design of mass housing were attempted to be determined as part of the scope of this study, after which alternative housing designs were developed based on these rules. Several aspects, including spatial connections and arrangements, decisions made by the designer, geometric

manipulations, and the overall architectural program, are taken into consideration. After that, space syntax approaches were used to conduct an analysis of the variances. Developed models were then reexamined based on the criteria that were used to choose the models.

2. Literature Review

The project inputs can influence the decisions and changes that are made during the process from the concept design stage to the final product creation. An in-depth knowledge of these inputs can be gained through using artificial neural network models, learning algorithms, mathematical equations, parameters, and computational models. The role of the computational approach, parametric/algorithmic stages, and the effect of digital design tools are enhancing day by day, and, its scope is expanding (Caetano et al., 2020). Furthermore, design activity can benefit from computational strategies when viewed as a paradigm for guiding design research (Liddament, 1999). According to Kotnik (2010, p.11), computability and its importance for digital design in architecture illustrate that “the computer is not a neutral” instrument, but actively shapes how designers approach design. Numerous academic works have been dedicated to the study of mathematical methods (e.g., descriptive geometry, geometric algebra, associative geometry, Boolean operations in CAD, etc.) for elucidating design difficulties and formulating methods for resolving them (Pottmann et al., 2015; March 1976).

The effective use of parametric modeling tools can affect the design stages in many ways (Abdelmohsen and Do 2009; Qian et al. 2007). By combining digital computation with analytical design processes, the parametric design provides architects and designers with new ways to explore, simulate, and analyze multi-dimensional forms (Tang, 2014). According to Kolarevic (2013, p.52), parametric design is a digital technique that enables endless variety of shapes and forms, either through the drawing and modeling software's “embedded geometry” or by “visual programming tools” or “scripting”. On the other hand, algorithms that seek repetitive patterns, universal principles, changeable modules, and inductive relationships can improve human intellect by extracting new knowledge (Terzidis, 2006). Approaches such as computational, parametric, algorithmic, and generative (Nagy et al., 2017) methods all begin with defining the rule set (except for machine learning models and generative adversarial neural networks). For instance, the parametric design approach entails activities such as defining parameters, formulating equations,

establishing connections (predecessors and successors), and making use of logical operators.

Artificial intelligence (AI) and machine learning have advanced significantly over the past couple of decades and now include a wide range of powerful tools that can be implemented thanks to the proliferation of low-cost computers, massive datasets, and the Internet (Nilsson, 2010). The field of machine learning, which includes concepts of "artificial intelligence, probability and statistics, computational complexity, information theory, psychology and neurobiology, control theory, and philosophy" (Mitchell 1997, p.17), is rapidly expanding in assorted disciplines. Neural network architectures trained with supervised or unsupervised methods are exploited in "aircraft control, credit card fraud detection, vending machine currency recognition, and data mining" (Nilsson 2010, p.509). Since the human brain can be thought of as a type of machine, there is no obvious boundary between the fields of AI (the study of making robots do tasks traditionally associated with human intellect) and psychology (Minsky, 1988). Compared to human intelligence, AI has the capacity to process large amount of complex data quickly and efficiently, hence, the current interest in neural networks and machine learning. The artificial intelligence ecosystem has seen different phases of development during the last century and has made significant progress and gained momentum in the previous ten years. Research in artificial intelligence started only in the 1950s after modern computers were invented, and it inspired a flood of ideas about how machines could do things that only minds could before (Minsky, 1988). Computer scientist Tom Mitchell (1997) divided the researchers working on the neural networks into two groups: The objective of employing ANNs to explore and mimic biological learning processes has inspired one group, and the rest of them has driven by the desire to develop highly effective machine learning algorithms, regardless of whether they mimic biological processes. Artificial neural networks are employed in the implementation areas of various disciplines such as archaeology (Pawlowicz & Downum, 2021), computer graphics (He et al., 2016), computational design (Chaillou, 2020), medicine (Frid-Adar et al., 2018), engineering (Tayfur & Singh, 2006), and architecture (Nauata et al., 2020).

Another computational model approach, space syntax (Jiang, 1998), is included in the analysis part of this study. The term "space syntax" refers to a range of approaches that can be used to represent and analyze various types of spatial layouts (Hillier, 1999). The analysis of spatial configurations has been the primary application of the mathematical framework known as “space syntax”, which is founded on topology and graph theory (Jeong and

Ban, 2011). In the study of Schaffranek and Vasku (2013, p. 2), they present "different approaches to using Space Syntax as a constraint in the computational design process." Recent works on space syntax try to “simulate spatial design proposals” and figure out how they would work by coming up with consistent ways to represent and analyze spatial patterns (Dursun 2007, p.4). Methodologies of space syntax, which are useful approaches in the fields of architecture and urban planning, it helps to obtain analyses such as the relationship between places and the interaction of users. The designer will also find great value in conducting research into the connections that exist between different areas. Consequently, it can be described as an efficient criterion for identifying design variations.

3. Methodology

Data collection, defining rules, building an artificial neural network (ANN) model, variation extraction, and spatial analysis make up the major components of the methodology utilized in this study. During the data collection phase, satellite images, sample projects, land boundaries (in the form of drawing files and 3d models), and project inputs were collected. During the formulation of the rules, the factors that impacted on the architectural program were considered. User types, social areas, areas with greenery, circulation areas, semi-open areas, closed areas, and open areas are some of the elements that are examined (Figure 1). A rule-based approach was used to design a mass housing project that included seventy-five flats and social facilities as part of the scope of this study. Iterative execution was used for all these processes. A process of iteration occurred between the act of sketching and the act of modeling. During the concept design phase, both digital and analog drawings were used to develop the project's initial models. Then, site plans were created based on parameters including area calculations, solid-void relationships, flat types, and project inputs (according to the results of the ANN model). An artificial neural network model was developed with the JustNN (Neural Planner Software, version 4.0b). All input and output values are standardized between [0,1]. The design iterations that were generated as a result were evaluated using space syntax tools. Assorted digital tools were employed in this study. “Harmony” project (Accessed 13 March 2021) was used to gain digital sketches. Furthermore, Autodesk AutoCAD® 2022 and Revit® 2022 were used to model (e.g., components and parametric objects) and modify geometries (e.g., surfaces, polygons, etc.). DepthmapX (Varoudis, 2012) was used to obtain visibility graph analysis (VGA). Visibility graphs for both site plans (Kumar, 2019) and architectural floor plans were examined. Besides,

Syntax2D (S2D) (Wineman et al., 2007) tool was used to obtain isovist analysis. AGraph (Manum et al., 2005) was used to get node-based graphs and internal distances, mean depth, relative asymmetry, difference factor, and integration values.

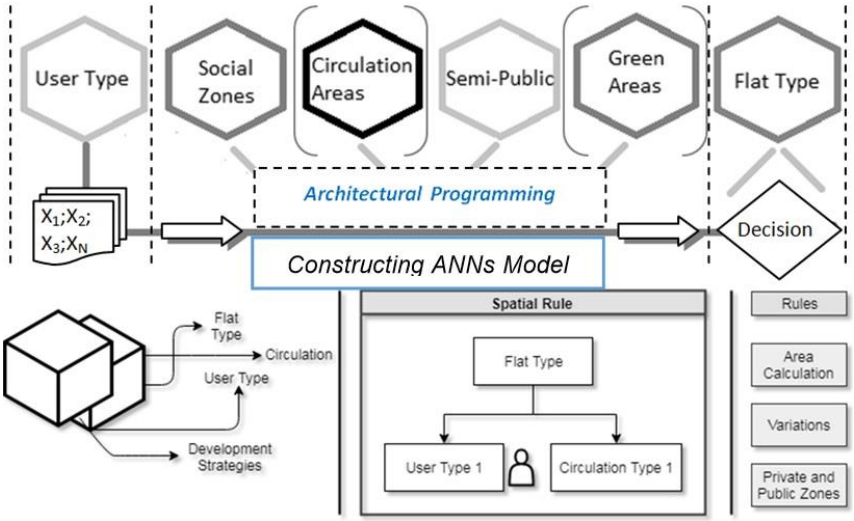

Figure 1. Architectural programming and primary rules for mass housing development

3.1. Analysis of Spatial Relations of Housing Units

Space syntax approaches can be used to understand the structure of houses and evaluate their spatial relationships (Hanson, 2003). Numerous strategies have been developed in space syntax approaches that utilize schematic representations to facilitate the identification of spatial variations and system components. Consequently, these strategies were based on the designs of the individual units that make up the mass housing structures, as well as the rules governing how they are assembled (e.g., shape grammars, cellular automata, rule-based approaches, parametric protocols, etc.). Initially, it is necessary to ascertain the areas (2d) and volumes (3d) that the architectural program requires. Justified graphs, which are tree-like structures, are used as part of the concept of space syntax (Orhun et al., 1995; Klarqvist, 2015). Besides, the integration of contemporary housing projects from an architectural firm with the spaces has been analyzed (Figure 2). Later, it was interpreted with the rule-based approach, and many alternatives were developed (Figure 2).

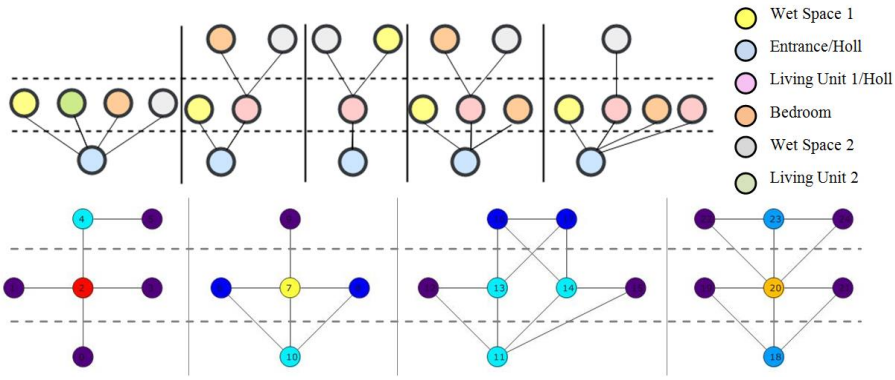

Figure 2. Accessibility graphs of examples of modern mass housing components (by functions) (upper) and suggested variations

Sample projects were examined and evaluated via space syntax digital tools (Figure 2 and 3). In this context, isovist analysis (occlusion, compactness, and area) was implemented at various points on the sample layouts (Figure 3).

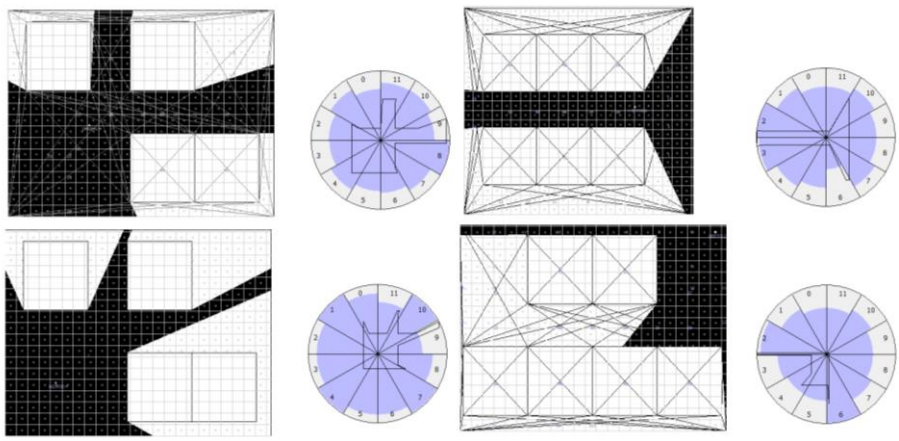

Figure 3. Point isovist analysis of the case studies' layouts

3.2. Constructing Artificial Neural Network (ANN) Model

According to Zadeh (1996), the pioneer of fuzzy logic, all approaches such as neural network theory, probabilistic reasoning, fuzzy logic, evolutionary computing, and chaotic systems could all be grouped under the umbrella of soft computing. One of the soft computing systems, these networks try to replicate the rudimentary tasks of neurons, axons, soma, dendrites, and

synapses in the human nervous system in a digital environment. Due of the sophistication of nerve cell structure, even supercomputers are inadequate; hence, basic neural models have been constructed (Baykal and Beyan, 2004). Neural networks, whose usage areas have diversified with the enrichment of data and the development of reference models over time, basically consist of input, output, and hidden layers. According to Tayfur (2020, p.14) “An artificial neuron is a model whose components have direct analogies to components of a biological neuron". The multilayer perceptron (MLP) has been applied to predict future trends, approximate relationships between variables, and classify data into discrete classes (Gardner and Dorling, 1998). Activation function (e.g., ReLu, log-sigmoid, ELU, TanH, etc.), number of neurons, optimization algorithm, learning rate, learning momentum, and epoch number are some of the hyperparameters for training ANN models. Within the scope of this study, the artificial neural network model was developed based on sample projects’ gross area, net area, number of rooms, number of bathrooms, whether there is a balcony, whether there is a vista, and preference score (in correlation with price) parameters (Figure 4). In final neural net, the gross area is not included in the model.

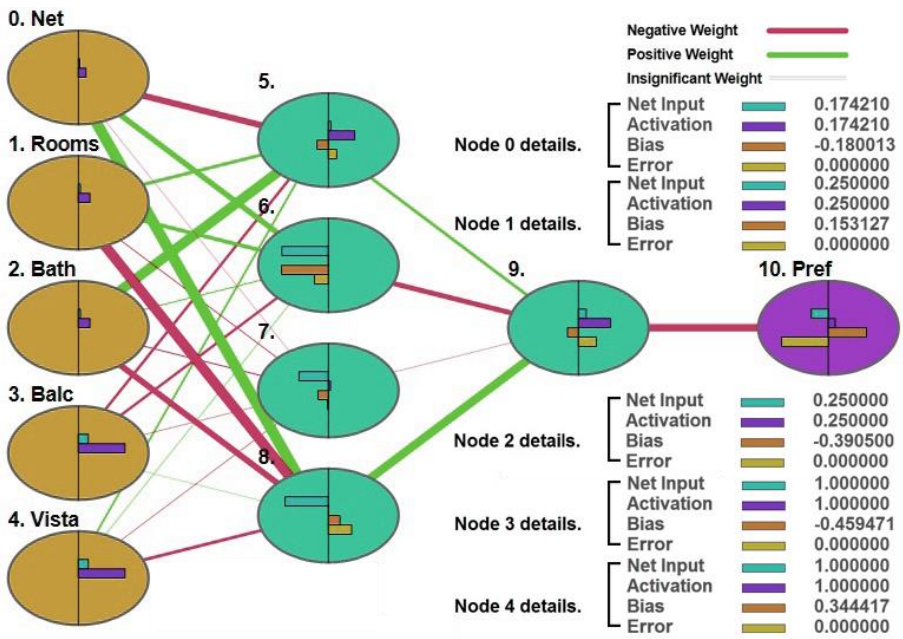

Figure 4. Development of the artificial neural network model

The artificial neural network model was developed with a feedforward and back-propagation learning algorithm. Only twenty-four instances were

used for training, while the remainder were utilized for validation. During the training phase, the learning cycle value was 18301, the mean error was 0.051%, the target error was 1%, the validation accuracy was 100%, the learning rate was 0.6, and the momentum was 0.8 (Figure 5). The relative importance of the input factors is as follows: net area, number of rooms, number of bathrooms, presence of a view, and presence of a balcony. (Figure 5).

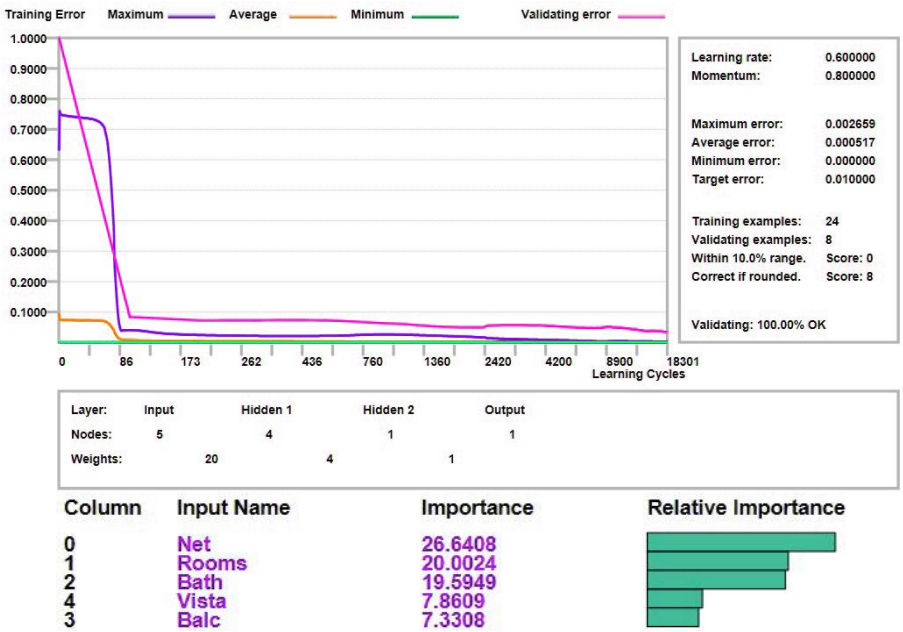

Figure 5. Network learning progress plot (upper) and inputs' relative importance chart

4. Results

The first result of this study is the development of concepts that were developed with digital and analog procedures for the initial part design stages. The rules that must be followed during the development process have been established, including the outputs of the ANN model, the architectural program, design decisions, space syntax approaches, and geometric characteristics. The investigation into the appropriate distribution of mass resulted in producing eight prototypes, six of which had solutions in two dimensions, while the remaining two contained solutions in three dimensions (Figure 6). According to the factors affecting the housing design (ANN model outputs were also taken as reference), design alternatives were produced iteratively with parametric CAD and BIM tools. Throughout this

development process, many parameters, such as solid-void ratios, outputs from neural network models, and space syntax methodologies, were utilized.

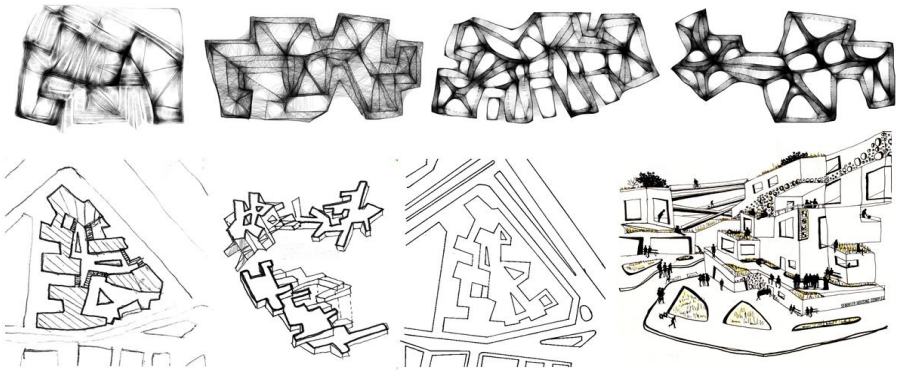

Figure 6. Schematic design phases with digital sketches (upper) and hand drawings

The process of iteratively modifying and fine-tuning mass geometries is an essential component of producing design alternatives. At this stage, another important concern is incorporating the social space design (e.g., open and semi-open space configurations) into the overall structure. During the first stage of design development, a total of twelve different settlement types and masses were created (Figure 7).

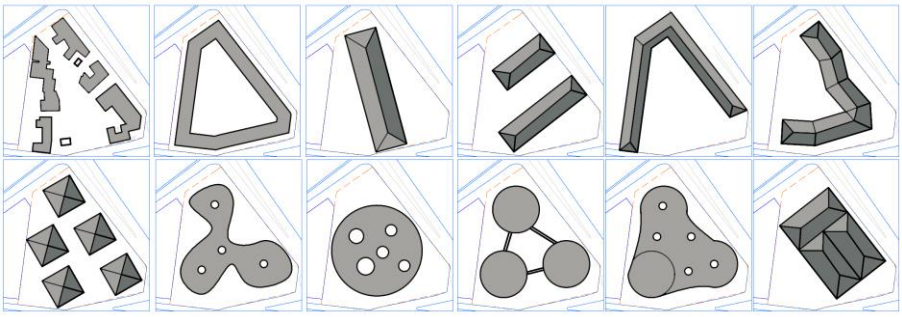

Figure 7. Mass modelling stages and design variations with parametric CAD tool

Nevertheless, according to the ANN model's input relative importance, just four of them were chosen, and the development phases was carried on from there. As a result of this, four dissimilar strategies have been investigated to lessen the density of the masses. The design decisions for floor plans and site plans incorporate all four of the previously mentioned alternative approaches. Simultaneously, visibility graph analyses (VGA) were obtained (Figure 8). In some blocks, the correlation between the number of rooms (input parameter of the ANN model) and the kind of

dwelling stays the same, but in other blocks, it veers off in a different direction. Besides, the organic plan scheme features block that have a geometry that combines multiple surfaces into polygons. The purpose of its multiple surfaces is to broaden the viewing area as well as facilitate the participation of a greater number of people in visual communication.

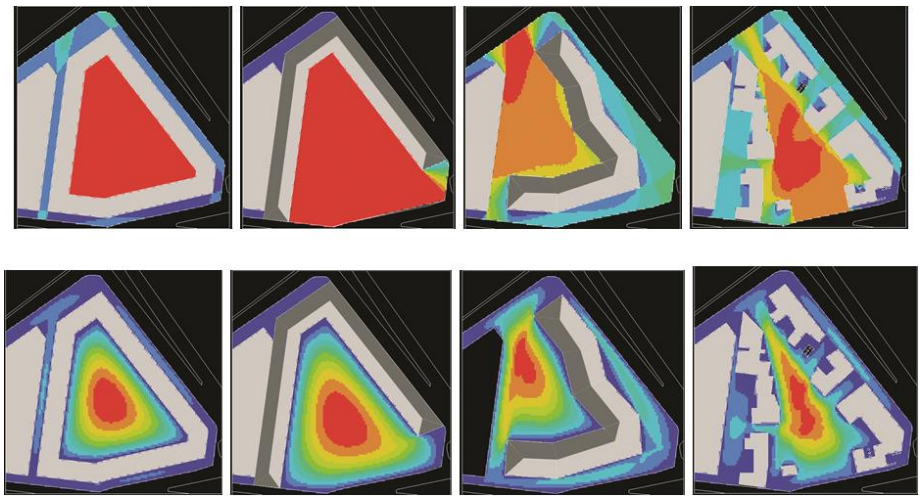

Figure 8. Results of visibility graph analysis (VGA)

Four dissimilar design possibilities were generated using technology from parametric computer aided design approach and building information modeling (BIM) (Figure 9). Since there are several phases of concept design, an attempt was made to improve the solid-geometry-based requirements that were generated. The level of detail in the variants was carefully maintained.

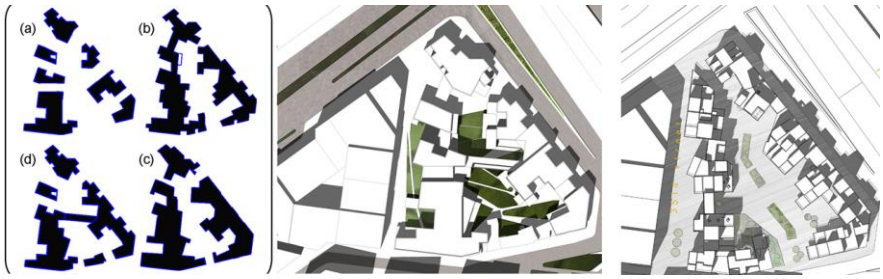

Figure 9. Schematic design variations via parametric CAD tool (left) and BIM tool

Boolean operations such as subtraction, union, and intersection (Sun et al., 2001) and geometric calculations are included in the modification and manipulation steps. Regarding the design of floor plans (Figure 10), the

application of space syntax methodologies has proven to be extremely helpful.

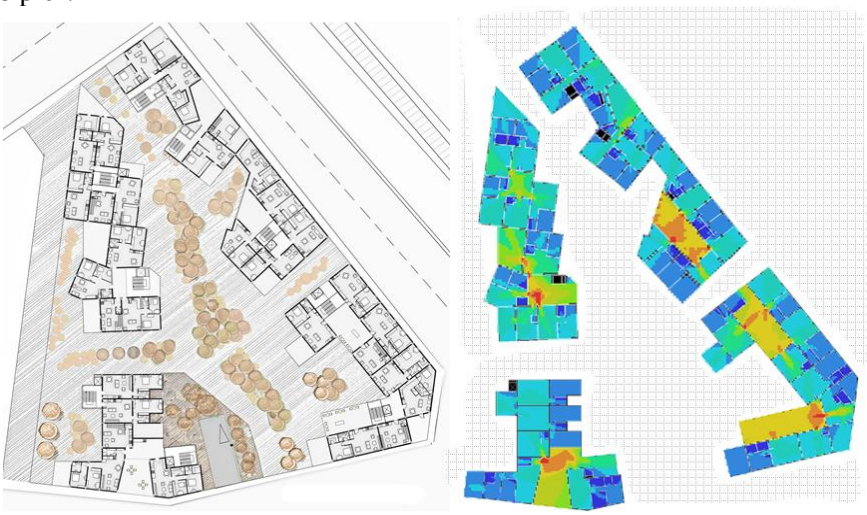

Figure 10. Producing floor plans (left) and results of VGA

As a result, it has made it possible to conduct metric analyses on the differences between the various design alternatives. Analyses were done on the potential routes and visibility of users, with an emphasis on connectivity (Figure 10). Following the completion of the mentioned computations, an attempt was made to reconstruct the proposed connection between the defined areas. In this regard, some flats do not share an entryway with neighboring flats (because some apartment types are two-storey, some are three-storey). In addition, when planning the layout of the communal spaces, their volume was considered. Furthermore, it is necessary to conduct a three-dimensional analysis due to irregular polygonal geometry, architectural programming, and multi-surface scenarios. This was done because it was essential to determine whether the buildings would have one or two levels. The mass formation benefits enormously from undergoing development stages as well as trials that take place in three dimensions (Figure 11).

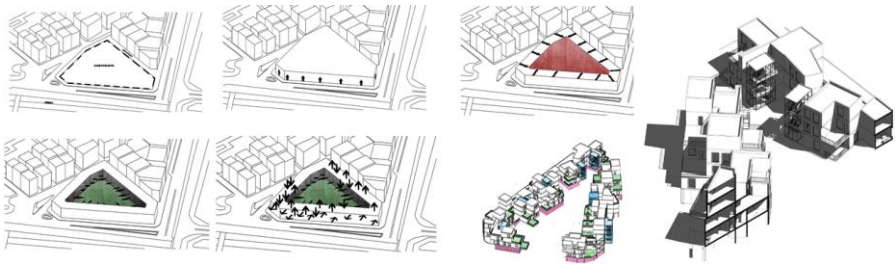

Figure 11. Modelling and modification phases of 3D geometries with BIM tool

5. Discussion

Digitalization has an impact on decision-making and problem-solving strategies for complex situations, such as extracting and analyzing design patterns. As the stages of design thinking entail several dimensions and phases, the process of establishing or attempting to comprehend precise design principles is laborious. Benefits in terms of decision-making can be reaped by employing the rules and ANN models' designated parameters. The settings of the rules and parameters that constitute the basis of these models are different for every design challenge that might be posed. Artificial neural networks, a form of machine learning, are a potent method for resolving complex design issues. The importance of creative thinking aided by sketches, rule-based design approaches, artificial intelligence methodologies, and space syntax techniques cannot be overstated in the context of the schematic design steps. Thinking with a sketch, which is the foundation of the design concept, is one of the primary components of analytical thought in the study of ill-defined design challenges. Iterative processes, which are features of creative thought, also contribute immensely to design thinking in a positive way. The need of producing prototypes iteratively and incorporating input has become a major aspect in tackling complex design problems. The resulting alterations on the design are of such a kind that they adhere to the established guidelines. Besides, the designer is able to construct the specified associative geometry using digital tools. On the other hand, these tools do not compete with the designer's authority; it only supports him/her. An artificial neural network model was developed at the beginning of this research project in order to gain a better understanding of the parameters of the mass housing design strategies. The training of the multi-layer perceptron is very significant for the stages that involve decision making. In addition to this, the developed network was put to use in order to gain an understanding of the relative input importance of the parameters that were specified. On the other hand, space syntax approaches (i.e., visibility graph analysis, isovist analysis, and node-based spatial analysis) have been used to evaluate design alternatives. This study demonstrates the importance of bridging the ANN model, space syntax methodologies, parametric CAD and BIM tools, and 3D design development procedures for mass housing design protocols. In future research, various learning algorithms will be employed to estimate the design characteristics of mass housing.

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DAY 1 - PARALLEL SESSION 5

TOPIC 2 - INFORMATION MANAGEMENT

A METHODOLOGY FOR MATERIAL-BASED COMPUTATIONAL DESIGN SUPPORTED BY MOBILE AUGMENTED REALITY APPLICATION

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Abstract. To represent design, both physical and digital models are utilized in the process. However, they usually don't function in unison. In order to synchronize these two types of models, the changes made in one model are generally translated into the other one later. This study intends to provide a conceptual framework for a simultaneous and synchronized model for the use of material, structure, and performance in the preliminary design stage. The methodology of the study includes evaluating material attributes, structural systems, and building performance of a physical model in the digital environment by using a Mobile Augmented Reality (MAR) interface. Because the cameras in MAR environment are mobile, the range of views can be expanded, and/or designs can be superimposed on user interfaces virtually. Thus, object interaction and navigation are all made possible. By offering a comprehensive, synchronized, and interactive design environment, where material, structure, and performance factors are incorporated both in physical and digital models, the suggested methodology will potentially aid users' decision-making process.

Keywords: *Mobile Augmented Reality (MAR), Material-based Computational Design (MCD), Building Performance.*

ملخص. بالرغم من استخدام كل من النماذج المادية والرقمية في العملية التصميمية لتمثيل التصميم، إلا أنها عادة لا تعمل في انسجام تام. ومن أجل التنسيق بين هذين النوعين من النماذج، فإن التغييرات التي يتم إجراؤها في أحد النماذج يتم ترجمتها بشكل عام إلى النموذج الآخر لاحقًا. تهدف هذه الدراسة إلى توفير إطار عمل مفاهيمي لنموذج متناسق ومتزامن لاستخدام مواد البناء والإنشاء والأداء في مرحلة التصميم الأولية. تتضمن منهجية الدراسة تقييم سمات مواد البناء والأنظمة الإنشائية وأداء المبنى لنموذج مادي في البيئة الرقمية باستخدام واجهة الواقع المعزز المحمول (MAR). نظرًا لأن الكاميرات في هذه البيئة

متحركة، يمكن توسيع نطاق العروض و/ أو يمكن تركيب التصميمات على واجهات المستخدم افتراضيًا. وبالتالي، يصبح التفاعل بين الكيانات والأشياء والتنقل ممكنًا. من المأمول أن تساعد المنهجية المقترحة في دعم عملية صنع القرار لدى المستخدمين من خلال توفير بيئة تصميم شاملة ومتزامنة وتفاعلية، حيث يتم دمج عوامل المواد والإنشاء والأداء في كل من النماذج المادية والرقمية.

الكلمات المفتاحية: *الواقع المعزز المحمول، التصميم الحوسبى المبنى على أساس مواد البناء، أداء المبنى.*

1. Introduction

Emerging technologies, such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), which can be used in relation to CAAD (Computer Aided Architectural Design) models, are capable of improving the design processes since they expand traditional techniques of design and making. AR and MR technologies are distinct from CAAD in that they can be superimposed on a real environment, which makes the design environment more dynamic and interactive. The most troublesome limitation of CAAD tools is the flat-screen interface's control by a mouse and keyboard. An AR interface, however, can be controlled by hand and body movements in space. Additionally, it offers real-time feedback (Thees, et. al. 2022). While VR and MR systems may demand some pretty costly equipment, the tools utilized for AR applications are freely accessible via mobile devices. Users could examine their designs for a particular environment by using MAR technology to evaluate designs that were simulated in the actual site context. By employing this technique, designers can increase design efficiency (Wang, et. al. 2007). AR technologies make it simple to collaborate, facilitate social interaction, and integrate digital information with mobile computing. Additionally, they gain flexibility in the design process, allowing them to work with multiple digital models and scales.

The disciplines of architecture, urban design, construction, and digital fabrication have begun to apply MAR applications. The implementation of the model in MAR applications and its enhancements enable the investigation of complicated challenges in the architectural design process. Although the target group of architecture students creates and uses digital 3D architectural models, they rarely factor material and structural performance challenges into their design solutions at the early design stage. Their lack of expertise in these domains is the main cause of this. Form, material, and structure are all considered comprehensively in the material-based computational design approach. Material-based Computational Design (MCD) is as a set of computational strategies supporting the integration of form, material and structure through performance analysis and fabrication (Oxman, 2010; Yazici and Tanacan, 2020).

In this study, the employment of MAR applications in MCD enables evaluating and changing material, structural, and performance-related properties without disrupting the physical model. Thus, it is possible to analyze material qualities, structural systems, and building performance comprehensively. A real-time, synchronized, interactive MAR interface enables the perception of non-visible information about a building. By rotating the building, the architecture students can manipulate it as though it were a 3D item using the computer's 2D interface. The purpose of this study is to construct a model at the preliminary design stage based on material, structure, and performance data in order to enable synchronization via a MAR interface. This would aid architecture students in the design process and help them comprehend design from a broad perspective. The research conducted in the areas of architecture, engineering, and construction (AEC), digital fabrication, MAR, and MCD has led to the study's junction of architectural design and construction.

292 research papers published between 2010 and 2022 are examined for the literature review in ScienceDirect, International Symposium on Augmented Reality, Google Scholar and Cumincad data bases, which includes annual conferences of the Association for Computer Aided Design in Architecture (ACADIA) and its sibling organizations in Europe (ECAADE and CAAD Futures), Asia (CAADRIA), the Middle East (ASCAAD), South America (SIGRADI) and International Journal of Automation and Computing (IJAC). Following the literature review, the methodology for the suggested MAR application model will be introduced (Figure 1).

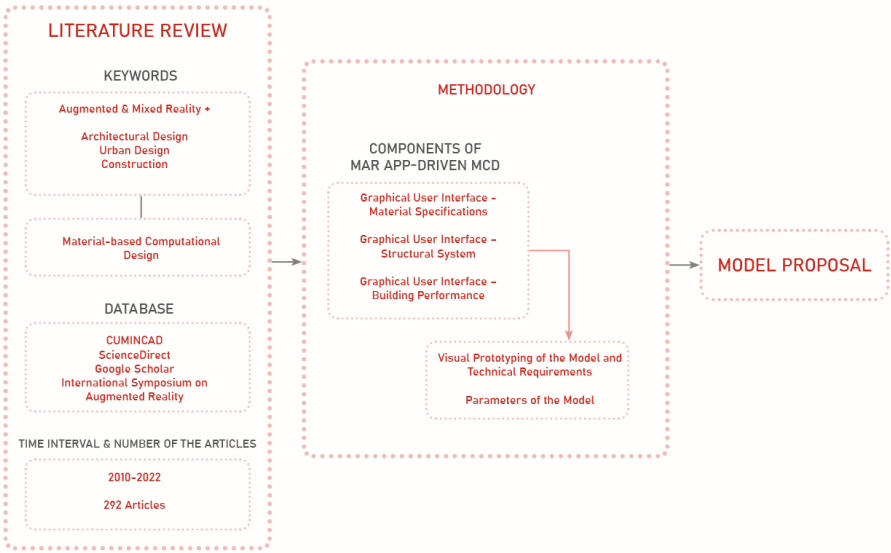

Figure 1. General Framework of the Study.

1.1. ARCHITECTURAL DESIGN AND RELATED EDUCATIONAL APPROACH

There are productions that do not immediately interfere by designing alongside a model and just utilize a marker (this can be a QR code), rather than directly designing on the model, in the literature review on architectural design and related educational approach such as in the article by Silcock et al. (Silcock, Schnabel, Moleta, & Brown, 2021). In another research, there is no synchronized state, but digital interventions can be made through finished structures (Song, et. al., 2021). A digital model and a MAR application were created by Grasser et al. (2019) for use in architectural design (Figure 2).

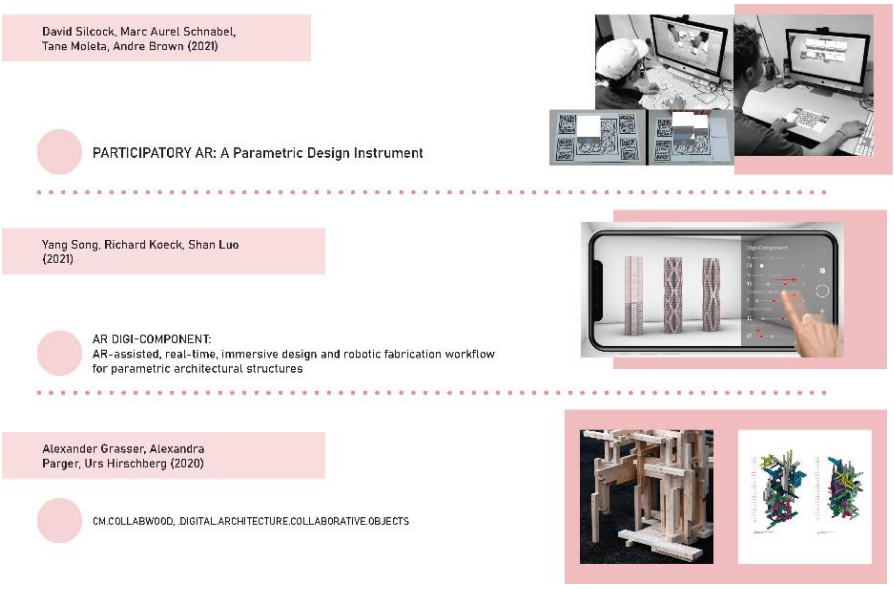

Figure 2. Studies undertaken at the intersection of Architectural Design, Architectural Design Education and AR applications.

There is no research on creating a comprehensive design that considers material, structural, and performance perspectives using a physical model related to MAR application in the literature study on architectural design and architectural design education.

1.2. CONSTRUCTION AND RELATED EDUCATIONAL APPROACH

In the study's construction and related educational approach section, it is examined in the literature that synchronous intervention with the physical model and digital model produced by a BIM program is achievable via a cloud system. However, rather than using tools more readily available to

architectural students or ordinary users, ".netcore" software and Microsoft Hololens hardware are employed (Lharchi et. al., 2020). While these technologies are harder to use than alternatives like Fologram®, Rhinoceros®, and Grasshopper®, they nevertheless enable working in sync with the digital and physical models. Additionally, this structural system did not use criteria like material change, structural analysis, or building performance analysis, which are the goals of current study (Lharchi, Thomsen, & Tamke, 2020). The method of using the Hololens to build an existing design over the same productions of a three-dimensionally modeled structure is shown in the second example. In addition, various technologies are used, including smart gloves and RFID (Radio Frequency Identification). But instead of employing a mass model research, using such wooden sticks at the start of the design process can help focus on the structural system instead. By utilizing predetermined elements in a mobile augmented reality application, the user can construct a structure comprehensively using the material and monitor the behavior of the building (Abe, et al., 2017). The AR application operates directly over a marker in the final example, just as it does in the architectural design section's example. It is only two dimensional and excludes haptic interaction (Turkan, Radkowski, Karabulut-Ilgu, H.Behzadan, & Chen, 2017) (Figure 3).

Figure 3. Studies undertaken at the intersection of Construction,Related Educational Approach and AR.

1.2.1. Digital Fabrication

Numerous examples in Digital Fabrication pertain to the creation of techniques for building intricate structures that have already been three-dimensionally modeled. Due of their 1:1 scale, a head mounted display like the Hololens is typically needed (Jahn, Newnham, Berg, & Beanland, 2018), (Goepel, 2019), (Fazel & Izadi, 2018) (Figure 4).

Figure 4. Studies undertaken at the intersection of Digital Fabrication and AR.

The studies on digital fabrication primarily concentrate on holographic instructions, and they have flaws in their improvisational design methods. Specifically, novice builders are constructing a 3D model by heeding these holographic directions.

The lack of literature is primarily the tactility, followed by convertibility between the materials, according to literature research in the disciplines of architectural design, construction, and related educational approach intersected with MAR applications. The proposal of MAR integrated MCD in the current study enables convertibility and tactility by utilizing a variety of building materials. The fact that MAR applications are useful, practical, and accessible to a wider audience is another justification for their deployment.

In the next part, a mobile augmented reality (MAR) application is proposed in order to fill a gap in the literature connected to architectural design, construction, and related educational approaches.

2. Methodology

The study's methodology entails superimposing three elements—material properties, structural system, and building performance analysis—onto a physical model with a MAR interface to analyze the effects of wind, light, and shadow. The visual prototyping of the model, technological needs, and model parameters were all driven by these three key domains.

The methodology is based on five stages:

(1) Definition of the Physical Model: At the beginning of this study, a physical model is required. This model should be translated into a digital model and integrated with Rhinoceros® by pre-identified QR codes on the Fologram® SDK. This enables the user to recognize the object being worked on.

(2) Design of the Graphical User Interface: Three different inputs (material properties, structural analysis, and building performance analysis) are added to this physical model by a mobile augmented reality application interface, and as a result, this analysis appears separately or optionally overlapped on the smart phone screen. Thus, the user can observe the effect of a digital intervention made on the physical model synchronously through simulations. Finally, the user would receive the necessary information from these three visual mockups.

(3) Specification of the Materials: The type, color and texture of the material is required. The material attributes are entered by the user.

(4) Specification of the Structural System: The structural element type should be selected from the interface of MAR application.

(5) Undertaking Building Performance Simulations: Location data, prevailing wind direction and light and shadow analysis is required as an input. The user enters the aforementioned attributes along with the properties of the material and structural system (Figure 5).

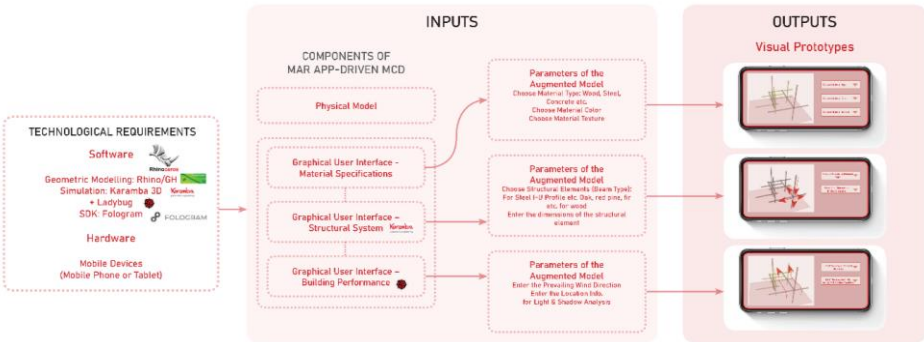

Figure 5. Methodology for MCD Supported by MAR Application.

2.1. TECHNOLOGICAL REQUIREMENTS

The case study prototype of the GUI (Graphical User Interface) is a skeletal construction with horizontal and vertical parts like columns and beams that offers a straightforward structural plan for prototyping. To make the system simpler and more flexible, the flooring is excluded. The Fologram® SDK includes pre-identified QR codes for each type of beam or column. As an illustration, the dimensions of a particular beam or column as modeled in the Rhinoceros®/Grasshopper® environment appear on the screen when the QR code on that beam or column is scanned. The Fologram® SDK is used to provide this object recognition. Because Fologram® includes a motion tracking feature, QR codes are located on the endpoints. It is possible to check if they are positioned horizontally or vertically in the algorithmic modeling environment known as Grasshopper®. Once the modeling and classification of each stick in the Rhinoceros®/Grasshopper® environment have been completed, the application can be launched.

The user-created design and the virtual data overlap when the application is running on the screen. In this program, the user is initially required to enter information for material properties from a list of possibilities, the structural system properties, and finally, information for simulating building performance (Figure 6).

The mobile application will be used and tested in the latter stages of this study. The visual interface prototype is developed in this stage of the study, and a methodology is proposed for the following stages of the investigation.

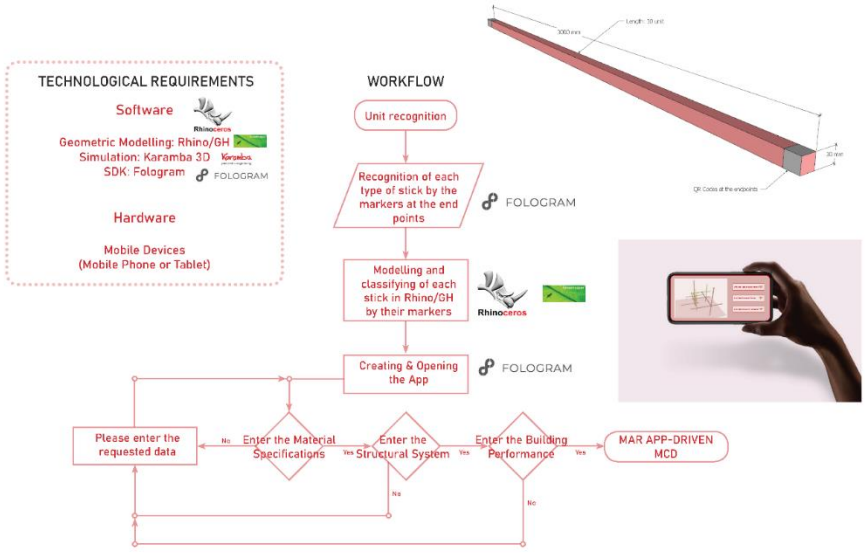

Figure 6. Technological Requirements and Workflow for MCD Supported by MAR Application.

2.2. GRAPHICAL USER INTERFACE – MATERIAL SPECIFICATIONS

The first set of inputs required pertains to three material attributes. The type of material is one crucial piece of information that the user needs to enter. This could be fundamental building elements like steel, wood, or reinforced concrete. The other data, which should be entered by the user, is the color of the material and the last one is the texture of the material. These three features can be altered directly through the MAR interface without any intervention on the physical model.

On the one hand, the ability to improvise in design is made possible by moving the beams or columns. This makes it possible for a more adaptable working environment. On the other hand, because of the type, color, or texture of the material, material specifications can place limitations on the composition of the design (Figure 7).

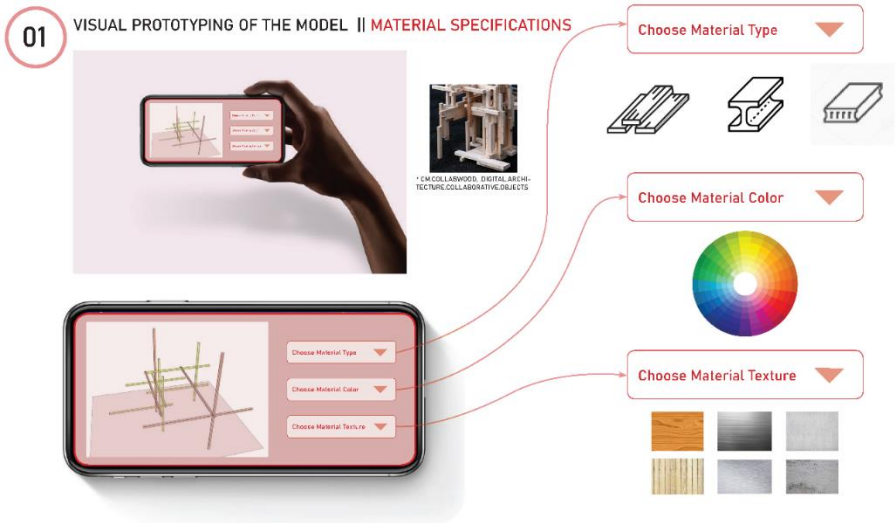

Figure 7. Visual Prototyping for Material Specifications.

2.3. GRAPHICAL USER INTERFACE – STRUCTURAL SYSTEM

The type of the structural element should be entered by searching from the application's library, which includes types of the structural elements, such as steel, wood, and reinforced concrete, similar to how the material specifications section is performed. For instance, options like I profile and U profile show up if steel is chosen. The dimensions of this particular structural piece are entered in the subsequent tab. The behavior of the structure, which is modelled

on Karamba® and simultaneously sent to the application via the Fologram® SDK, is seen on the MAR application screen (Figure 8).

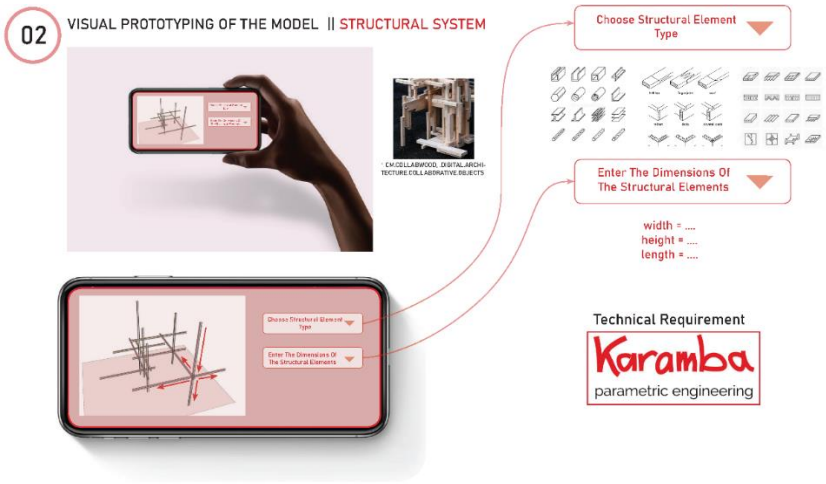

Figure 8. Visual Prototyping for Structural System.

2.3. GRAPHICAL USER INTERFACE – BUILDING PERFORMANCE

The building performance interface, which is linked to the Ladybug® and Butterfly® tools for the simulations and simultaneously brought back to the screen, should be filled out with information such as the position and direction of the prevalent wind (Figure 9).

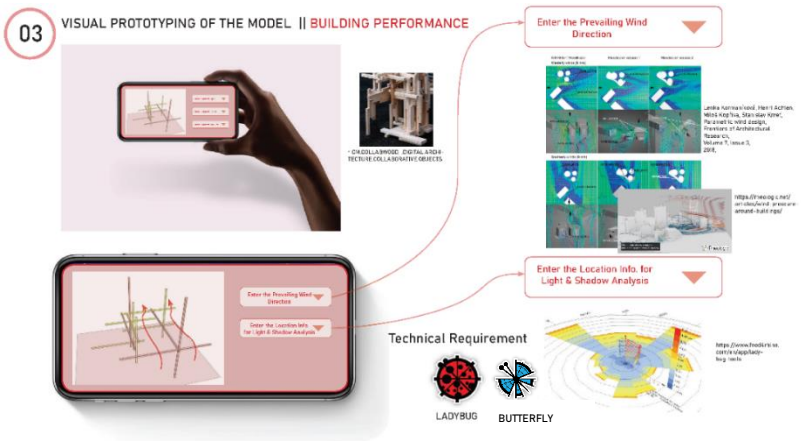

Figure 9. Visual Prototyping for Building Performance.

Users can compare these three different forms of data side by side or independently. They are able to be incorporated into their context and surroundings, and in that environment, simulations tailored to the performance of buildings can be run. This makes it possible to calculate numerous architectural design, construction, and performance factors.

3. Conclusions

The capabilities of integrated approach are improved by using emerging technologies in architectural design. For instance, CAAD technologies make it possible to see building components accurately using representations like plans, sections, elevations, and 3D models. Data-driven design and material-based computational design have more potentials thanks to emerging technologies like virtual reality, augmented reality, and mixed reality that aid with architectural representation. This technology helps the target group not only visualize the data from the developed models, but it also allows them to interact with the model and improve the design before it is implemented.

3D models can be interacted with in a more flexible setting with AR. The experiment of designing with real and virtual items is enhanced by AR. The creative design process can be improved by experimenting with and changing actual and virtual items together. In addition to being necessary for creative design, data-driven design and material-based computational design are also critical parts of design. As a comprehensive and coordinated design production tool, this decision support system offers to incorporate the material, structure, and performance characteristics of physical and digital models into the design. Compared to 2D paper drawing or utilizing traditional CAAD tools, the architectural design process necessitates more flexible solutions. The decision-making processes in design are successfully supported by haptic and digital interaction, creating a 3D interactive model, and experiencing the digital results in a real-time environment.

Students will be able to gather a variety of data simultaneously and become aware of both the emerging tools and the data that are crucial in the design phase by incorporating this proposed technique into both architectural design and architectural education. Students and professors can also collaborate together on designs while using MAR applications.

The visual interface prototype is developed as part of this research. The mobile application will be created and tested in the latter stages of this study. Additionally, future iterations of the technique could incorporate a variety of performances.

An integrated approach to architectural design should be taken into account in future study by concentrating on the contextuality and technology components of working with a physical model and the site condition

combined. The context and environment of a building, which have an impact on the building's functionality, form, and materiality, are absent from the current article. Taking this into account at the outset of the design phase enables more overall design. In the future, this might potentially be put to the test by the employers or the professors.

The Graphical User Interface (GUI) and the methodology are the sole components that are designed and offered in this research. Upcoming studies will also examine how the application is used in practice.

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APPLICATION OF IMMERSIVE TECHNOLOGIES IN THE EARLY DESIGN STAGE IN ARCHITECTURE EDUCATION

A Systematic Review

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Abstract. This paper reviews existing research on the use of immersive technologies, Virtual Reality in particular, in various stages of the architectural design process. Nine research papers were systematically reviewed and analyzed. They were filtered down by using the *keywords:* 'Virtual/Augmented Reality, Architectural Education, Gravity Sketch, Unity and Virtual Environments' from two main databases that focus on digital and computer-aided design research: Cumulative Index about publications in Computer Aided Architectural Design (CuminCAD) and Elsevier's abstract and citation database (Scopus). The selection of papers was filtered down based on relevant approaches which investigate architectural design, creative thinking and teaching methodology using immersive technologies. Another criterion applied to the filtering process of the research papers is the exploration and integration process of new tools and overlapping external software to aid the existing workflow of the user. Our findings explore the evolution of immersive tools to highlight the advantages and disadvantages of virtual reality-based software and hardware, as a creative development tool in the field of education and practice. This paper also proposes a

novel teaching methodology that incorporates immersive technologies in the early design phase of architectural education.

Keywords: *Virtual Reality; Architectural Education; Gravity Sketch; Unity; Virtual Environments.*

الملخص. تستعرض هذه الورقة الوضع القائم فى الأبحاث التى تتناول استخدام التقنيات الغامرة، والواقع الافتراضي على وجه الخصوص، في مراحل مختلفة من عملية التصميم المعماري. تمت مراجعة وتحليل تسع أوراق بحثية بشكل منهجي، وتمت تصفية الأوراق باستخدام الكلمات المفتاحية التالية: "الواقع الافتراضي/ المعزز، والتعليم المعمارى، برنامج جرافيتي سكتش، برنامج يونيتى، والبيئات الافتراضية"، وذلك من خلال قاعدتي بيانات رئيسيتين تركزان على أبحاث التصميم الرقمي بمساعدة الكمبيوتر: الفهرس التراكمي حول المنشورات في التصميم المعماري بمساعدة الكمبيوتر (كيومنكاد) وقاعدة بيانات سكوبس للملخصات والاستشهادات التابعة لـ"السيفير". وتمت تصفية عملية اختيار الأوراق البحثية بناءً على الأساليب ذات الصلة التي تبحث في التصميم المعماري والتفكير الإبداعي ومنهجية التدريس باستخدام التكنولوجيا الغامرة. وكان المعيار الآخر المطبق على عملية تصفية الأوراق البحثية هو عملية الاستكشاف والتكامل للأدوات الجديدة والبرمجيات الخارجية المتداخلة لمساعدة سير العمل الحالي للمستخدم. وتدور نتائج البحث على استكشاف تطور الأدوات الغامرة لتسليط الضوء على مزايا وعيوب البرامج والأجهزة القائمة على الواقع الافتراضي كأداة تطوير إبداعية في مجال التعليم والممارسة. وتقترح هذه الورقة البحثية أيضًا منهجية تدريس جديدة تتضمن تقنيات غامرة في مرحلة التصميم المبكرة للتعليم المعماري.

الكلمات المفتاحية: *الواقع الافتراضي، التعليم المعمارى، برنامج جرافيتي سكتش، برنامج يونيتى، البيئات الافتراضية.*

1. Introduction: VR/VE Evolution & Accessibility

Since the introduction of immersive tools in the ’90s, the architectural platform has utilised VR/VE (Virtual Reality/Virtual Environment) tools to evolve traditional design techniques and approaches (Alvarado & Maver, 1999). The use of immersive tools in various stages of architectural design allows the user to grasp space on a 1:1 scale via a virtual reality walk-through for design analysis and visualization. VR/VE utilisation has since evolved, by testing out various interactive techniques like 3D sketching and collaborative design methods in the VR/VE environment. In a similar timeframe, Bricken & Byrne (1992) explored VR as a new input tool to use as part of the design process in a summer workshop series. Achten et al. (2000) also explored the potential of VR software by developing a testing DDDoolz, a 3D voxel-based platform that allows the users to sketch in a 3D space. Given the direct nature of interaction offered in VR that is usually missed from using a traditional monitor, users are actively able to inhabit and interact with a digital space with

the ability to directly modify and interact with the space via the built-in tool's set-up by the designer (Achten et al., 2000; Bricken & Byrne, 1992).

VR/VE technology integration has since been expanded upon by exploring different design approaches via updated modern software and hardware. Immersive hardware has also extended compatibility to industry-standard software to allow the user to export, edit and analyse their designs and function through multiple stages of the design process in VR. The design methodologies that incorporate immersive tools typically follow a preset system and workflow that is made accessible to the user.

The use of VR and VE tools for the first time can result in a steep learning curve (Schroeder, 1995). This is similar to using any new software or hardware and adapting to a new system and user interface. It is also important to acknowledge that advancing technology increases in accessibility and is less 'complex' with each iteration as it becomes more commercially available to consumers each year, this is due to the software UI (User Interface) and hardware designs evolving to appeal to wider consumer demographics instead of being limited to advanced academic and research platforms. This evolution of hardware and software design flattens the learning curve gradually with every iteration of VR/VE technology that is released to the public (Bricken & Byrne, 1992; Myers et al., 1999). Recent technologies remove various limitations of hardware setup, devices like the Oculus Rift device that was released in 2016 require several connections and sensors to set up, this can be compared to more recent hardware like the Oculus/Meta Quest which offers inside-out tracking and a single cable for charging and optional PC connection (Figure 1.). The simplification of the setup process by eliminating external sensors, additional cables, and a high-end graphic PC allowed for a quicker experience and an increase in accessibility to a wider consumer and professional demographic.

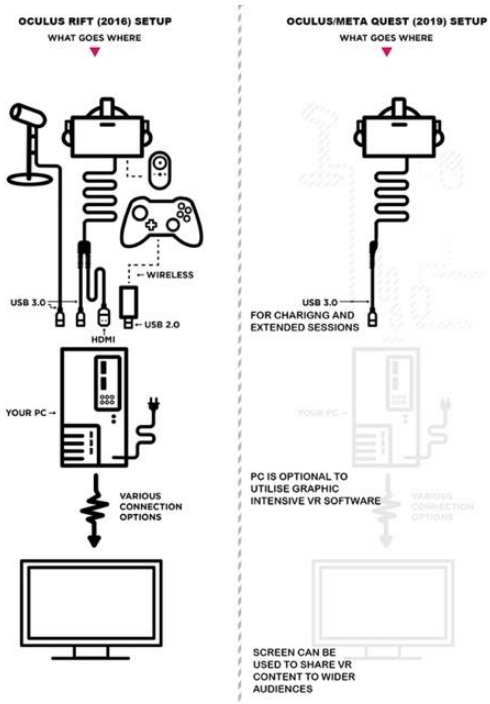

Figure 1 Hardware setup for Oculus Rift 1 and Oculus/Meta Quest 1/2

In architectural education environments, the use and integration of AR/VR technologies in the design process is still rare and if present at all, it is usually limited to a few weeks per semester to introduce, teach and implement immersive technology to students, this is due to the technology's complex setup which resulted in little to no practical implementation of immersive VR/VE tools in current design education. Simplifying the approach taken to set up and utilise this technology as part of the architectural design workflow becomes a crucial point when adopting the tool for practical design and academic implementation.

2. Review questions and aims

Although various methods have been applied in past research to explore immersive technology, only a few scholars have justified the choice of software, or have deeply provided in-depth analysis to compare different VR platforms and potential conventional approaches to developing a design methodology that can be accessible and become an applicable addition to the architectural design process. In continuation to our previous research

(Agkathidis, 2016), the current paper investigates which existing VR software and hardware is accessible and suitable to aid the architectural design process. In particular, this paper addresses the following research questions:

- How can we develop an educational framework incorporating virtual environments into the early stages of the design process in architectural education?
- What existing software and hardware can be utilised to achieve, develop and test this framework practically?

3. Review Methodology

Our systematic review method consists of four phases (Figure 2.). 1) Article search through databases including Scopus and CuminCAD, 2) Screening of selected papers, 3) comparatively analysing and categorising each paper and its design methodology approach, 4) evaluating each software and methodology through charts and tables.

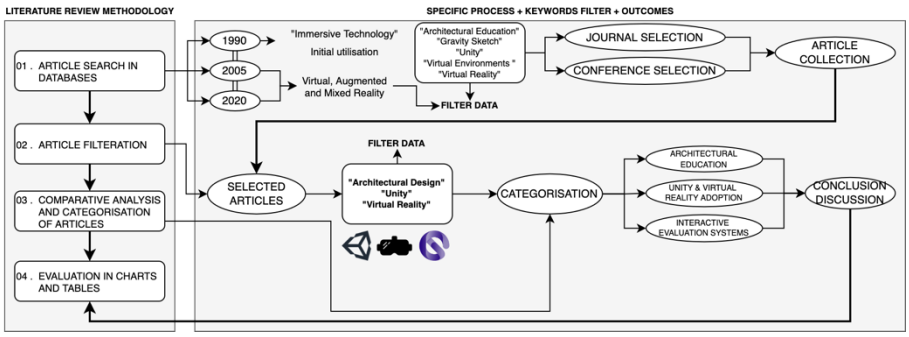

Figure 2. Literature Review Methodology

In the first phase of our research, two main databases that focus on digital and computer-aided design research were used: Cumulative Index about publications in Computer Aided Architectural Design (CuminCAD) and Elsevier's abstract and citation database (Scopus). These databases were selected due to their reliability and accuracy. The keywords searched include Virtual Reality; Architectural Education; Gravity Sketch; Unity and Virtual Environments in titles, abstracts and given keywords of the articles. The search results reveal higher numbers in conference papers than journal papers since digital design and VR/VE in architectural education continue to emerge in recent years as technology evolves. CuminCAD revealed the highest conference publication count for our search. CuminCAD is one of the main databases for digital design in architecture supported by ACADIA,

CAADRIA, eCAADe, SIGraDi, ASCAAD and CAADfutures. In contrast, Scopus comprises mainly journal articles and book sections related to our research. As a result of our filtered search, 57 academic publications were found. In the second phase, these articles were filtered by removing review publications and low-relevance articles. Furthermore, articles not dealing with VR/VE/AR or Unity in architectural education were removed, resulting in the remaining nine articles reviewed here. In the third phase of the literature review, the nine articles were categorised systematically and analysed according to the following: 1) architectural teaching methodology, 2) Unity & virtual reality adoption, and 3) integration of interactive evaluation systems. Finally, in Phase four, these categorised articles are analysed and compared to answer our research questions.

4. Past & current research on VR/VE integration in architectural design/education

4.1. VR/VE in the 1900s

Some architects and researchers in the ’90s have applied Virtual Environment (VE) tools to traditional architectural design methods. One of the initial highlighted research projects explore the use of a panoramic screen that displays a wide field of view, the display was located in a physical room that hosted up to 14 students per session, in addition to allowing the main user to present a series of pre-built projects to the students via the medium (Alvarado & Maver, 1999). This cinematic room setup is referred to as the Virtual Environments Laboratory (VEL). The design and development aspect of the paper is further explored through the integration of online learning and virtual live communication via a private network between two academic institutions which include: Strathclyde Institute and Mackintosh School of Architecture. VE exploration is also utilised by the students to assess their digital models, unfortunately, the files were limited in graphic capability and did not show as many details due to the low polygon count that had to be maintained to reduce the lag. This was a common obstacle involving the technological limitations that were available at the time. The paper successfully portrays the approach of digital tool integration available at the time and how the same approach can be used today with new immersive technology, to explore not only VR head-mounted devices but also the different VE approaches to involving multiple people in a single immersive experience.

In 1991, the VE Technology offered 10 students between the age of 10-15 to utilise the technology each week spanning throughout the

Technology Academy summer program. A pre-session was prepared to allow the students to familiarize themselves with the platform through initially understanding the concept of how the technology works and later experiencing a series of demo virtual spaces. In a later stage, students worked in groups of three to share one computer with the VE setup. With the guidance of an instructor, students had the opportunity to explore the development of virtual spaces. Given the 'clustered' work environments, students had the ability to exchange knowledge and design approaches which resulted in various virtual worlds that were accessible in VE. The pragmatic approach of this series of workshops led to a practical understanding of the contributions that VR offered at the time, and hence an understanding of the possible implementations that VR can be adapted for in future iterations of the technology.

4.2. Interactive, Inclusive and accessible design: Voxel Design

Virtual reality was initially limited in graphical power and visualisation in the early 2000s. Voxel design was an innovative approach to accommodate this limitation, by utilising a building-block scheme to provide the user with the ability to create sculptural and structural forms in a 3D blank space in VR by stacking and colouring a number of cubes. DDDoolz has been developed by Bauhaus Universität in Weimar with a primary incentive to achieve a simple user interface that supports easy creation in a VR environment (Figure 3.). The interface also supported easy navigation and manipulation in the VR environment to support spatial understanding of the design at 1:1 scale (Achten et al., 2000).

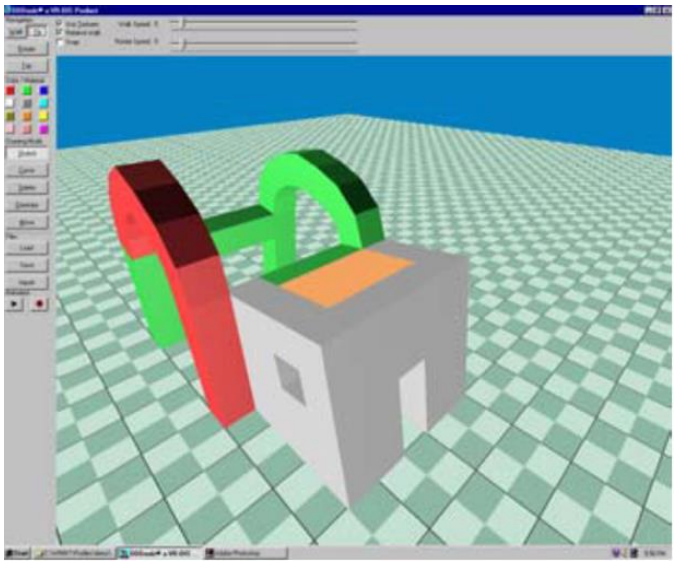

Figure 3. Sketch in DDDoolz (Achten et al., 2000)

Conventional architectural approaches involved site analysis; 2D sketches and 3D programme massing using physical models to develop the building design. The use of DDDoolz layered these stages in a more immersive layout, allowing the user to develop and experience quick sketch models for further analysis. Voxel Design becomes very effective in the initial design process as the user is forced to simplify their thought process into simple forms and shapes that can highlight the different proposed building programmes from 2D to 3D.

Voxel design is also adopted in a recent case study that utilises the popular multiplayer sandbox game, Minecraft, which was developed by Mojang (Delaney, 2022). The conducted research took place during the Covid-19 pandemic period, exploring remote collaboration, public participation/contribution and live feedback and connectivity to an ongoing public-site project. Minecraft is a voxel-based open-world sandbox video game that supported local and online multiplayer gameplay. The game offered a ‘Survival ’mode which incorporates an open-world adventure, involving enemies, crafting tools and weapons to mine resources for building advanced items and shelter. The ‘Creative ’mode which Delaney compares to LEGO building blocks, placed players in an infinite 3D blank ‘canvas’, allowing them to build and compose structures using the large array of material selections in the game.

The research tested the creative potential of voxel design that extends from Achten's research. The project utilised the Creative mode of the game to conduct a research study that focused on public participatory design open to a wide age range and various backgrounds. Given the popularity of the game, the project attracted various age groups, the younger demographic in particular that ranged between 16-24, the game's popularity was also complimented by how accessible it is mainly due to the various platforms the game has been ported into, including PC/Mac, gaming consoles and mobile devices. This is made possible mainly due to the low graphic requirements of the game. Public participation was conducted in a live site that was recreated in the virtual voxel environment. Each participant was given a plot in the open world with a copy of the same site to design and build on by following a particular design brief (Figure 4.).

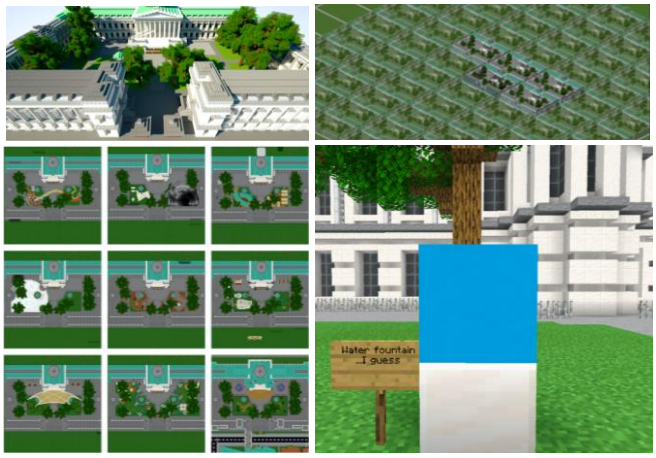

Figure 4. Research output preview of the selected site, plot organisation and site design outcomes (Delaney, 2022)

The voxel medium initially portrayed visual limitations but encouraged players/designers to think outside the 'box 'and creatively attempt to develop their designs using the in-game tools. The live design and multi-user implementation of this project also allowed for live feedback and a number of multi-user collaborations. The assessment of this project was conducted in a survey format after participants completed their designs. The survey outcomes revealed a positive outcome that showcased interest to participate in similar future projects mainly due to the simplicity of design and accessibility of the game. This research further emphasizes the importance of accessibility and simple user interfaces, this is also complemented by Mojang's recent announcement to allow users to explore and build their existing and future

Minecraft projects in VR (Mojang, 2022). This offers the potential to further utilise VR as a design tool by expanding their virtual environments in the existing software to achieve a more immersive design experience.

4.3. Freeform Sketching & Accessible VR software.

Barczik (2018) developed a study to explore interactive design and performative movement. Unlike the previous papers that have embraced voxel design, Google Tilt Brush is utilised in this research (Barczik, 2018). The software design of the application took an artistic approach, by allowing the user to sketch and layer a series of flat 3D brush strokes with various shapes and paint textures to create their compositions. In contrast to voxel modelling utilised in DDDoolz and Minecraft, Google Tilt Brush offered more expressive output, breaking free from the 'box 'and allowing designers to express detailed free forms. The study takes a *unique* theoretical and practical approach to the architectural design process by involving performative gestures that are recorded using the VR controller. "*Exploring movement in 3D and 4D space for architectural design has little if at all investigated*" - Barczik (2018). As a theoretical-based paper, it is interesting to see that the project and course structure applied by Barczik is not fixed, this is done by providing a flexible design methodology that allowed the student to adapt and utilise the VR tools without any limitations. One student embraced the performative aspect of the design brief by focusing on "*non-immersive trace*", this excluded the immersive element of VR and only used the controller to blindly trace the body movement in physical space (Figure 5.).

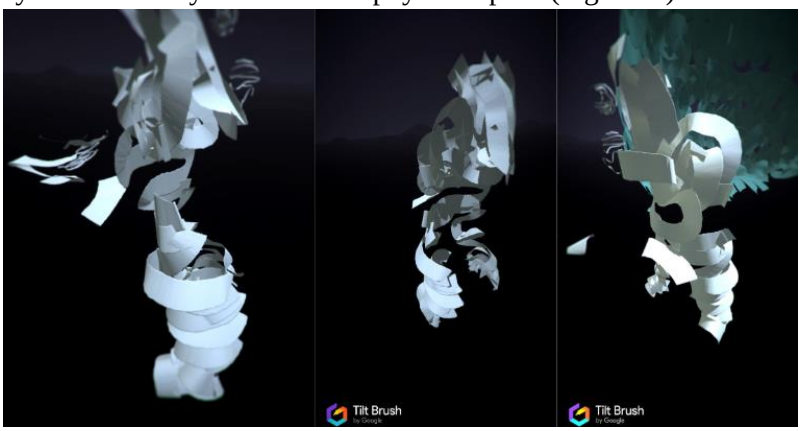

Figure 5. Non-Immersive Trace: Tilt brush Screenshot (Barczik, 2018)

As a theoretical-based paper, exploring this form-finding technique resulted in the ability to trace, analyse and extract movement into external software for further modification and refinement. Given the artistic intent of Google Tilt Brush, the model mainly consisted of flat brush strokes layered to create a form that has no volume. The output of these models required further refinement using external software like Rhinoceros – a 3D CAD tool. The external tool is used to extrude the multiple flat surfaces into 3D. This showcased a limitation within the software as it prioritised the visual aspect of the 3D sculpture, with little control to edit and modify the 3D sketch in VR.

4.4. Advanced Software & Interactive Design Limitations

Software like Google Tilt Brush used by Barczik (2018) falls under the digital sculpting category, enabling the user to sketch in 3D space. Other software like Google Blocks and Gravity Sketch follow similar frameworks to Google Tilt Brush, with different user demographics in mind for each platform. This is made clear when highlighting the toolset and export options that each software offers. Asanowiz's research explores a similar approach to Delaney's (2022) and Barczik's (2018) paper. The research was executed by enabling live model interaction within the process of creation while considering the possibility of implementing the idea of "direct design" (Asanowicz, 2018).

The main limitation of the software is primarily the lack of design tools that enable the user to scale and modify specific faces of the model to achieve higher details in their 3D sketches. Complex tool limitations can be overlooked when software like Google Blocks and Google Tilt Brush aims to achieve higher accessibility and quick sketch development, in contrast to precisely detailed models and sculptures. The author discusses the student's response to the software while highlighting the ease of accessibility due to the efficiently designed user interface that supports a "fast learning curve" (Asanowicz, 2018).

By introducing an accessible modelling tool to a cohort of students that might have not experienced VR before, accessibility becomes an important key factor that will allow students to embrace the medium in the future and potentially explore more advanced tools like Oculus Medium, Oculus 'powerful VR sculpting app. The student's work is further assessed with a comparative study between the physical architectural models and the digital models developed in VR. The paper concludes with potentially exploring a future Game Design course that enables the users to import their

3D polygon models to explore interactivity via game-engine software including Unity or Unreal Engine to elevate the “Static visuals” and explore potential interactive concepts within their developing building designs.

4.5. Game Engines, Interactive Design & Immersive assessment

Game engine software has evolved with the intention to appeal to various platforms including architectural and visualisation professions. Game engines like Unity follow a similar UI design language to 3D design software Autodesk 3DS max (Figure 6.). This UI similarity allows users to increase the adoption of the platform due to its familiar UI design. Game engines provided an extra layer to the design development approach, giving the designer the ability to experiment with interactive applications to their existing designs.

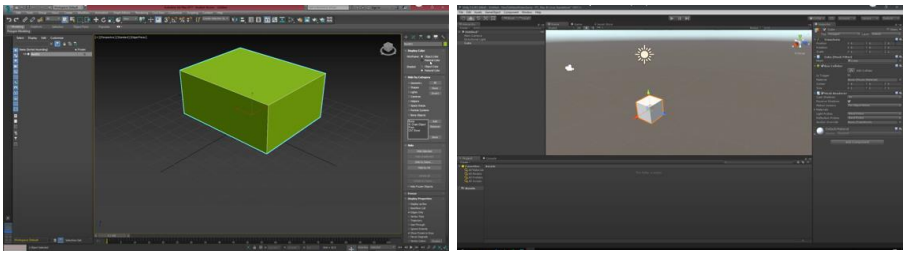

Figure 6. Software interface comparison Autodesk 3DS Max (Left) and Unity game-engine (Right)

The VR scope box focuses on enabling the user to visualize details in 3-dimensional space at a 1:1 scale with accurate material representations (Morse & Soulos, 2019). The research embraces the Unity game engine to explore CAD-developed models in sectional detail, allowing the user to visualise any part of the imported building segment in sectional view to preview internal material layers and details. The idea of evolving the static architectural 3D model into an interactive experience in a VR system elevates the immersive experience for analysis and development. The approach to incorporating a game engine into the design process can result in a steep learning curve. The learning curve can be bypassed by developing a preset setup that integrates these assessment tools to efficiently be taught to participants to import their own designs. Morse and Soulos (2019) took this approach to export the Unity assessment tool setup into a preset file that was made accessible to the students and teachers to import the designed models for reviewing and assessment in several ongoing design projects.

Assessment of design through the utilisation of immersive technologies can lead to more informative analysis, VE tools provide the

ability to inhabit a design in VR, or to place the digital model in physical space using AR. Weissenböck (2021) utilises AR in her research to explore remote learning approaches to architectural education. The course was hosted remotely, students were introduced to Rhinoceros3D and Grasshopper and were assigned to work in groups to develop their designs. Each participant was then asked to individually place the group design in their own physical space and adapt the form using physical QR-code/ArUco Markers. These markers were placed on the wall or floor to track the position of the model in the physical space using AR and Grasshopper. The series of markers provided a physical interactive element that allowed the user to make any adjustments to the model by moving the ArUco Markers to adjust the design to suit their physical space (Figure 7.).

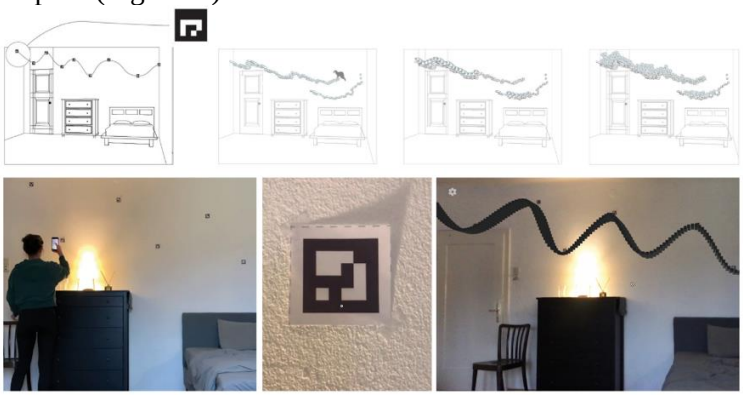

Figure 7. Project 1.1: "flow follows fologram"; design ideas (top), the process of scanningArUco markers on the wall with the smartphone app, and adapting parameters with sliders in the ARapp, which are synchronized to the computer (Grasshopper window and Rhinoceros model window) (middle and bottom).98|eCAADe 39- CAAD and education - Volume 2

5. Analysis and discussion of the filtered papers

Bricken and Byrne (1992) researched one of the first initial uses of immersive technology in architectural development according to our analysis. The VR-based project took place during a summer workshop series, involving multiple users to develop and create a series of virtual spaces using Swivel, a 3D modelling software, and later experiencing them on the VR platform. The immersive outcome of this project resulted in positive and "*enthusiastic feedback*", based on the follow-up survey results from the participants (Bricken & Byrne, 1992).

In a similar time frame, Alvarado & Maver (1999) researched the VEL (Virtual Environments Laboratory). The VEL was categorised as a VE system that consisted of a cinematic panoramic display. Given the limitations

of the technology in the 90s, the visualisation of the designs was limited due to graphical power. Given this minor setback, users were still able to utilise the medium and experience their designs from a new perspective. The VEL also supported up to 12 users at once, with the addition of remote connectivity with different institutions to promote collaborative learning and development.

Achten et al. (2000) followed up in the early 2000s, delving into the interactive aspect of digital design. Achten et al. worked on DDDoolz, which explored the concept of Voxel sketching in VR. Developing compositions with cubes was limiting, but the simplified medium provided more room for creative composition and immersive exploration that was accessible to the user. Voxel design was seen as accessible mainly due to its simple visual, this was proved in a more recent project by Delaney (2022) using Minecraft. The modern video game/software welcomed a large number of contributors due to the platform's popularity. The project also resulted in a positive outcome when it came to addressing inclusive collaborative and interactive design.

The integration of interactive design becomes a focal point when it came to utilising game engines as part of the design process. Game engines like MediaStage and Unity were utilised as a part of a study to explore interactive and immersive-based assessment (Morse & Soulos, 2019; O'Coill & Doughty, 2004). Game-engine-based software enabled the students to develop immersive experiences that involve interactive input systems that can be used for spatial analysis and visualisation, incorporating this process played a major role in the teaching methodology approach as it gave control to the student to customise their interactive and immersive experience. The use of parametric design complements further the integration of interactive design. Rhinoceros3D/Grasshopper enables this experience through various plugins that enable different VE immersive tools to be used. In a recent study, AR was paired with multi-marker tracking to enable the user to translate and modify their 3D parametric models to fit in specific locations through the AR lens (Weissenböck, 2021). The project took place virtually, enabling the students to work remotely and collaboratively in groups throughout multiple iterative design stages to develop a single model that adapted to each individual user's physical space.

Free-form and design testing are also addressed as an extension of Achten et.al (2000) research. Removing the restrictions of voxel design and enabling detailed 3D models. Google Tilt Brush and Google Blocks are both utilised in different design projects in the academic platform. The mediums were used to explore form-finding and design exploration techniques in VR.

The use of VR tools led to a series of digital models developed by the students. These models were assessed and contrasted with the physical models developed in the earlier stages of the design project. Asanowicz (2018) assessed the difference between the two approaches and takes a practical approach to test out the level of interactivity that is enabled by the user to assess the quality and design outcome. Barczik (2018) Took a similar approach but instead focused more on the performative aspect that theorised the variation of form-finding techniques in VR throughout the initial architectural design stages.

6. VR/VE Tools & Potential Design Techniques

VR/VE tools can lead to unique results that can vary based on the adopted software and design brief. This paper aims to utilise software that is accessible and offers a set of advanced tools that can lead to more complex results. Consequently, the software must also offer multiple export options and enable multi-user support for potential collaborative design. Based on the analysed papers, most of the software used showcased some limitations including, design toolset, accessibility and ability to export the model for further development (Table 1.).

TABLE 1. Softwares list used for VE architectural development

Software	Release Date	XR type	Hardware Support	Techniques used	Import / Export options	Advanced tools?	Multi-user support	Integration in design studio	Reference
Swivel	1992	VE	PC/VR	3D modelling	NO	NO	NO	NO	(Bricken & Byrne, 1992)
VEL	1999	PC	PC	Visualisation	NO	NO	YES	YES	(Alvarado & Maver, 1999)
DDDoolz	2000	VR	HMD	3D Voxel Sketching	NO	NO	YES	YES	(Achten et al., 2000)
MediaStage	2004	VE/ VR	PC	3D Visualisation	NO	NO	NO	YES	(O'Coill & Doughty, 2004)
Unity	2005	VE/VR /AR	PC/Mobil/ PCVR	Site Analysis	YES	YES	YES	YES	(Morse & Soulos, 2019)
Minecraft	2011	VE	PC/Mobil/ PCVR	3D Voxel Design	NO	NO	YES	NO	(Delaney, 2022)
Rhinoceros/ Grasshopper	2014	VE/VR /AR	PC/Mobil/ PCVR	3D model extension	YES	YES	NO	YES	(Weissenböck, 2021)
Google Tilt Brush	2016	VR	Oculus Quest/ PCVR	3D Sketching	YES	NO	NO	YES	(Barczik, 2018)
Google Blocks	2017	VR	Oculus Quest/ PCVR	Polygon 3D sketching	YES	NO	NO	YES	(Asanowicz, 2018)
Gravity Sketch	2017	VR	Oculus Quest/	3D Sketching	YES	YES	YES	NO	**No publications on this software**

			PCVR						
VR Sketch	2018	VR	Oculus Quest/ PCR	SketchUp VR control/ modelling	YES	YES	YES	NO	**No publications on this software**

7. Conclusion

Throughout the filtered papers, only four papers have attempted to integrate VR and AR tools as a substantial part of the design methodology. Substantial use is defined by the level of VR/AR technology utilisation throughout different stages of the architectural design process, instead of limiting the tool for visualisation purposes only. Each of these papers utilised VR and AR using different techniques. Some enabled the student to Sketch, explore, alter and assess their designs throughout different stages of the project, others showcased the remote potential for collaborative design and assessment techniques between peers and the lecturer (Asanowicz, 2018; Barczik, 2018; Morse & Soulos, 2019; Weissenböck, 2021).

Furthermore, according to Table 1., we have identified three primary software that can be implemented into the developing design methodology. Softwares include 1) Gravity Sketch, 2) VR Sketch and 3) Unity. Little to no research has been done using Gravity sketch. Even though the software showcases great accessible potential to be used as sketching, modelling and refinement tool throughout the architectural process. Gravity Sketch is a recent tool released in 2017, housing a number of design tools like 3D sketching, edge-grab, massing, surface, scale, materiality and others. As an extension to this, Gravity Sketch also enables model import and export in various formats that enable external software compatibility. Site models can be imported to scale to allow for 1:1 scale sketching and design exploration. VR Sketch is the second software that users will import their designs into via SketchUp 3D. No research has been published using VR Sketch as a modeling collaborative tool. The software showcases great potential as a collaborative and immersive tool. As a plugin to Sketchup, the user has remote access and control to a SketchUp model in VR with the addition of the SketchUp modelling tools. The Unity game engine will finally combine the interactive element to allow the user to develop, import and assess their designs on the VR platform.

Finally, having analysed the different pedagogic approaches in the integration of VR/AR technologies into the design studio process, we propose a novel design and teaching framework enriching the generative design methodology proposed by Agkathidis (2016), by integrating VR/VE tools and exploring contextual based problem-solving techniques similar to the research done by (Delaney (2022). Throughout the design and interactive process, the design workflow can cycle through multiple iterative stages, allowing the

users to refine their designs throughout the project (Figure 8.). The proposed framework is an output of the review that has been conducted. The framework will be tested and evaluated in design studio classes in our future work, aiming to provide a conventional methodology for immersive architectural design.

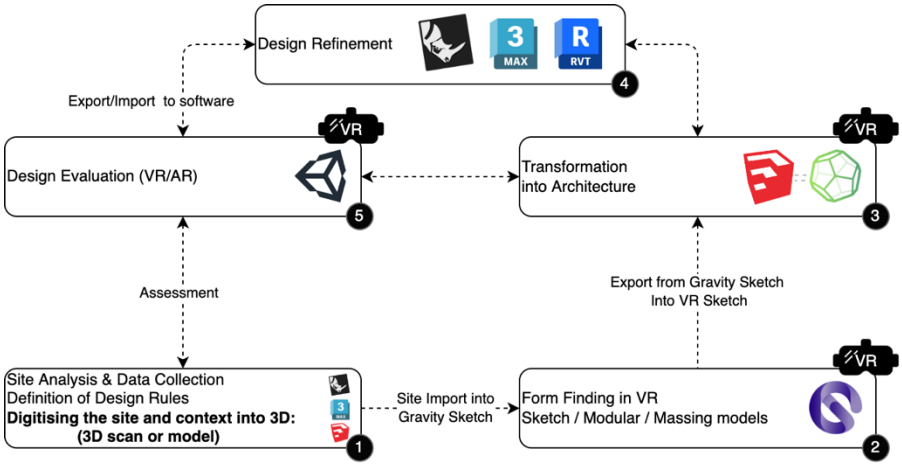

Figure 8. Design Methodology: Design Framework

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COMPUTATIONAL DESIGN APPROACH FOR APPLYING NEURO-ARCHITECTURE PRINCIPLES IN HEALTHCARE FACILITIES

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Abstract. Neuroscience tools' advancements have paved the way for neuroscience and architecture collaboration, spawning "Neuro-architecture." Neuro-architecture studies in various settings have been tentatively translated into design principles to improve the mood, perception, and satisfaction of healthcare facility users, as well as patient wellbeing and recovery rates. Integrating such principles into computational design methodologies should benefit users' mental health and reduce the gap between computational design and human mental needs. The research was conducted in two phases: in the first phase, typologies used in evidence-based design research (EBD) were applied in order to determine neuro-architecture design principles for the interior environment of healthcare facilities. In the second phase, the research employed space syntax analysis to evaluate the incorporation of neuro-architecture principles into healthcare facility interiors. The method visualises and evaluates spatial qualities that reflect the application of planning and navigation neuro-interior principles for the inpatient ward of a healthcare facility.

Keywords: *Evidence-based design, navigation, wayfinding, spatial qualities, space syntax.*

ملخص. مهدت التطورات التي حققتها أدوات علم الأعصاب الطريق للتكامل بين علم الأعصاب والعمارة، مما أدى إلى ظهور ما يسمي بـ"العمارة العصبية". وقد اهتم هذا البحث بترجمة دراسات العمارة العصبية في سياقات مختلفة مبدئيًا إلى مبادئ تصميم لتحسين الحالة المزاجية والإدراك والرضا لمستخدمي مرافق الرعاية الصحية، فضلاً عن معدلات رفاهية المريض والتعافي. ومن الواضح أن دمج هذه المبادئ في منهجيات التصميم الحوسبي ذو فائدة بالنسبة للصحة العقلية للمستخدمين وتقليل الفجوة بين التصميم الحوسبي والاحتياجات العقلية البشرية. تم إجراء البحث على مرحلتين: في المرحلة الأولى، تم تطبيق الأنماط المستخدمة في أبحاث التصميم القائمة على الأدلة (EBD) من أجل تحديد مبادئ تصميم العمارة العصبية للبيئة الداخلية لمرافق الرعاية الصحية. وفي المرحلة الثانية، استخدم البحث علم تحليل بنية الفراغات لتقييم دمج مبادئ العمارة العصبية في التصميمات الداخلية لمنشآت الرعاية الصحية. تقوم المنهجية المتبعة

بتصور وتقييم الصفات المكانية التي تعكس تطبيق مبادئ التخطيط والملاحة الداخلية العصبية لقسم المرضى الداخليين في منشأة الرعاية الصحية.

الكلمات المفتاحية: *التصميم القائم على الأدلة، الملاحة االفراغية، علم إيجاد الطريق الفراغي، السمات الفراغية، علم بنية الفراغات.*

1. Introduction

Understanding how spaces influence people has long been a priority for architects and environmental psychologists. Their conclusions, however, were founded on empirical research. Using evidence-based design, they studied how people act differently in diverse contexts. However, because to technical constraints at the time, such studies were unable to detect brain responses in the same way that they are now. As a result, they are unable to deal with the full intricacy of the relationship between neurology and architecture. Nonetheless, the capacity to consciously process information is less than 1 percent of the ability to process information in an unconscious manner (Nani and Cavanna, 2012). As a result, the factual observations from external observers or the user's conscious opinions are only the result of the response to the stimulus, not the actual response.

It has been consistently proven that hospital architecture has an influence on patient satisfaction with treatment, emotional condition, and rate of recovery (Ulrich et al., 2008). Results from studies conducted in selected medical conditions have been tentatively translated into design principles that are applicable to health-care environments and the application of these principles is recommended to enhance recovery (Dan, 2016). Measurements of spatial features, visual parameters, and visibility analysis study may provide a novel and adaptable paradigm for the quantitative examination of the application of neuro-architecture interior design principles in healthcare facilities. As such, this study intends to investigate space syntax analysis as a computational methodology for evaluating the interior spaces of healthcare facilities through the analysis and measurement of several visual and spatial qualities that can ensure the use of neuro-interior design principles.

2. Neuro-Architecture: The Effects of Space on the Brain

The relationship between the human brain and the built environment has been studied from both theoretical and methodological perspectives. The relationship between neuroscience and architecture was divided into three categories by (Arbib, 2013). Individual reactions to the built environment are the subject of this research.

Neuroscience technologies such as psychophysiological measurements and brain imaging methods paved the way for collaboration between neuroscience and architecture. Because the study topic is interdisciplinary, the collaboration

utilizes several techniques that include environmental, behavioral, and neurological components using digital technology. As seen in Figure1, below are the several approaches used in neuroscience and architecture research that are described in literature.

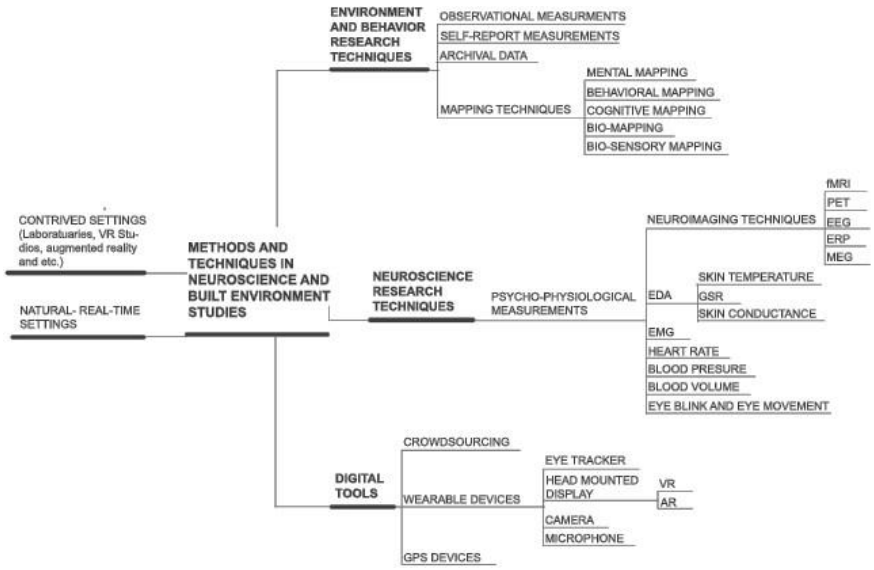

Fig. 1. Research methods for the built environment and neuroscience investigations (Karakas and Yildiz, 2020)

3. Neuro-Architecture Design Principles for Healthcare Facilities

The ideal approach to developing a technique for applying neuroscience to interior design is to first comprehend and investigate the findings of neuroscience in connection to interior space, as well as the case studies in which these discoveries were applied. The design process begins with the identification of the many stimuli that must be elicited inside an interior space. Additionally, it is critical to comprehend the various interior spaces and their main aspects, as well as to use neuro-design concepts aimed at eliciting inspiration or a sense of enlightenment (Refer to Figure 2).

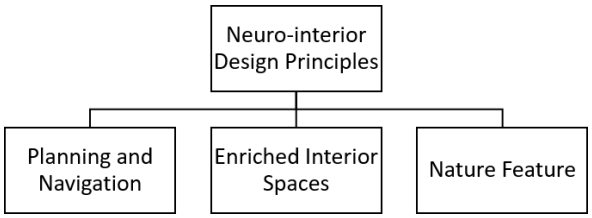

Fig. 2. Neuro-Design Principles (Ibrahim, 2019)

To begin comprehending the relationship between neuroscience and interior space, we may look at our fundamental actions, which include the use of our five senses to perceive our surroundings. There is no doubt that perception involves spatial properties such as color, light, texture, smell, and sound, as well as our navigation through space, where the human brain registers sensations through sight, sound, and touch, and interior design elements such as form, color, materials, natural light, and nature influence the human psyche.

Neuroscience explores the influence of our physical surroundings on our cognition, problem-solving abilities, and emotions. Understanding these concepts can help interior designers build spaces that promote spatial orientation while also reinforcing cognitive abilities and mitigating negative emotional and motivational effects.

There are several design concepts for interior spaces that are influenced by neuroscience. Classifying these concepts clarifies the neuro interior design process and enables the designer to adjust them for diverse spaces (Refer to Figure 3).

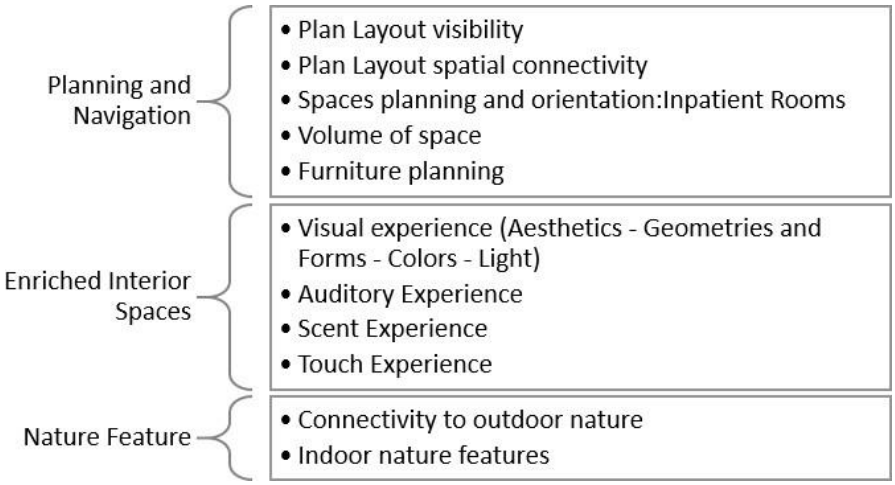

Fig. 3. Healthcare facilities neuro-interior design principles classification

Space visual/ locomotive permeability is confirmed to have effects on the brain with activating structures underlying perceived visual motion, so closed rooms elicit exit decisions and activated the anterior midcingulate cortex (aMCC) in contrast with open rooms (Vartanian et al., 2015).

Poor wayfinding may induce anxiety, whereas excellent wayfinding design can reduce stress. (İlker Erkan, 2018; Morag et al., 2016). According to these findings unobstructed lines of sight linking entry spaces and other critical, central spaces such as atria to vertical circulation systems such as staircases in addition to frequent and consistent sight lines to elements such as exterior vistas,

atria, or visually significant architectural features should be taken into consideration when planning. These also could positively affect wayfinding behavior according to (Dalton et al., 2015).

When planning multilevel-facility, minimization of the disparity in multi floor plans is recommended that's because users will think that each floor is identical to the preceding one. Deviating too far from this will lead to needless confusion. (Hölscher et al., 2006; Dalton et al., 2015)

According to Ulrich's theory of supportive design, perceived control in the design of a healthcare facility can be achieved by assuring accessibility to all spaces, corridors, toilets, and services. (Harris et al., 2002; Andrade et al., 2017)

4. Computational Approach for Integrating Neuro-Architecture Principles in the Interior Environment of Healthcare Facilities

The research emphasizes on the planning and navigation neuro-architecture principles and introduces a space syntax analysis computational approach for the evaluation of the spatial qualities of healthcare facilities. The approach focuses primarily on the spatial configuration of the healthcare facility's floor plans and the quantification of spatial qualities in order to apply neuro-design principles targeting the wayfinding behavior of visitors to inpatient wards, in addition to the visual connectivity between nurses' stations and inpatients' room entrances and between nurses' stations and each other. Because a good wayfinding experience reduces stress and anxiety, visual connection to inpatient rooms is expected to positively encourage nurses to provide more care for patients, and the inter-visibility between the nurses' stations and each other supports the social interaction, satisfaction, and performance of nurses, thereby enhancing the quality of the medical care they provide. Depthmap X is used to analyze the main benchmarks involved in measuring spatial qualities, such as visual connectivity, integration and 2D isovists.

4.1. SPACE SYNTAX ANALYSIS METHODOLOGY

In the areas of neuroscience, cognitive science, and space syntax research there is a growing body of evidence that provides a foundation for design, especially in the case of wayfinding and navigation in complex buildings like the case in healthcare facilities. Although these studies were not applied with neuroscience tools and brain neural activity was not recorded, these findings were supported through empirical experiments and observations not through questionnaires. So, these studies could be considered dependable considering that poor wayfinding may induce anxiety, whereas excellent wayfinding design can reduce stress. (İlker Erkan, 2018; Morag et al., 2016) (Refer to Figure 4).

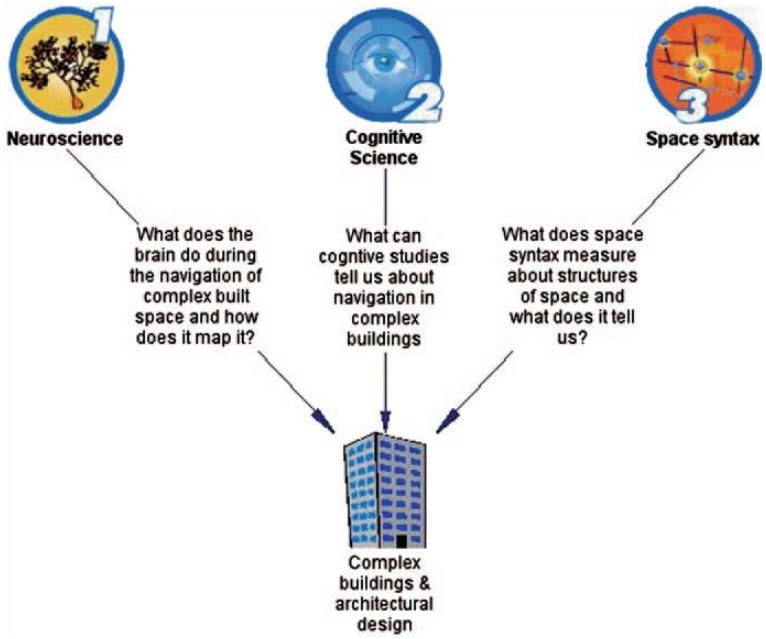

Fig. 4. The relative contributions of neuroscience, cognitive science, and space syntax analysis to the design of complex buildings (Dalton et al., 2015)

Space Syntax theory and methodologies have improved during the previous four decades. (Hillier and Hanson, 1984; Hillier et al., 1978) The development of the theory has led to mathematical and technical techniques, as well as the creation of several computer software applications. According to Baskaya et al. (2004), space syntax and wayfinding systems are influential environmental elements for indoor wayfinding. Since the late 1990s, Space Syntax has been used extensively in the analysis of healthcare facilities. As a result of this shift in emphasis and the number of papers published since then, Space Syntax is now important to healthcare researchers.

On the basis of its theoretical tenets, Space Syntax offers a variety of computer programs for analyzing plan drawings. Since the value of a space is determined by its relationship to all other spaces, any change in the number of spaces in the design (known as the spatial system) or in the connection pattern anywhere (a door added or removed, a corridor blocked off, etc.) will alter the value of that place. In most cases, space numerical measurements are statistically compared to a performance indicator, and conclusions are drawn based on the significance of the comparison (Haq and Luo, 2012).

Because Space Syntax may be modelled on a suggested floor plan, it has the potential to be an effective testing tool prior to detailed design or construction. In this manner, evidence may be immediately used and tested during the phase of preliminary design.

4.1.1. VGA

VGA is frequently used to evaluate connection and layout integration. (Chau et al., 2018) In VGA, a grid of points is superimposed on the graph's construction design. Then, each point is connected to every other point it can perceive. VGA is utilized in this study for both connection and visual integration (Geng et al., 2020).

Visibility graph analysis helps in computationally visualizing the visual connectivity of the public spaces of a complex floor plan. This analysis helps in identifying threshold points and identification of corridors of longest line of sight which work as main routes in the floor plan. This helps in allocation of manifest cues at the threshold position and prioritizing the primary against the secondary route and altering the spatial geometry in every decision point according to this approach. Once a primary path has been identified, a new geometric design should be applied to it (Kondyli et al., 2017).

4.1.2. 2D Isovist Analysis

There are several ways to depict isovist, and we claim that the discrepancies between the approaches may impact the isovist's interpretation. The technique of visualization will be determined by the representation of isovist. Visualization plays a significant part in the study since it may provide insight into the efficacy and efficiency of a system, as well as enabling the rapid identification of intriguing characteristics and trends (Wijk, 2005). Isovist may be represented as a closed polygon as in Figure 5 containing all sets of observable points from a single vantage point (Benedikt, 1979).

4.1.3. Spatial Connectivity

In Space Syntax, the amount of direct linkages to other spaces is referred to as connectivity. (Haq, 2003). The integration value is derived by a mathematical computation that considers both the number of corridors to which one is linked and the step depth of each of those corridor connections. A corridor with great integration is, on average, closely coupled to all other corridors in a given configuration. In comparison, a corridor that is isolated from all other corridors on an average basis is termed segregated (Haq and Luo, 2012).

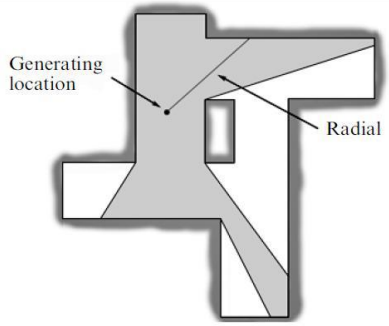

Fig. 5. Polygonal depiction of isovist and the inability to visualise the influence of distance. (Turner et al., 2001)

Haq and Luo (2012) concluded the fact that corridor utilization by explorers is proportional to their integration-n values. Moreover, when undecided about where to travel, a bigger share of visitors chooses destinations with higher integration values. Another lesson learned is that more people tend to congregate in more integrated locations.

Yi and Bozovic-Stamenovic (2009) found significant correlations between Syntax scores and both space exploration and navigational use. Consequently, they reinforced the relevance of integration values in wayfinding and exploration, indicating that these aspects a consistent independent of the design ideas of individual buildings. (Haq, 2003) investigated a variety of Syntax variables and approaches for characterizing plans from the perspective of Space Syntax. Integration-3 revealed to be the most significant predictor of hospital building wayfinding.

Haq et al. (2005) highlighted prior findings about the predictive value of axial integration-3 for hospital visitor navigation and spatial cognition. In conclusion, an integration study of a hospital's design accurately predicts which corridors visitors are likely to stroll through and remember.

Previous research confirms that Syntax factors have a crucial influence in predicting which hospital corridors would be more commonly utilised by visitors exploring and navigating. Integrated corridors are also more likely to be "mapped" in cognitive knowledge and may thus play a larger role in navigation.

4.2. CASE STUDY

Four new hospitals in Cairo, Egypt, have been selected for analysis. Refer to Table 1. It was intended to rely on the floor plans' analysis and simulation rather than post-occupancy observations, so that the approaches offered may aid in the preliminary design process. In addition, the study's findings may be of use to decision-makers at the four institutions.

VGA was made for the floor plans of the inpatient wards of the four hospitals. In order to compare their spatial configurations 2 of each nurse stations were chosen to share the same typology. These graphs have been shown to have a correlation with ease of access and wayfinding, and a positive wayfinding experience has been shown to positively affect the mind of the navigator and reduce stress and anxiety, particularly in stressful environments such as hospitals.

In addition, a 2d Isovist analysis is performed on the inpatient wards of the four hospitals in order to examine the social-psychological and environmental support anticipated from the current spatial configuration of the inpatient ward and the inter-visibility between nurse stations and inpatient room entrances. Monitoring the entrances to the inpatient rooms provides patients and their families with a sense of safety and security, which reduces stress. Also, empirical evidence demonstrates that a sense of control and privacy for patients and their families reduces stress levels and consequently improves mental and physical health.

The analysis also considers how the patient's room is viewed from the nurse's station to ensure privacy. On the same inpatient ward, the visibility between nurse stations and each other is investigated. Visibility between nurse stations facilitates social interaction and positively impacts performance. The purpose of the study for the four hospitals is to utilize a computational approach for analyzing and evaluating spatial and visual configurations that support the neuro-architecture principles associated with wayfinding behavior and social and psychological support of healthcare facility users.

TABLE 1. Research Settings

Abbr.	Hospital Name	Inpatient Ward Typology
H1	Ahl Masr Hospital	Racetrack (Linear Double Corridor)
H2	Ain Shams for Pediatric Surgery Hospital	Single Corridor
H3	New Baheyya Hospital	Single Corridor
H4	Magdy Yacoub New Global Heart Center	Racetrack (Linear Double Corridor)

4.2.1. Visual Integration Analysis

The visual integration analysis is made on the inpatient ward of H1 of the first-floor plan by Depthmap X software. The ward consists of 17 inpatient room and 3 nurse stations. The typology of the ward is linear double corridor. The average visual integration of the nurse stations concluded from the graph is equal to 7.13. The graph depicts the presence of nurse stations in areas with the greatest visual integration. This is anticipated to be beneficial for both ward navigation and care distribution among inpatients (Refer to Figure 6).

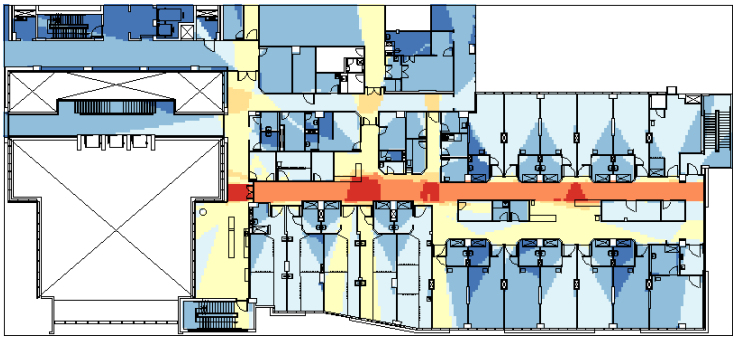

Fig. 6. Visual Integration of Inpatient Wrad of H1 by Depthmap

For H2, the inpatient ward consists of 13 inpatient rooms and 2 nurse stations. The typology of the ward is single corridor typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.26. Even though H2 and H3 inpatient wards share the same typology, the locations of their nurse stations differ. The placement of one of the 2 nurse stations in H2 are in marginally lower visual integration zones (Refer to Figure 7).

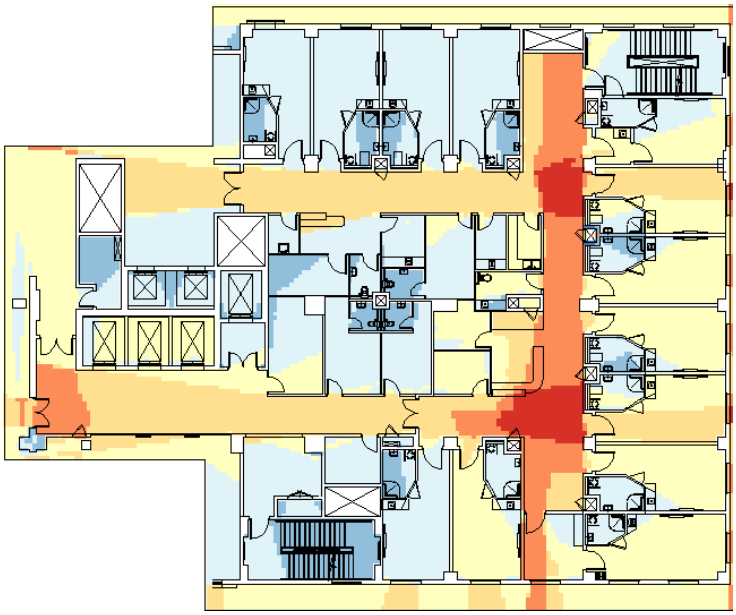

Fig. 7. Visual Integration of Inpatient Ward of H2 by Depthmap

The visual integration analysis was also made on the inpatient ward of H3 of the second-floor plan. The ward consists of 14 inpatient room and 2 nurse stations. The typology of the ward is single corridor typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.57. Knowing that the highest visual integration for this inpatient ward is 10.60, the graph indicates that nurse stations are not located in the most integrated areas of the floor plan (Refer to Figure 8).

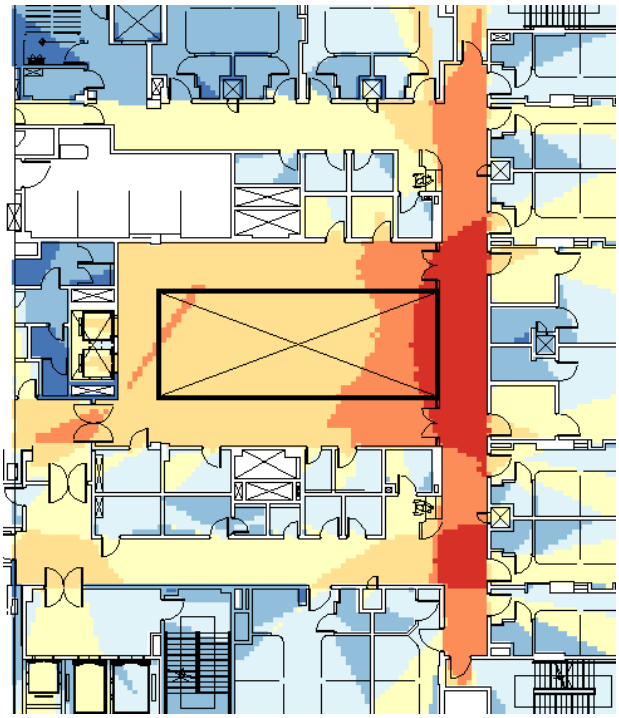

Fig. 8. Visual Integration of Inpatient Ward of H3 by Depthmap

The inpatient ward of H4 consists of 28 inpatient room in addition to 3 isolation rooms and 4 nurse stations. The typology of the ward is double corridor typology. The average visual integration of the nurse stations concluded from the graph is equal to 6.34. H4 inpatient ward shares the same typology with that of H1 which is linear double corridor but for almost double the number of inpatients rooms. The visual integration analysis result shows the allocation of the adults' isolation inpatient room in a low visually integrated area. The main nurse station is located near high visually integrated areas, which is not the case for the last 2 nurse stations. This might

indicate the difficulty of wayfinding inside the ward (Refer to Figure 9).

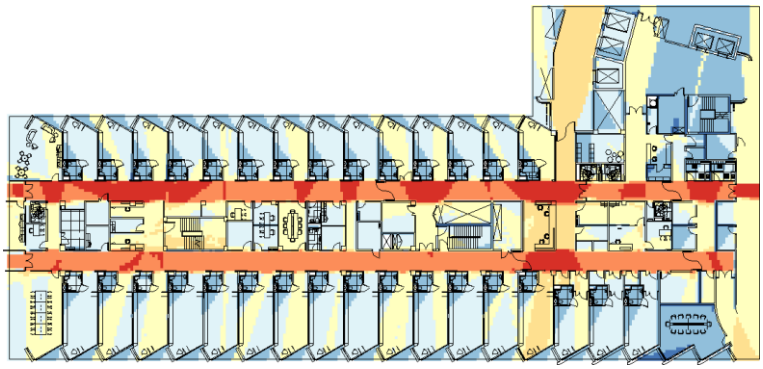

Fig. 9. Visual Integration of Inpatient Ward of H4 by Depthmap

4.2.2. Isovist Analysis

For H1, inpatient beds are not visible from nurse stations, resulting in increased patient privacy but a diminished sense of security. Four out of the seven- teen inpatient rooms are not visible from the stable nurse stations. The patients and their families can anticipate receiving less care and feeling less secure in these rooms. The graph also illustrates the inter-visibility among three nurse stations (Refer to Figure 10).

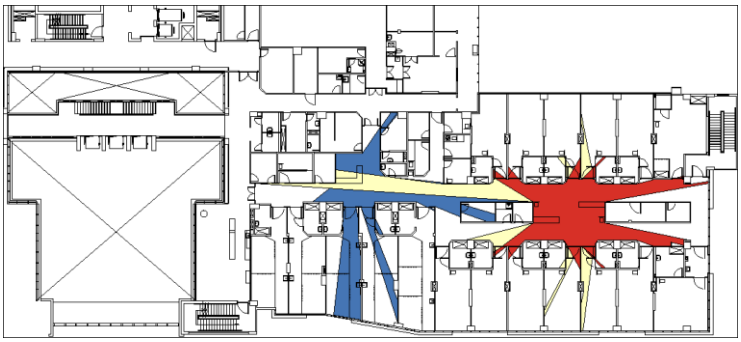

Fig. 10. Isovist graph analysis for H1 Inpatient Ward by Depthmap

Regarding H2, the isovist analysis of the inpatient ward's nurse stations shows no mutual visibility between nurse stations and that 3 of the 13 rooms entrances are not directly visible from the stations. Also, the graph shows that for some rooms, patients' privacy may be affected by the location of the nurse station near the ward entrance from the visitor elevators' lobby (Refer to Figure 11).

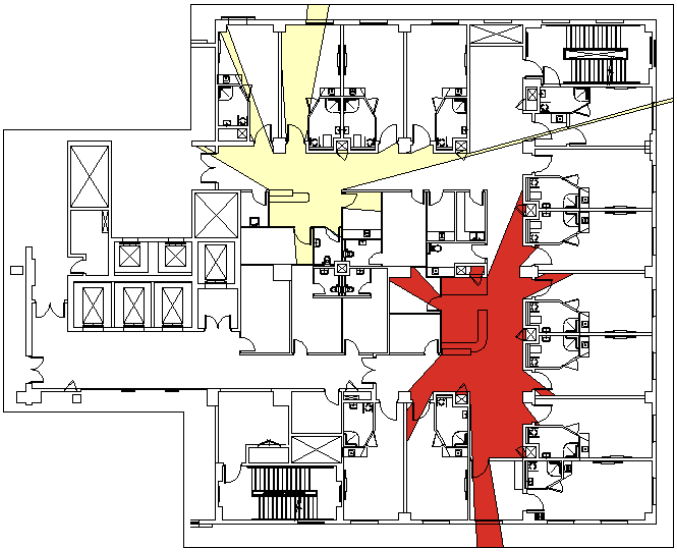

Fig. 11. Isovist graph analysis for H2 Inpatient Ward by Depthmap

Four of the fourteen inpatient rooms of the inpatient ward of H3 are excluded from the view field of stable nurse stations (Refer to Figure 12).

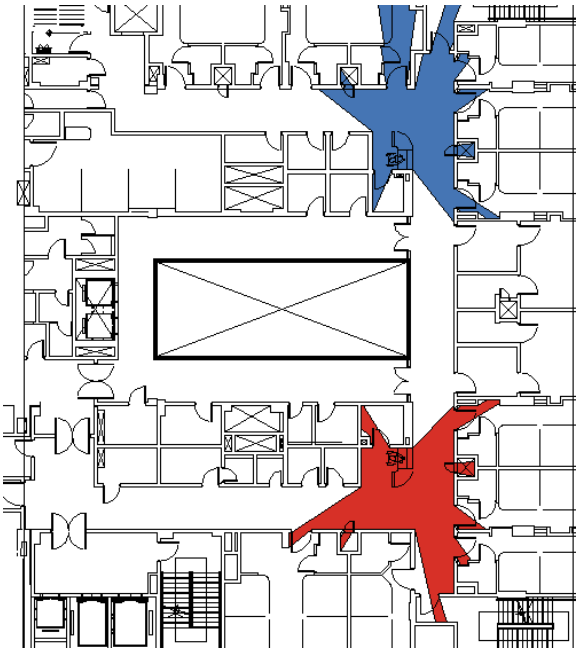

Fig. 12. Isovist graph analysis for H3 Inpatient Ward by Depthmap

The lack of mutual visibility between the four nurse stations of the inpatient ward of H4 is revealed by the isovist analysis of the nurse station locations, which would have a negative impact on nurse interaction and performance. Furthermore, none of the nurse stations monitor sixteen of the thirty-one rooms. This could impact the patients' and their families' sense of security. In addition, the isovist analysis reveals that certain rooms are completely observable from the nurse station, which would compromise the patients' and their families' sense of control and privacy (Refer to Figure 13).

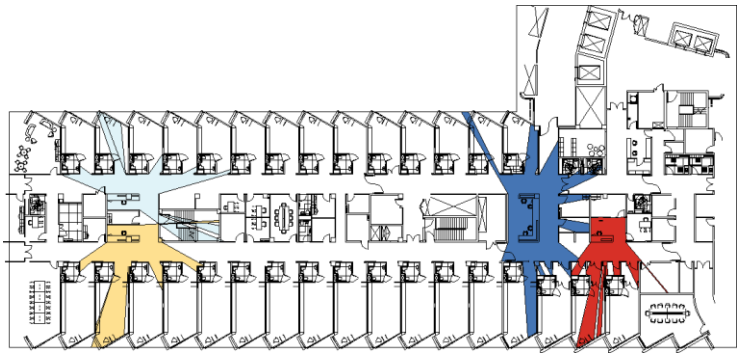

Fig. 13. Isovist graph analysis for H4 Inpatient Ward by Depthmap

4.2.3. Results

Although H2 and H3 share the same single corridor layout and nearly the same number of inpatient rooms, the H3 inpatient ward's nurse stations have a slightly higher average visual integration of 6.57 than that of H2. This may indicate that positioning nurse stations at threshold locations like the case in H3 might be better for the visitors to find their way easier.

The difference in the visibility analysis was because of the distribution of the nurse stations and inpatients rooms entrances. This distribution of the nurse stations of H2 ensured slightly better visibility to more inpatient rooms entrances than that in H3. Higher visibility to inpatient rooms entrances from nurse stations predicts more visits to the rooms according to empirical psychological studies and observations. Also monitoring inpatient rooms entrances increases sense of security and safety for patients and their families according to studies mentioned. Both nurse stations in the 2 hospitals have no inter-visibility between each other. This is not recommended for the importance of the social support of the nurses which might affect the performance and care given to patients.

Among to the 4 hospitals, H1's inpatient ward nurse station has the highest visual integration (7.13). Even though H1 and H4 inpatient wards share the same Racetrack (double corridor) typology, H4 inpatient ward nurse stations

were not found to have a high visual integration value to inpatient rooms' entrances in relative to the rest of the nurse stations of the four hospitals even though studies confirm the advantage of the double corridor over that of single corridor. This may be because of the large number of inpatient rooms in H4 inpatient ward (31 inpatient rooms in comparison to 17,13 and 14 inpatient rooms for H1, H2, H3). The isovist analysis of the inpatient ward of H4 shows bad coverage of the inpatients rooms entrances (16 of 31 inpatient rooms aren't visible from the stable location of nurse staions of the ward compared to 4 out of 17, 3 out of 13 and 4 out of 14 for H1, H2 and H3 respectively) and shows no mutual visibility between 4 the nurse stations. Also, the isovist analysis shows that some of the inpatient rooms are almost completely visible from the nurse station which might affect privacy and sense of control for patients and their families.

5. Conclusions and Discussion

This study adhered to the EBD research typologies and proposed heuristics to facilitate the application of neuro-architecture principles in healthcare facilities. This study also presented a space syntax analysis method for computationally integrating neuro-quantifiable architecture's design principles into the interior environments of healthcare facilities. This approach was introduced to visualize and evaluate the visibility and spatial connectivity of the plan layout of healthcare facilities to describe and quantify certain spatial qualities that reflect the application of the planning and navigation neuro-interior principles for the healthcare facility.

Four hospitals with different typologies of inpatient wards were chosen to apply the introduced method for visualizing and evaluating the spatial qualities of their inpatient ward's nurse station. Using Space Syntax analysis, the visual integration of the inpatient ward nurse stations and their accessibility from the visitors' elevator lobbies, as well as the distribution of the nurse stations in the ward in relation to the inpatient rooms, were analyzed. The visual integration reflects the ease of wayfinding for visitors, which has a positive effect on the visitor's brain and psychological state and reduces stress. The visibility of the inpatient room entrances, the good distribution of nurse stations within the ward, and the inter-visibility of nurse stations within the same ward all contribute to the social interaction and performance of the nurses, and thus to the quality of medical care provided to the patients. The computational method is supposed to facilitate the practical application of the neuro-architecture design principles in healthcare facilities, which have been demonstrated to positively impact the facility users' mental state, performance, and recovery rate.

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CONCEPTUAL PROCESS MODEL FOR METAVERSE ARCHITECTURE

SSADT's design process

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Abstract. At the articulation of the two themes: "Virtual Environments and Emerging Realities" and "Parametric Design and Digital Fabrication," our proposal subscribes at the intersection of innovative technologies in architectural practice, such as blockchain, collaborative platforms and digital twins. Our purpose is to propose a conceptual design process model for architectural digital twin as a compound of metaverse architecture. The challenge is to achieve a Shared and Secure Architectural Digital Twin (SSADT). To model our SSADT's design process model we are based on blockchain approach. To do this, we will firstly start by defining the principal compounds of an architectural digital twin. Secondly, we will explain the different steps for modelling a blockchain application. Then we will prototype our process for a SSADT. Finally, we will discuss our results and we will explore future perspectives.

Keywords: *Digital twins, Blockchain, collaborative platforms, process, Architecture.*

ملخص. في تمحور مفصلي بين الموضوعين : "البيئات الافتراضية والحقائق الناشئة " و"التصميم البارمتري والتصنيع الرقمي" يتمركز مقترحنا في تقاطع التقنيات المبتكرة في الممارسة المعمارية مثل تقنية البلوك تشين، والمنصات التعاونية والتوائم الرقمية. هدفنا هو اقتراح نموذج فكرى لعملية التصميم للتوأم الرقمي المعماري باعتباره عنصرًا من عناصر البيئة الافتراضية الموازية. ويكمن التحدي فى تحقيق توأم معماري مشترك وآمن. ولتحقيق هذا التحدي نعتمد على منهج البلوك تشين حيث نبدأ أولًا بتحديد المكونات الرئيسية للتوأم الرقمي المعماري، ثم نشرح الخطوات المتبعة لتصميم وتطبيق البلوك تشين ثم نقوم بتقديم نموذج ونختم بمناقشة النتائج وكشف وجهات النظر المختلفة.

الكلمات المفتاحية: *التوأم الرقمي، البلوك تشين ، المنصات التعاونية، عملية تصميمية، هندسة معمارية .*

1. Introduction

Digital twin is a concept that refers to the digital model of a physical object, system or process that exists or may exist in the physical world. It lives and evolves in a computer, like a virtual avatar (Geneux, 2021). The concept of a digital twin, relatively new to architecture, is becoming a desirable prospect. It is a favourable innovation to build a fine insight into the static and dynamic state of infrastructure or building at each phase of its life cycle. It is a catalyst for increased collective intelligence by combining different information from each trade and citizens. It offers them the same global and systemic vision of a project to build or operate. However, the concept of "digital twins" is not just a "buzzword", but it is the cornerstone of an engaged, responsible and sustainable digital transformation.

To ensure all interactions and exchanges of data, the digital twin must be coupled with a "collaborative platform." Blockchain technology is considered as a key to the development of such platforms (Girault, 2020). It's laying the foundations for a new decentralized internet. It has already transformed the business world. From finance to construction, the possibilities for leveraging blockchain are limitless (Massimo, 2017).

Girault (2020) defined the key components for modelling a digital twin of the project and the locks for its implementation. The Gemini Principles set out values to guide the national digital twin and the information management framework that will enable it (Bolton and al., 2018). We will base on these researches to model our SSADT's design process. To unlock the locks, we propose to take advantage of the benefits of blockchain technology defined by Teisserenc & Sepasgozar, (2021).

What process model could we propose for the design of a shared and secure digital twin? At what level could we integrate the application of blockchain in the design process? And ultimately, what could be the impact of such a digital twin on design processes?

2. Towards a Shared and Secure Architectural Digital Twins: SSADT

For the implementation of an architectural digital twin, two key components were defined by Girault (2020):

- **A collaborative platform** to collect and host all the data produced by each actor, consolidate them, ensure their consistency, and ensure that the digital twin offers the "point of truth" of the project. Other technologies have to be coupled with this platform to offer better relevance and efficiency to the digital twin such as the structuring of digital twin data, the conversion of data between different formats, the management of data access modes and the protection of Intellectual Property. This will also guarantee the traceability of actions, requests, and data exchanges, between actors, provides access to knowledge bases and business services and ensures the long-term archiving of data.

- **The process of co-evolution: the "*backbone of the digital twin*"**

Co-evolution allows the monitoring and the piloting of the entire project during its life cycle. *"The coevolution is similar to a chain of formulations of design problems (Pi) and prototype solutions (Si) – sequential and/or parallel sequences that begin with the initial formulation of the project problem and end with solutions that point to nil (marking the end of a sequence)."* (Girault, 2020). To visualize the traces of the co-evolution process Girault defined a representation in the form of a map that he called the "PST-map". It provides access to all data through problem formulation and requirements. Therefore, it will be possible to manage the co-evolution in order to be able to restore the genesis of the project. The different actors will be able to understand the evolution of the problem formulation during the project, the choices that have been made and their justifications and to propose alternatives.

Visualizing the co-evolution process in the form of a PST-map can be very cumbersome, even too tedious for designers. User interfaces could therefore be envisaged to facilitate and lighten the designers work and to automate certain time-consuming operations.

The relevance of an architectural digital twin is its ability to host all project data and ensure digital continuity. According to the Gemini Principles, digital twin ecosystems for the public good should be secure, reliable, trusted, open, transparent, and collaborative, with data interoperability and access control rules guaranteeing privacy. Blockchain technology could guarantee the trust, security, and transparency required for integrated shared DT platforms (Sallaba & al., n.d.). We are pointing to a shared and secure architectural twin (SSADT). Interoperability, security, and transparency are therefore the key concepts and the major challenges for modelling our model. Blockchain technology can enhance proof of provenance, data trustworthiness, data security, and data traceability for digital twin of manufacturing supply chains (Mandolla et al., 2019).

Therefore, to meet these challenges we have thought of relying on blockchain technology to design our process model. *"BCT* (block chain

technology) *could guarantee the trust, security, and transparency required for integrated shared DT(Digital Twins) platforms"*(Teisserenc & Sepasgozar, 2021). The architectural design process is characterized by ever-increasing flows of information between the various stakeholders: Exchange of data and paperwork such as tenders, contracts, authorizations, claims but also many other administrative details. We propose to integrate blockchain technology into the architectural design process to enhance trust, collaboration, transparency, efficiency, data sharing, and information security. A complete platform could be provided to ensure design, administration and project management transactions in a simultaneous manner.

2.1. A BLOCKCHAIN APPLICATION FOR A SSADT'S DESIGN PROCESS

The blockchain technology allows everyone involved in the process to standardize and manage all data in a single, reliable and incorruptible platform. It can ensure trust, by facilitating the information exchange through the long-term chronological keeping of an archive. According to Scott Nelson, CEO of Sweetbridge, in Harvard Business Review: "*Traditional project management techniques still work, but projects can benefit from a more decentralized and agile approach, where transparency is high, and where parties can be remunerated for the results as well as the work done."* .

The Blockchain technology could be a key pillar for an engaged and responsible digital transformation (Beddiar & Imbault, 2018). With information about each building material, designers will be able to make better decisions about efficiency, economy, and sustainability. This will allow access to the history of each material, know these origins, and predict the cycle life of a building and its impact on the environment.

2.2. THE MODELLING STEPS FOR A BLOCKCHAIN APPLICATION

Before the modelling of our process, we start by clarifying our idea. Firstly, we have to identify the main reasons for which we think to integrate blockchain technology in our SSADT's design process model. "*Blockchain is an emerging technology that is being used in many industries and businesses to achieve authenticity, transparency and to overcome some difficulties in their operation processes"*(Muthu, 2022). The principal challenges of using the Blockchain technology, in our case, are:

- **Security:** We aim for a decentralized process. Blockchain technology is more secure than centralized database systems. This means that a Blockchain is much less likely to be a hack attempt target, as there is

no single point of failure. The project data will be more secure because it will not only provide stakeholders with insight into data, but also it will allow them to control access to it.

- **Interoperability :** Blockchain improves interoperability in each phase of the process between the different actors, the public institutions and the other construction service providers (Muthu, 2022). All these stakeholders will be able to collaborate and to benefit from an equitable and synchronous perception on the progress of different phases of the design and to control the evolution of the project to be designed.

- **Transparency:** Blockchain systems can also give to different stakeholders enhanced levels of transparency on data related to the execution of the different design tasks for each phase. They also provide an additional level of security against inconsistencies and possible errors. Thanks to smart contracts, blockchain technology helps to avoid intentional falsifications.

Secondly, we identify the importance of blockchain in the process (Is it really necessary to integrate this approach into the architectural design process?): The architectural design process is characterized by a high number of data flows: regulatory and technical data, (structural, environmental, economic, etc.), quantitative and qualitative data relating to construction materials and organisational data relating to the planning and execution times of the various design tasks and of the project execution ... Blockchain technology makes sense to manage the transaction and guarantee the security of this data, and to ensure mutual trust between the various stakeholders. To increase the level of security and respect the intellectual property, we plan to manage the mode of access to the data either in reading or in modification. This means that, each actor can access only the data to which he has the rights in reading and/or modification. This will allow us to ensure all exchange traceability and its origins. Each stakeholder works in his own environment, and he can receive the data transmitted by the other actors. "*In processes of digital exchanges between heterogeneous actors, by introducing this system of proof, an exchange inscribed in a blockchain becomes a signed contract, which protects the one that emits as well that he who receives"*(Beddiar & Imbault, 2018). We need a centralized security system for each module (in the inter-modular environment) and decentralized in the intramedullary workspace (in our case the collaborative platform). We are advancing a hybrid Blockchain (Consortium).

Then we have to define the problem to solve by combining blockchain technology with digital twins' design process. On the one hand, the higher the data flow and the greater the numbers of speakers, the more difficult will be to manage, to transmit and to capture information in a fast and efficient manner. Nowadays, we need to build faster, and we are

searching for more efficient communication interfaces such as 5G. In addition, the implementations of digital twin are limited due to a lack of standards and recognized interoperability, especially in the manufacturing domain (Muthu, 2022). On the other hand, it is still difficult to ensure a digital continuity for an architectural project and to visualize all the data relating to its history. In the case of a project restoration, for example, designers do not always have access to its history: the data relating to the supporting structure, the materials used, the proposed solutions to problems encountered during the execution...

Our model aims to facilitate data sharing among stakeholders by focusing on relations (how information is received—understood and heard) and to ensure digital continuity throughout the project life cycle.

Fourthly, we define our system actors (in our case the SSADT design process): Our process model focuses on those involved in architectural design, namely designers (architects, interior architects, engineers, etc.) to facilitate communication and information sharing. It also takes into consideration:

- The client: to promote a participatory approach;
- The public institutions: to monitor the proper application of regulatory standards;
- The services companies: to manage tenders documents for the execution of the project;
- The administrator: The IT specialist (a computer scientist) to architecture the platform, and the blockchain system.

Referring to Muthu (2022), actors can be divided into many categories, under to the role they play in the system: Developers are charged with writing and reviewing the code that builds the Distributed Ledger Technology (DLT) and its interconnecting systems. Administrators control access to the system's central code. Gateways are fundamentally the entities that help the system fulfil its tasks in developing the processes transacted by their components. Gatekeepers ensure participant access to the network. Oracles are in charge of communicating the external data to the network. Issuers are in charge of issuing or exchanging tokens that represent the assets registered in the system. Participants who represent the interconnected design teams (often referred to nodes) that criss-cross information and messages in order to create the digital twin.

Finally, we have to identify the most appropriate consent mechanism. This is a job of the system administrator who selects the most appropriate consent mechanism for each project.

3. Global Architecture of the SSADT Design Process

We start by defining the different design phases of our SSADT system. Each phase corresponds to a private workspace for a team of predefined designers. In each phase, we have to define a problem (P^x) to arrive at a solution (S^x). To achieve an optimal solution in each phase, it is necessary to use a prototyping of possible solutions. This is the process of co-evolution that we defined earlier. As a result, each workspace has a *"PST-map^x"* delivered at the end of each phase for other stakeholders to develop the other phases. The proposed solutions correspond to the different models of prototyping and representations of solutions developed and transformed throughout the design process, such as sketches, plans, drawings, perspective drawings, 3 D computer models...

The data in each phase should be stored, shared, processed, and accessed securely. As a result, each workspace in each phase corresponds to a blockchain network. The Blockchain offers more transparency to each workspace, as it maintains a distributed directory within the team of designers involved in the network. At the beginning of each new project, the architect is in charge of creating a new project file which is in our case the SSADT. He then defines the teams of dedicated speakers for each phase. Therefore, each involved in the design process is registered in advance in the system in the workspace to which he has the right of access. Each actor will therefore have its own account and access keys to the workspaces to which it is entitled. Once the project file has been created, we will be able to make copies distributed and shared to all teams of the different phases. This is the network of nodes of the blockchain. "*Unlike a «classic» database, a blockchain only allows additions. Different copies of a register exist simultaneously on different computers (which are both clients and servers: we speak of node of the blockchain network). When a block is added, it is added on all nodes*" (Beddiar & Imbault, 2018). Actors will be able to view all the data related to the project design and add more (Figure 1).

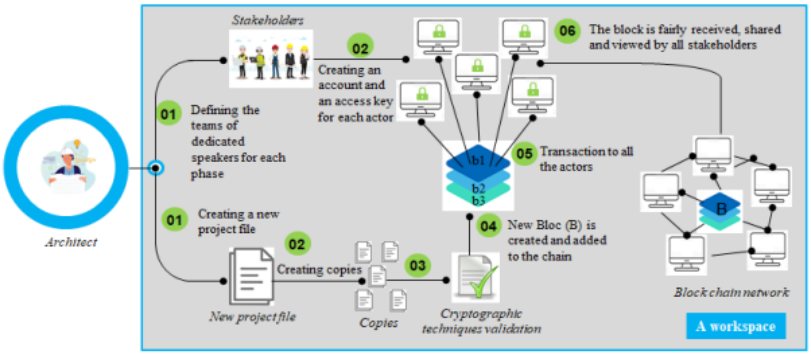

Figure 1: Global operation of our blockchain

When inserting a new data, the system must first check the Blockchain validity. At this time, the system will detect any kind of violation that might happen to the project file. And since there are several copies of this folder in the Blockchain network, the data can be recovered simply, so we are able to recover the folder validity. After the validation task, each data added will be injected to the project folder by creating a new block. This new block will only be added after approval of all stakeholders. In the extra-modular space that is the collaborative platform, the client can only consult the evolution of his project, view it or leave comments in a discussion space.

We define four phases of our design process model.

3.1. A FIRST PHASE B1: PROBLEM FORMULATION

This phase is defined by referring to Girault (2020*) "the resolution of design problems results from the co-evolution of problem formulation and solution development."*

In this phase, the problem formulation is defined at the time the architect begins the project design. It is based on the various data available or transmitted by information, guidelines and directives contained in the programme. That defines the expectations and constraints to be considered in developing the solution. This first block is divided into four levels (sub-blocks):

- Level 1 (b_1^1): Contains project context data. These data allow the definition of the nature of the project, its environment, its level of complexity, the human, financial and material resources to be mobilized, the constraints identified throughout the design process, use cases, etc. and the specific needs of the system as well as possible assessment tools for decision-making and validation of solutions.
- Level 2 (b_1^2): It stocks data related to the constraints and technical requirements set by the specifications, as well as environmental, geographical, social, cultural, and economic data. It holds also, the human, financial and material income to mobilize. The time allowed for the design process, the specific needs for each given SSADT and the tools and means available for the evaluation, decision-making and validation of the solutions.
- Level 3 (b_1^3): The objectives and requirements set, generally, by the owners (owner, user) that correspond to the definition of the program and its expectations (description of functions, zones, materials, etc.).

3.2. A SECOND PHASE B2: DEVELOPMENT OF POSSIBLE SOLUTIONS

- Level 1 (b_2^1): It concerns all research related to the morphology of the physical twin.

During the design phase, architects are required to produce images to give shape to his project and communicate it. To do this, they are basing on a chosen architectural concept, style, or references. The project must show originality. At this level, architects are working on a real process of creativity.

- Level 2 (b_2^2): At this level, architects search for solutions related to the functionality. “Form follows function” (Sullivan, 1896). By functionality, we mean all the functions of the physical twin, its role, its usefulness, the action they exert on us and on its environment.

- Level 3 (b_2^3): This level is for communication and configuration.

The professional responsibility of the designers is to bring all the parameters back into the field of the project which is in our case the SSADT. They deal with these different parameters according to their knowledges and techniques to meet the challenges. It is through the communication established between the different actors that the SSADT is created in continuous iterative returns until a consensual solution.

3.3. A THIRD PHASE B3: SYSTEM BEHAVIOR SIMULATION

To simulate the behaviour of our twins, we propose an MEI flow modelling classified according to three levels of blocks: It is by reconciling these three levels that the research space as well as the SSADT evolve during the process by enriching its selves with new knowledges related to the sciences or trades.

- **Level 1 (b_3^1):** material flows (M);
- **Level 2 (b_3^2):** Energy flows (E);
- **Level 3 (b_3^3):** information flows (I).

The consensual solutions in B2 are considered like reservoirs, since it corresponds to stocks of materials, energy and information. To visualize this, we are referring to the analogies of D'Arcy W. Thompson (1917) for whom *“the form is a diagram of forces”*. The developers will simulate the SSADT’s behaviour, by using operating rules valid for all systems. Our system is then endowed with behavioural laws, which make it possible to inject values into the different flows that animate the interactions between the two twins. The integration of the time variable favours simulation, since it becomes possible to play with the values associated with the initial conditions, to create prospective alternative scenarios. Then the designer will be able to study and predict the behaviour of our SSADT.

3.4. A FOURTH PHASE B4: FORMULATION OF THE OPTIMAL SOLUTION

It involves using the model to target our SSADT, learn from it and design again in the B1 (Reformulation of the problem), or make decisions that allow action in the actual design (Physical Twin). Designers can follow several studies:

- **Qualitative study:** it corresponds to a descriptive pathway. It is a question about detailing the SSADT qualitatively so that it can be considered as an optimal solution validated by all designers and stakeholders. It's not just the technical details of execution, but also information about data, context, constraints, purpose, elements and relationships, operating rules, etc. This information allows the designer to develop his self-referential, by a reference space dedicated to the practice of architecture in a general way.
- **A quantitative study:** it corresponds to a prescriptive pathway. Quantitative research of the SSADT system with precision and real measurement in order to improve it by working on its formalisation or by quantifying some of its interactions.
- **A heuristic study:** this study is for the construction of possible scenarios based on our theoretically developed SSADT to look for all reasonably conceivable solutions to a given problem.

The three studies may be continued simultaneously or consecutively or in parallel.

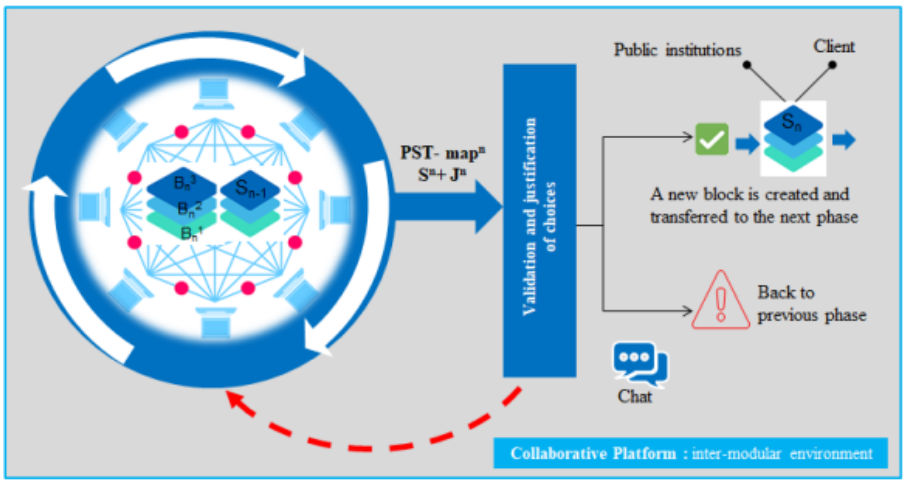

Figure 2: Phase operation

As we said earlier our proposed model focuses on relations. We have not indicated the direction of the relations in the model because we think that it

must be characterized by the designers (it can be one-way or two-way, have a positive or negative effect on the system, be inhibitory or arousing, regulate and feedback, etc.). This will give our model flexibility to adapt to the nature of the project. There may be different hierarchical or nested relational networks in subsystems (phases). In all cases, we try to offer a subjective freedom to designers, to ensure a continuous balance between the logic imposed by the rules prescribed by the specifications, and the creative logic of the invention.

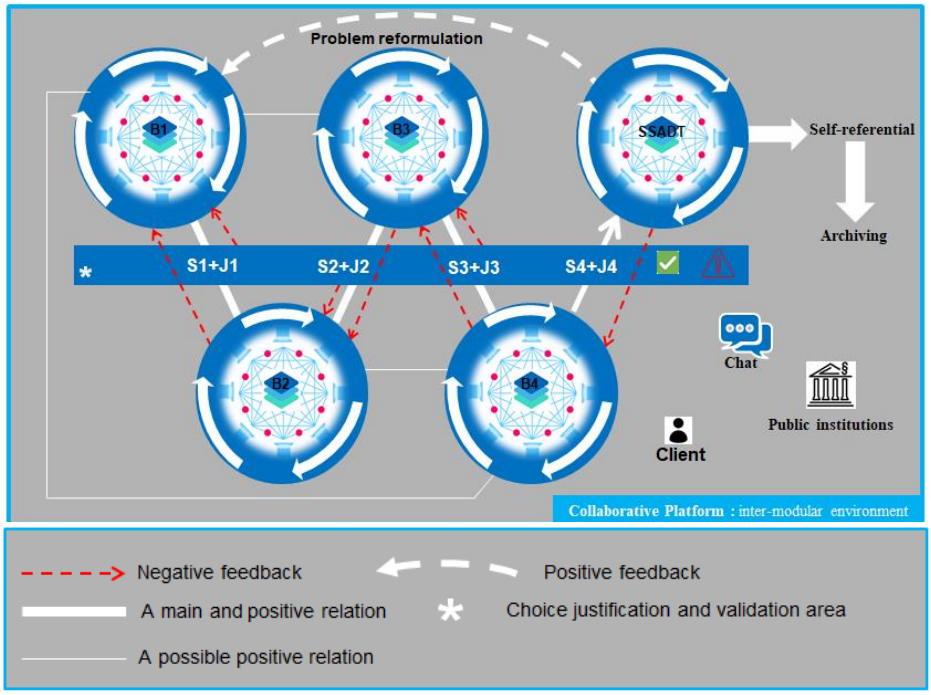

Figure 3: Conceptual design process for an SSADT

4. Conclusion

We consider the blockchain technology to be promising. It paves the way for a committed and responsible digital transformation in the field of architecture. Through this reflection, we were able to shed light on the issues that we can meet if we integrate blockchain technology into the design process because we have noticed that it is little explored in the field of architectural design.

The major contribution of this reflection is that through the proposed model it is possible to adopt a participatory approach in the design process

while ensuring on the one hand a fair foresight to all stakeholders on the state of the project in real time and on the other hand data security and respect for intellectual property. However, an empirical study remains essential to validate this process model in real-life cases of metaverse architecture.

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DAY 2 - PARALLEL SESSION 1

TOPIC 1 - ARTIFICIAL INTELLIGENCE

COMPUTATIONAL DESIGN FOR ARCHITECTURAL SPACE PLANNING OF COMMERCIAL EXHIBITIONS

A Framework for Visitors Interaction using Parametric Design and Agent-Based Modeling

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Abstract. Using computational tools for evaluating spatial layouts of commercial exhibitions provides an opportunity for assessment of performance before execution. However, most evaluation techniques take into consideration only the physical qualities of the built environment, excluding important factors such as crowds. Crowds are essentially dynamic obstacles that hinder visibility and can induce flight response, but they are also a sign of good exposure when in reasonable amounts. This is mostly due to the challenge of quantifying spatial qualities such as users' interaction and movement for computational representations. This paper proposes a framework using agent-based modeling for simulating user interaction in commercial exhibition spaces combined with a parametric representation of the built environment. The framework is then evaluated by applying it to a case-study of three layout scenarios in a generic exhibition hall. The simulation results show that layouts with vertical aisles, and less horizontal aisles have better footfall distribution.

Keywords: *Space Planning – Commercial Exhibitions – Agent Based Simulation-Parametric Design.*

ملخص. إن استخدام أدوات الحاسوب لتقييم التخطيط الفراغي للمعارض التجارية يتيح الفرصة لتقييم الأداء للمبني قبل تنفيذه في الواقع. لكن معظم طرق التقييم تأخذ في الاعتبار الخصائص المادية للبيئة المبنية، وتستثني بعض العوامل الأخري مثل تزاحم الزائرين داخل فراغات العرض بالمعارض التجارية. يعتبر تزاحم الزائرين عقبة تعيق تحركهم وفي نفس الوقت تعطي احساس بالرغبة في الهروب من تلك الفراغات، على الرغم من ذلك، فإن هذا التزاحم في بعض الأحيان يعتبر علامة جيدة لنجاح ورواج المعروضات داخل تلك المعارض. تهدف هذه الورقة البحثية إلى اقتراح إطار عمل لاستخدام النمذجة القائمة على الوكيل وذلك لمحاكاة تكامل تفاعل الزائرين في المعارض التجارية مع التمثيل البارامتري للبيئة المبنية. تم تقييم إطار العمل المقترح من خلال تطبيقه علي دراسة حالة لثلاثة مقترحات تصميمية لقاعات لمعرض تجاري ودراسة حركة الزائرين بها. اظهرت نتائج المحاكاة أن التخطيط الفراغي الذي يتكون من الممرات االرأسية يؤدي الي توزيع أفضل للزائرين علي أجنحة العرض.

الكلمات المفتاحية: *تخطيط الفراغات، المعارض التجارية، النمذجة القائمة على الوكيل، التصميم البارامتري.*

1. Introduction

Commercial Exhibitions play a vital role for businesses to sell their products, gain exposure and interact directly with consumers (Patel, 2017). Due to the importance of the opportunity produced by these events business owners pay a great deal for getting maximum exposure, by reserving the best spots for their attractive booths. Studies have shown that the layout configuration of commercial facilities affects traffic patterns, visitors' emotional responses, and behavior (Bohl, 2012). Also, it is found that users are influenced by environmental cues produced by surrounding users (Dalton, Hölscher and Montello, 2019).

Recently there has been an increase in computational power, extending the capabilities of architects. One of these opportunities lies in advances in computational simulations to evaluate buildings before execution. Computational simulations provide insight and analysis of designs beyond human designers' capabilities (Helbing, 2012). Space is defined as a result of the dynamic activities of designers and occupants, it extends beyond physical static boundaries (Andia and Spiegelhalter, 2015). However, most traditional computational simulation techniques deal with quantifiable metrics and represent the built environment as a static entity.

Agent-based models have proved successful in simulating human behavior and producing realistic results (Bonabeau, 2002). Although Agent-based simulation has been studied in many architectural applications such as museum exhibitions (Batty, 2008,Pluchino et al., 2014), shopping malls (Sousa, Caetano and Leitao, 2017, Feng, Yeung and Mayne, 2016), , hospitals (Lu, 2011; Lee and Lee, 2019, 2020) no studies were found applying it to commercial exhibitions layout design. (Nagy et al., 2017) had discussed the commercial exhibition layout planning problem from the

generative design process approach and how to evaluate the resulting design space, however, their process needs very high expertise, and the resulted oblique layouts may cause navigation difficulties.

This paper aims to propose a framework using parametric modeling and Agent-based simulation to help architects evaluate visitors' interaction in commercial exhibition layout design.

2. Overview of Commercial Exhibitions and User Experience

In this section, an outline of the planning process of commercial exhibitions is discussed with a highlight on the effect of crowding on user experience in commercial buildings and how Agent-based modeling can help in layout design.

2.1. THE PLANNING PROCESS FOR COMMERCIAL EXHIBITIONS

The usual process of commercial exhibition layout planning starts with choosing an appropriate premise, then organizers start by dividing the exhibition hall layout into aisles and corridors and dividing the remaining spaces for booth allocations. Premium booth spots are sold to clients willing to pay more. High-traffic zones are characterized by high visibility, these are spaces near entrances and exits, main aisles, within the visible triangle zone from the entrance, and at the center of the exhibition. Since booths of popular brands usually gain a lot of traffic, organizers try to spread those out for equal traffic distribution (Adams, 2022).

For creating a positive experience, visitors need to find their way easily. A successful layout should help in reducing bottlenecks, waiting times, the number of dead spots, and provide wide enough circulation space for walking, stopping, bending to view exhibited products, talking, and exchanging information (Patel, 2017). Also providing equal exposure to both large and small businesses is important for exhibition success.

2.2. THE EFFECT OF CROWDS ON USER EXPERIENCE IN COMMERCIAL BUILDINGS

Commercial exhibitions usually attract many visitors and crowding is an important parameter in this case. In retail environments, perceived crowding is found to have an inverted U-shaped effect on visitor experience, crowded spots to a certain level can act as a pointer to popular destinations, however, after that point, it can lead people away due to feelings of stress (Mehta, Sharma and Swami, 2013). Perceived crowding can be due to the number of people in space or its geometrical configuration(Machleit, Kellaris and

Eroglu, 1994). (Penn, 2005) shows that crowding causes people to keep moving instead of viewing exhibited products and engaging with them. Crowding also acts as a dynamic obstacle to visibility. Research using Agent-Based Modelling and experimental studies have shown that visibility is one of the prime factors that affect navigation and wayfinding, and one of the environmental factors affecting navigation is the environmental topology that allows for more gaze range (Barton, Valtchanov and Ellard, 2014).

3. Agent-Based Modeling for Architecture Simulation

Agent-based modeling is a computational model that simulates dynamic interactions between autonomous agents and the environment. The agents act in different situations according to pre-defined rules (Bonabeau, 2002). A lot of commercial agent-based simulation tools are available and used by architects, although they usually need some special expertise, like Pathfinder, PedSim, Repast Simphony, NetLogo, AnyLogic, and many others (Bamaqa et al., 2022, Abar et al., 2017). Agent-based simulations are used in social experiments, industrial design, and architectural design-related applications such as pedestrian movement, evacuation studies, form finding, and circulation evaluation (Puusepp, 2011).

Many studies used Agent-based modeling for evaluating building safety. (Pluchino et al., 2014) used Agent-based modeling to evaluate the carrying capacity of the Castello Ursino museum in Catania (Italy), the main aim was to find the number of visitors to the building to perform well without any safety issues, the authors evaluated factors such as waiting time at artifacts and time taken for evacuation in different exit scenarios and different amount of visitors.(Sousa, Caetano and Leitao, 2017) proposed a framework of Agent-based simulation and generative design to test evacuation time in a shopping mall.

(Schaumann et al., 2016) used Agent-based modeling coupled with a detailed activity sequence to simulate nurses' movement trajectories to increase layout efficiency by reducing nurses' walking distance. Agent-based modeling can also act as a driver for form generation, (Ghaffarian, Fallah and Jacob, 2018) developed a tool to generate architectural space through an organic form-finding process by using agent-based behavior systems.(Puusepp, 2014) used Agent-based modeling to generate circulation systems both on the urban and the dwelling scale.

4. Method

This section presents an outline of the design framework utilizing parametric modeling and Agent-based simulation, then an application using a generic case study for framework evaluation and the simulation method applied.

4.1. PROPOSED FRAMEWORK

The presented framework as shown in Figure (1), consists of two main parts. The first part is the parametric representation of the exhibition layout, this is to introduce change to the proposed layout configuration in a fast and flexible manner. The second part is to simulate visitors' movement using Agent-based simulation. Both processes are done in Grasshopper (an add-on to Rhino 3D modeling software).

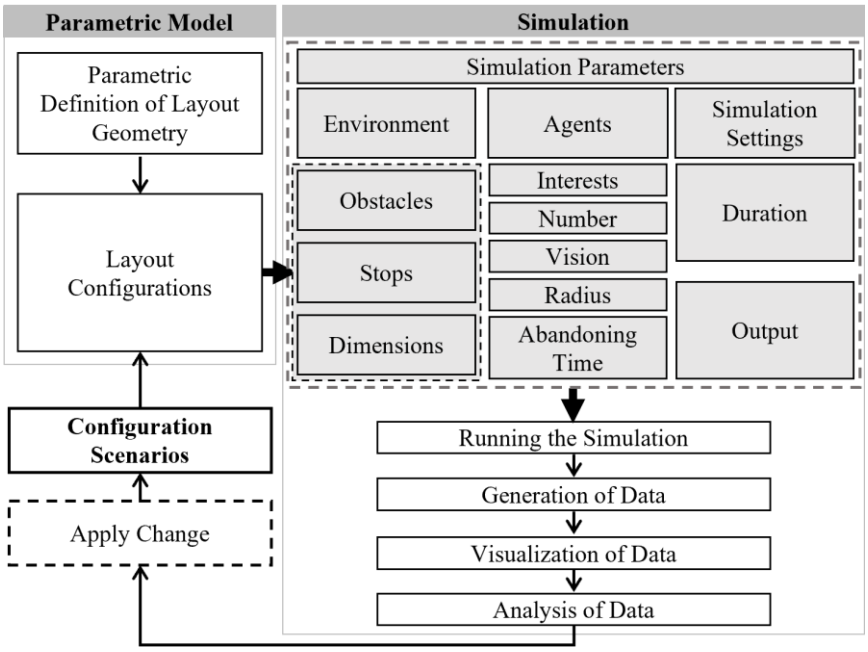

Figure 1. Framework outline

4.1.1. Parametric representation of commercial exhibition layout

The model consists of three main parts, border booths adjacent to three sides of the hall with spacing between them to allow for secondary exits (for evacuation and services). Then a central area, with different booth configurations. The third part is the area adjacent to the entrance and exit.

The main division method is using control points to divide the central area, whether it is used as a whole or divided by main aisles. The model has three outputs designed specifically for simulation purposes, an outline of booth groupings for obstacle representation, booths divisions, and central access points to be used as interest stops. The model was built to be adaptable to any orthogonal space for layout plan modeling, all output is in 2D. A diagram of the geometry definition is shown in Figure (2).

The model parameters are:

- Width and length of exhibition space.
- Location of booths at border walls.
- Width of booths adjacent to exterior walls (a constant value of 3 meters).
- Central area booths width (these vary according to vertical aisle width).
- The number of vertical aisles.
- Number and width of horizontal aisles of central area (these are split according to the resulting subsets from horizontal main aisles).
- Main vertical aisle width.
- Main horizontal aisle width.
- The number of booths.
- Entrance area length (the width is the width of the exhibition hall).

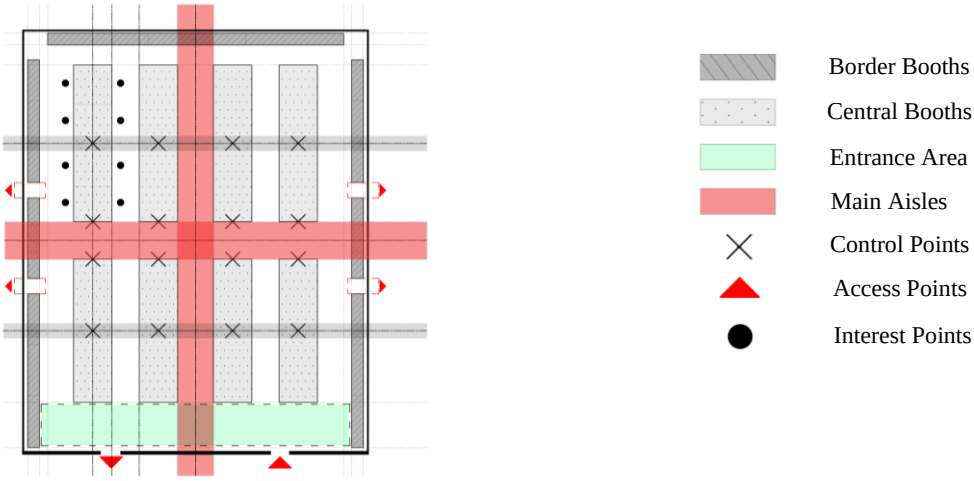

Figure 2. Parametric representation of commercial exhibition layout

4.1.2. Agent-Based Simulation

The software used for simulation is PedSim (commercial version), an add-on to Grasshopper, this tool is based on the social-force model (Helbing and Molnár, 1995). Agents are driven by multiple forces, target forces, person and obstacles repulsion forces, and a random noise force to reduce bottlenecks (Wang, 2022). PedSim is chosen for this study due to its ease of

use, and ability to connect to other parametric and simulation tools. Also, social-force models are shown to be an accurate method for predicting pedestrian behavior (Bauer, 2011).

PedSim had been applied in many applications regarding agent interaction. (Chen et al., 2022) used PedSim for producing a dataset of people's movement in an underground shopping space to be later used for predicting COVID-19 transmission. (Lee, Lee and McCuskey Shepley, 2020) used it to simulate the pedestrian movement of nurses in hospital nursing units. (Abu Ghazala et al., 2021) designed a simulation environment that combines agent-based social simulation with IoT ecosystems to test the interaction between agents and the systems. (Lee and Lee, 2020) proposed an approach integrating space syntax and agent-based analysis for an evaluation framework to measure spatial and social attributes to study how layouts can encourage inflows to common gathering spaces, which would lead to an increase in social participation of the residents in older adult care facilities. (Yeung Cho et al., 2021) proposed an approach using PedSim to help model different scenarios with various intervention strategies like layout changing, social distancing, and population limitations for safe accessibility of office spaces.

The simulation model consists of the physical environment, the agents, and the engine. The physical environment is an output of the parametric model and input as obstacles for walls, transparent obstacles for booths (they are assumed to be open enough to be see-through), stops for entrances, exits, and a point of interest at each booth. The agents here represent exhibition visitors, the agents' parameters are defined in "person templates". Finally, the engine calculates possible agents' trajectories and runs the simulation.

4.2. APPLICATION

For testing the proposed framework, a case study of a generic exhibition hall is used as the premise of simulation. The hall is of an area of 10,000-meter square and 90 m in width and 110 m in length. Each hall has 6 openings, 2 main entrances, two side entrances, and two service entrances. All common features of commercial exhibition spaces.

The proposed simulation scenarios as shown in Figure (1), are meant to test different movement aisle configurations. Scenario 1 "A" starts with a basic case of only 4 vertical aisles, then horizontal aisles are added in "B" and "C" with the same width as vertical aisles. For Scenario 2 "A", a main vertical aisle is introduced and same as Scenario 1, horizontal aisles are added. In the last Scenario 3, both vertical and horizontal main aisles are added, this divided the central area into four quarters, each has horizontal aisles added to it in "B" and "C". The number of booths is constant in all scenarios (100

booths), with a minimum dimension of 3 meters. The border booths width is 3 meters, and the central booth width is set to 5 meters.

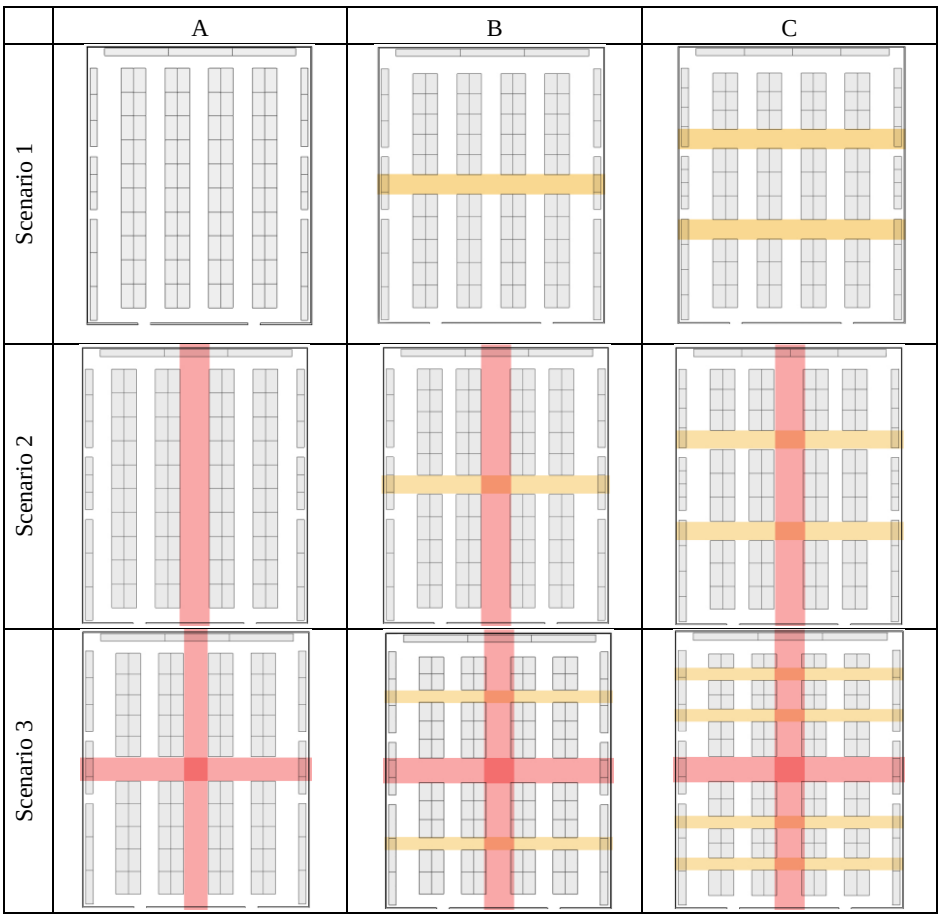

Figure 1. Configuration scenarios.

For all scenarios, there is only one main entrance and exit. Other stops represent interest points, these are central points at accessible sides of each booth. The layout is divided into three zones as shown in Figure (3). Each represents three different interests. Agents are divided equally into three groups; each is interested in one interest .The number of agents' visits per interest is 10 visits, 30% of booths per zone (Expo Exhibtion Stands, 2022), with a visiting time of 30 seconds, within the range of time spent per exhibit by visitor according to (Sandifer, 2003). The capacity of each interest stop is 5 agents (fitting 50% of booth space). Number of visits per booth and booth capacity vary greatly according to exhibited product, these data can be collected by exhibition managers from past events for more accurate

simulations, however for the purpose of framework application, recurring numbers in the literature are assumed.

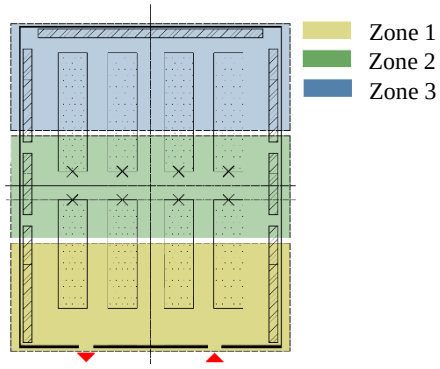

Figure 3. Interest zones division

4.3. SIMULATION

Agents' stops and obstacles are collected from the baked output of the parametric model. Agent properties set are vision as panoramic 360-degree vision, an abandoning time of 60 seconds, which means a person will abandon the current target of interest if this time has passed and moves on to the next visible target (this measures the effect of crowds making certain booths not accessible), and body radius of 0.3 m.

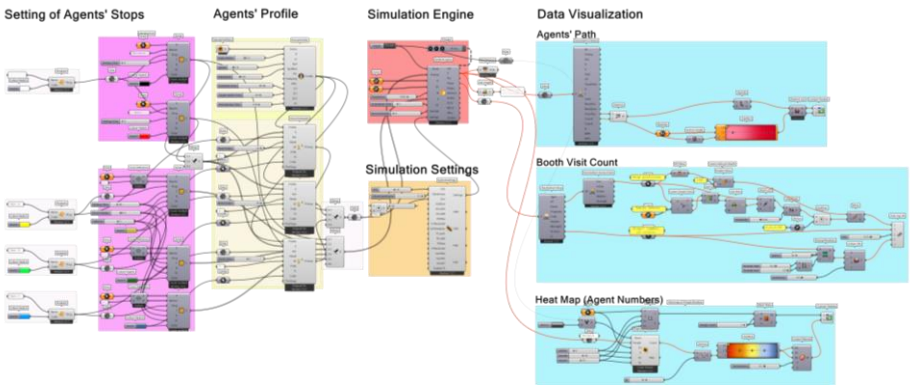

Figure 3. Grasshopper Definition

Simulation settings are a duration of 20 minutes and a population of 1000 agents (this number is an average number collected from past similar events in a similar-sized venue).

Data output and visualization: PedSim records agents' trajectories, number of agents per cell, and visit counts per stop. The cumulative density

of agent path trajectory is used to measure visitors' movement at the start of the exhibition, these are recorded 10 minutes from start. Visitors number per cell heatmap to define bottlenecks and dead zone areas, the cell size is 2*2 meters for easier computation. The number of visitors per booth is calculated to investigate both booth and zone exposure. Also, several screenshots were recorded showing agents' interactions.

5. Results and Analysis

5.1. CUMULATIVE TRAJECTORY

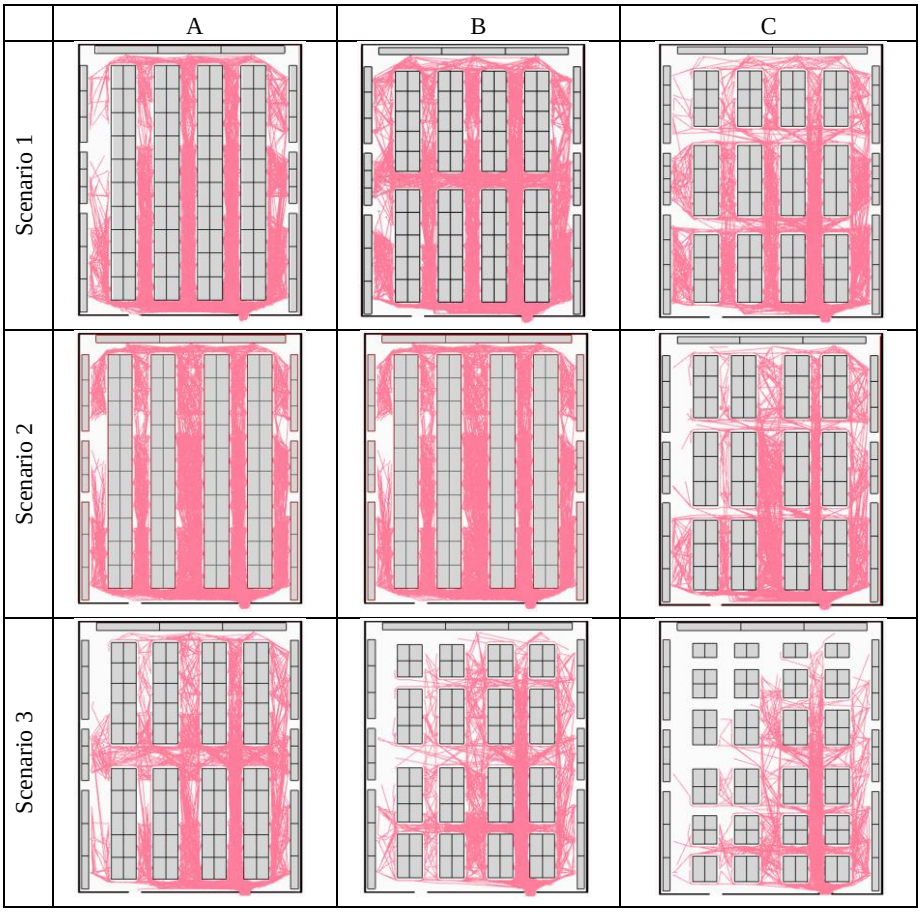

Figure 5. Cumulative trajectories at the start of simulation

During simulation, it is observed as shown in Figure (5) that aisles facing the entrance are first to get filled with visitors, even if this aisle is not the

main aisle. Increasing aisle width helps in lessening bottleneck zones too and reducing loitering areas forces visitors to move on to their next target directly with less traveled distance which creates more even distribution of foot traffic.

5.1. NUMBER OF AGENTS PER CELL HEATMAP

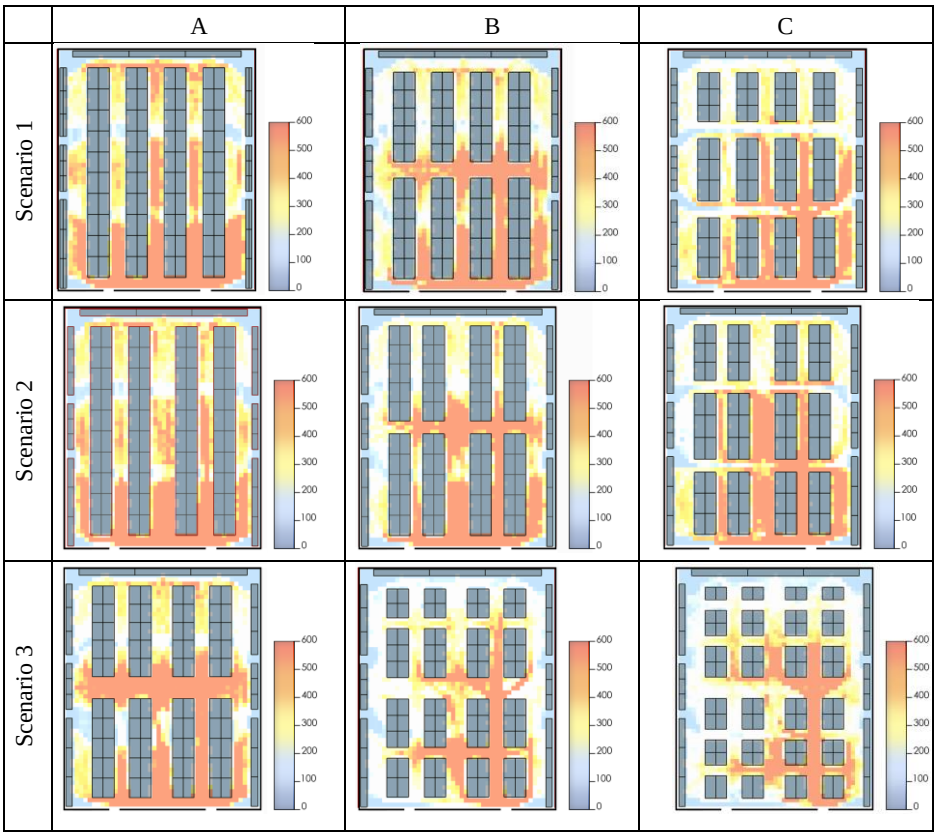

Figure 6. Agents Number Per Cell Heatmap

As shown in Figure (6), in scenario 01, bottlenecks exist in zones near the entrance, for “A” high traffic exits especially in aisles closest to the entrance. Adding horizontal aisles concentrates high traffic and reduces traffic in vertical aisles but increases dead zones at the furthest quarter from the entrance. In scenario 02, adding the main aisle distributes traffic better near the entrance, however, dead zones are increased in the furthest half. In scenario 03, adding both main vertical and horizontal aisles create bottlenecks at their intersection, this could prevent agents from reaching

further zones. Overall scenarios with vertical aisles have better foot traffic distribution.

5.2. AGENTS VISIT COUNT PER BOOTH

Figure (7) shows the distribution of zones with highest visitor counts and lowest visitor counts, it is observed that there is a quarter-like distribution, with the quarter closest to the entrance with the highest count and a quarter further away with the least visitor count.

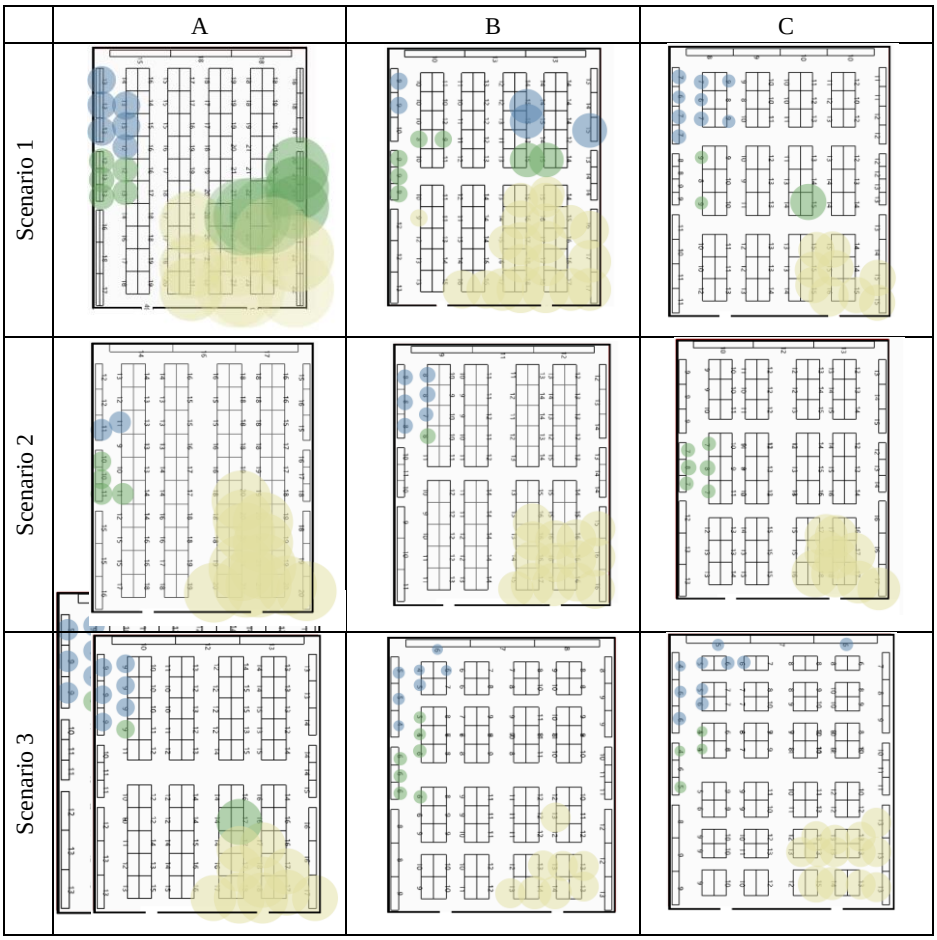

Figure 7. Map of Highest and Lowest visitors count per booth

In Figure (8) Scenarios with vertical aisles only seem to have the highest visitors count as seen in scenarios 01 and 02 case “A”. Scenario 02 “B” however has the best visit count distribution although the visit count isn’t as

high as vertical aisles only scenarios. In most scenarios, zone 3 being furthest from the entrance always has the least visitor count, except in cases "B" in scenarios 01 and 02, these cases have better visit count distribution.

According to (Shaw, 2018), The crowd density ranges from loose crowds needing about 1 meter square per person to extremely dense crowds of 0.3 meter square per person, according to the maximum number of visit counts, a single grid cell would hold about 5 to 10 users which is quite dense.

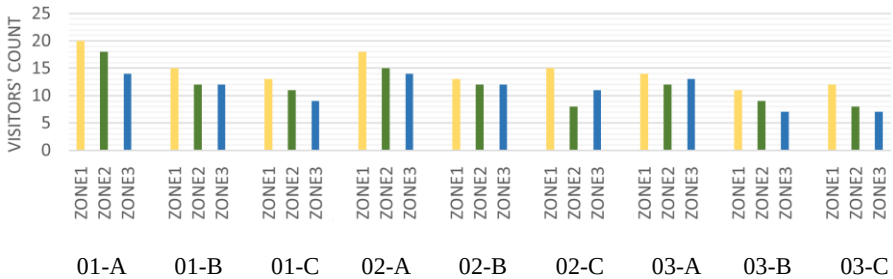

Figure 8. Visitors' Count per Interest Zone

5.3. BOOTHS TYPE ZONING

Zoning of booths according to possible visitor interest influences visitor accessibility to points of interest, this is observed during the simulation in Figure (6), visitors of zone 1 create bottlenecks that hinder other visitors from reaching their points of interest. In some scenarios, bottlenecks at horizontal aisles create that same effect creating bottleneck areas twice, although no stops are present in this area.

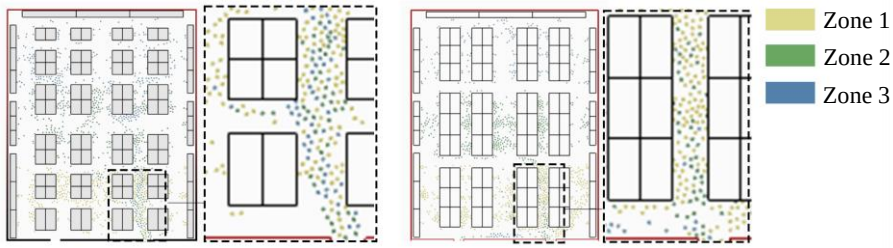

Figure 9. Map of Highest and Lowest visitors count per booth

6. Discussion and Conclusion

Users' interaction in spaces of public buildings has a great impact on user experience and proper building functionality. In the case of commercial

exhibitions, layouts undergo a lot of change in very little time due to their temporary nature. Proposing a framework using agent-based modeling for simulating user interaction and the effect of the crowd on booth accessibility can provide important insight for proper decision-making in the layout design process. Agent-Based Modeling has many advantages that make it suitable in this regard, as stated by (Helbing, 2012), it provides us with the opportunity to visualize the interaction between different individuals and entities, it is modular, flexible, and has a wide range of applications. Also, it can be smoothly combined with other kinds of models allowing expansion of simulated scenarios and parameters. This is tested by adding a parametric representation of the commercial exhibition layout to the proposed planning framework, which increases the flexibility of making alterations to the layout design. Also, both the parametric and simulation models are run on the same platform (Grasshopper), reducing time and complications caused by the transfer of data from drawing platforms to simulation platforms since simulation platforms require precise drawings with no geometry overlap.

However, there exists a couple of limitations to the Agent-based modeling approach. First there is the difficulty in verification and validation of such models, due to the lack of data (Heppenstall and Crooks, 2012). Second, the abstraction level of the model itself has to be suitable to the application goals, as too much abstraction can miss vital parameters and too high level of detail can make the model too complex to run and understand (Couclelis, 2002). Agent-based models are also computationally expensive. Finally, there is the issue of the complexity of modelling human behavior, as the motivations of these behaviors can be due to a number of reasons, both rational and emotional (Kennedy, 2012). (Batty and Torrens, 2005) argues that such models should be used in the capacity of learning rather than forecasting, and that the stochastic nature of these models is an important parameter that enables Agent-based models to simulate complex processes even though that means the results may vary with each run.

The proposed framework has proven successful in pointing out possible bottleneck areas and dead zones. The simulation results coincide with the previously mentioned booth spots that attract visitors the most. Also, the simulation points out that features such as aisle width and configuration, and booth grouping have an influence on foot traffic distribution, and the most successful layouts being those with no or a small number of horizontal aisles. For future work, many other scenarios can be furtherly tested, such as adding several entrances, dividing booths groups irregularly, changing interest zones division and experimenting with multiple populations.

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PROGENY

A Grasshopper Plug-In That Augments Cellular Automata Algorithms For 3D Form Explorations

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Abstract. Cellular automata (CA) is a well-known computation method introduced by John von Neumann and Stanislaw Ulam in the 1940s. Since then, it has been studied in various fields such as computer science, biology, physics, chemistry, and art. The Classic CA algorithm is a calculation of a grid of cells' binary states based on neighboring cells and a set of rules. With the variation of these parameters, the CA algorithm has evolved into alternative versions such as 3D CA, Multiple neighborhood CA, Multiple rules CA, and Stochastic CA (Url-1). As a rule-based generative algorithm, CA has been used as a bottom-up design approach in the architectural design process in the search for form (Frazer,1995; Dinçer et al., 2014), in simulating the displacement of individuals in space, and in revealing complex relations at the urban scale (Güzelci, 2013). There are implementations of CA tools in 3D design software for designers as additional scripts or plug-ins. However, these often have limited ability to create customized CA algorithms by the designer. This study aims to create a customizable framework for 3D CA algorithms to be used in 3D form explorations by designers. Grasshopper3D, which is a visual scripting environment in Rhinoceros 3D, is used to implement the framework. The main difference between this work and the current Grasshopper3D plug-ins for CA simulation is the customizability and the real-time control of the framework. The parameters that allow the CA algorithm to be customized are; the initial state of the 3D grid, neighborhood conditions, cell states and rules. CA algorithms are created for each customizable parameter using the framework. Those algorithms are evaluated based on the ability to generate form. A voxel-based approach is used to generate geometry from the points created by the 3D cellular automata. In future, forms generated using this framework can be used as a form generating tool for digital environments.

PROGENY: A GRASSHOPPER PLUG-IN THAT AUGMENTS CELLULAR AUTOMATA ALGORITHMS FOR 3D FORM EXPLORATIONS

Keywords: *Cellular Automata, Grasshopper, Generative Design, Framework.*

ملخص. الأتمتة الخلوية (CA) هي طريقة حوسبية معروفة قدمها جون فون نيومان وستانيسلاف أولام في الأربعينيات. منذ ذلك الحين، تمت دراسة الأتمتة الخلوية في مجالات مختلفة مثل علوم الحاسبات والأحياء والفيزياء والكيمياء والفن. تعد خوارزمية الأتمتة الخلوية الكلاسيكية عبارة عن عملية حسابية لشبكة من الحالات الثنائية للخلايا بناءً على الخلايا المجاورة ومجموعة من القواعد. ومع اختلاف هذه المتغيرات، تطورت خوارزمية الأتمتة الخلوية إلى إصدارات بديلة مثل الأتمتة الخلوية ثلاثية الأبعاد، والأتمتة الخلوية متعددة الجوار، والأتمتة الخلوية متعددة القواعد، والأتمتة الخلوية العشوائية. وقد تم استخدام الأتمتة الخلوية – كخوارزمية توليد قائمة على القواعد – كنهج تصميم من أسفل إلى أعلى في عملية التصميم المعماري في البحث عن الشكل، وفي محاكاة حركة الأفراد في الفراغ، وفي الكشف عن العلاقات المعقدة على المستوى الحضري. وتوجد تطبيقات لأدوات الأتمتة الخلوية في برامج التصميم ثلاثية الأبعاد للمصممين وذلك فى هيئة نصوص أو مكونات حوسبية إضافية. ومع ذلك، غالبًا ما يكون لهذه المكونات قدرة محدودة على إنشاء خوارزميات الأتمتة الخلوية القابلة للتخصيص بواسطة المصمم. تهدف هذه الدراسة إلى إنشاء إطار عمل قابل للتخصيص لخوارزميات الأتمتة الخلوية ثلاثية الأبعاد لاستخدامها في الاستكشافات ثلاثية الأبعاد من قبل المصممين. تم استخدام برنامج Grasshopper3D، وهو بيئة برمجة نصية مرئية في Rhinoceros 3D، لتنفيذ إطار العمل. ويكمن الاختلاف الرئيسي بين هذا العمل والمكونات الإضافية الحالية لـ Grasshopper3D لمحاكاة الأتمتة الخلوية في إمكانية التخصيص والتحكم في إطار العمل بطريقة متزامنة. وتعتبر المتغيرات التي تسمح بتخصيص خوارزمية الأتمتة الخلوية هي: الحالة الأولية للشبكة ثلاثية الأبعاد وظروف الجوار وحالات الخلية وقواعد الأتمتة. تم إنشاء خوارزميات الأتمتة الخلوية لكل متغير قابل للتخصيص باستخدام إطار العمل. وتم تقييم تلك الخوارزميات بناءً على القدرة على توليد الشكل. وتم استخدام نهج يعتمد على voxel لإنشاء هندسة شكل عن طريق النقاط التي أنشأتها الأتمتة الخلوية ثلاثية الأبعاد. ويمكن مستقبلا استخدام الأشكال التي تم توليدها باستخدام هذا الإطار كأداة لتوليد الأشكال والنماذج للبيئات الرقمية.

الكلمات المفتاحية: *الأتمتة الخلوية، برنامج جراسهوبر، التصميم التوليدى، إطار عمل.*

1. Introduction

The word "design" can describe the process of designing an object and the object that is the result of this process. According to Dino (2012), a generative system is not a production system that defines the design product but a higher-level definition, or design process, that encodes the "making" phase of the design product. Therefore, generative systems allow the designer to "design a design tool" as an alternative to the task of designing an object. In this study, a design tool that uses Cellular Automata as a generative system has been produced. The contextual relationship with the concept of "rhythm" has been examined.

2. Background

The theme of the work is "Rhythm". The difficulty in researching the concept of rhythm is the lack of a generally accepted, clear definition (Fraisse, 1982). Rhythm comes from the Greek words "ρυθμός" (rythmós) and "ρέω" (réo)(to flow) (Fraisse, 1982). Rhythm, which is defined as repetitive movements and symmetry (Liddell and Scott, 1996), is characterized as "the movement defined by the organized repetition of strong and weak elements or by opposing or different conditions" (Anon, 1971).

The most common use of the concept of rhythm is music. Additionally, in linguistics, the development of languages and their interaction with each other are used to describe situations. The word rhythm is also used outside of these contexts in the language we use daily. The concept of "Rhythm" is confused with "Tempo" in cases where a person defines the rhythm of his activities during the day, or the rhythm of a city is explained. Tempo describes the speed of a rhythm. In this work, while tempos are compared with each other in terms of speed, rhythms are compared with each other structurally.

2.1. RHYTHM / FORM / FORM FINDING

According to Benveniste (1951), the semantic connection of the words rhythm and flow was not inspired by the repetitive motion of the waves, as is supposed. "Rhytmos", which appears as one of the keywords of Ionian philosophy, is defined as a more developed, instantaneous, and variable "form" with a generalized meaning of "form" (Fraisse, 1982).

Form finding is one of the critical components of the design process. Different definitions have been made over time for the concept of form-finding. Haber and Abel (1982) define the form-finding problem as the "initial balance problem" (Veenendaal & Block, 2012). This definition has been further discussed later on. According to Lewis (2003), form finding is "the search for the optimal shape of a form-active structure at or near equilibrium". This definition has been accepted and used by most people. Looking at more recent definitions, the definition used by Coenenders and Bosnia (2016) is "finding the appropriate architectural and structural form". Basov e Del Grosso (2011) states that shape finding is "a structural optimization system that uses point coordinates and variables".

Form production methods have been applied primarily in physical and digital environments with the development of technology. Antoni Gaudi's experiments with hanging chains, Heinz Isler's experiments with hanging various membranes, and Frei Otto's experiments with soap bubbles can be

shown as examples of form-seeking experiments in the physical environment (Veenendaal, D., & Block, P., 2012). With the development of digital tools, the variety of form-finding methods has increased. Just as gravity is the form-determining force in Gaudi's experiment by hanging chains, the laws of physics, the growth and development mechanisms of living things, and mathematical equations, such phenomena were recreated in the virtual environment and used in form-finding experiments in the digital environment. Cellular Automata (CA) is one such method. Within the scope of this study, CA methods are discussed to find form. The working logic of different CA algorithms has been examined, reproduced, and diversified. As a result, a design tool based on the CA algorithm has emerged.

2.2. CELLULAR AUTOMATA

Cellular Automata is a subject studied in fields such as computer science, mathematics, physics, and theoretical biology. It was also considered a productive system and a research topic during the design process. The cellular automata approach allows the simulation of neighborhood relations, in the field of architecture, both in the search for form (Frazer, 1995; Dinçer et al., 2014), in simulating the displacement of individuals in space, and in revealing complex relationships at the urban scale (Guzelci, 2013). It has been the subject of practice and debate in the fields. It is the change of different viability states of cells in a set based on rules depending on the relationship of cells with other cells around them. 1, 2, 3, or more sizes of CA can be defined (Adamatzky, 2010). Although the first studies on CA were made in the 1950s, it was not at a level that would attract the attention of a broad audience until Conway's CA application named "Game of Life" (GoL) was published in the "Scientific America" magazine in 1970 (Adamatzky, 2010).

In this application, some cells can be found in "alive" or "dead" states on the grid formed by a two-dimensional matrix. For each cell, the cells which are interacting with it are called “neighbor cells”, and the definition of this interaction is called “neighborhood”. The "Moore" neighborhood format defined in the GoL application consists of 8 cells located 1 unit away from the cell. A "Generation" is the set of states of all cells at a given moment. The state of each cell in the next generation is determined by the living or dead state of the neighboring cells, according to the rules. According to the GoL application, a living cell can continue to live in the next generation if there are 2 or 3 cells in its neighborhood. Otherwise, it goes dead. A dead cell becomes alive in the next generation if three living cells are in its neighborhood. The system develops step by step depending on these rules and produces new geometries. The gradual intergenerational progression of the form generation process in CA can be described as rhythmic growth. In

addition, the contrast of vitality and deadness gives a contextual reference to the definition of rhythm. Form generation methods can be diversified by differentiating the neighborhoods, rules, and living-dead situations, which are the basic features of CA.

2.2.1. Neighborhoods

In a CA algorithm, the set of surrounding cells used to determine whether a cell complies with the rule that will determine its status in the next generation is called "neighboring cells". These cells are usually located near the parent cell. As seen in Figure 2, Von Neumann and Moore's neighborhood can be shown as an example of neighborhood forms in 2D CA. Von Neumann neighborhood considers cells where the cell is adjacent in the horizontal and vertical directions (Adamatzky, 2010). On the other hand, Moore's neighborhood covers eight neighboring cells by taking the nearest cell in the diagonal direction and adjacent cells in the horizontal and vertical directions (Adamatzky, 2010).

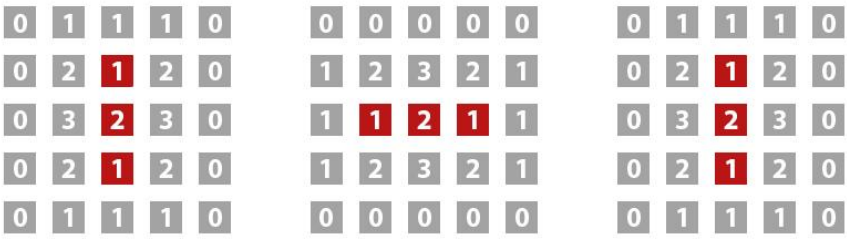

Figure 1. CA calculation between generations.

2.2.2. Generations

In the CA algorithm, each cell has a specific state. Whether this situation will change in each new generation is calculated according to the rule defined in the algorithm. For example, in GoL, cells are either "alive" or "dead". Various patterns are obtained by showing live and dead cells in different colors (live = black, dead = white) (Figure 1).

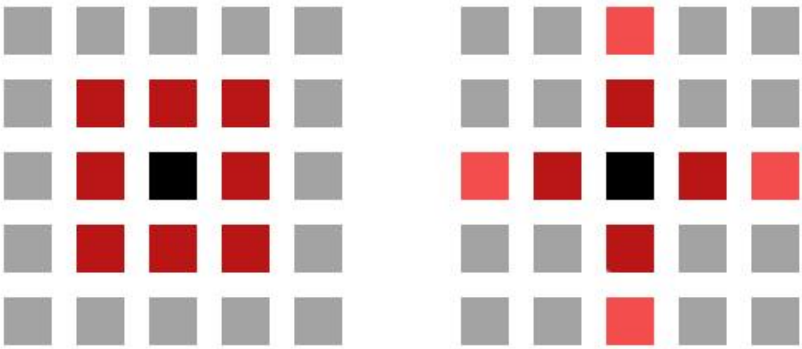

Figure 2. Neighbor cells in different neighborhood types.

2.2.3. Rules

In the CA algorithm, each cell has a specific state. Whether this situation will change in each new generation is calculated according to the rule defined in the algorithm (Figure 3). For example, in GoL, cells are either "alive" or "dead". Various patterns are obtained by showing live and dead cells in different colors (live = black, dead = white).

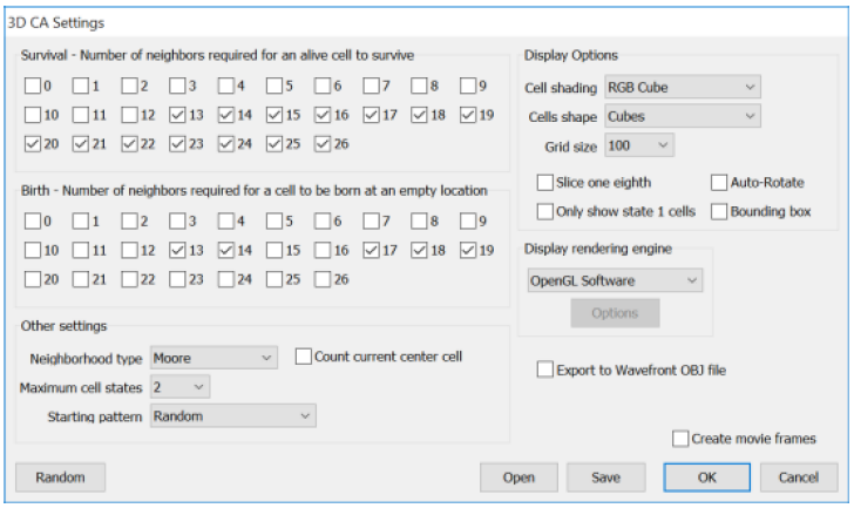

Figure 3. Rules for 3D Cellular Automata (Visions of Chaos).

3. Research Background

The first studies of the Cellular Automata algorithm were performed without computer support by drawing each generation separately, moving objects on a grid. There are tried-and-tested examples available, such as Rabbit (Url-2) and Vision of Chaos (Url-1). However, these methods are slow and limited. With the development of computer technology, the number and quality of studies in this field have increased by calculations being made by computers. Today, running the CA algorithm in most programming interfaces with visual output is possible. While it is possible to see the outputs of only specific rules in some more advanced applications, it is possible to define rules and print out a 3D model besides the visual output. Additionally, there are programs that allow multiple dimensional CA algorithms, different neighborhoods, and different cell states are numbered and inserted in the text after the first reference to it.

3.1. PROCESSING: GAME OF LIFE

In this study, first of all, the "Game of Life" application, which has an essential role in the spread of CA applications, was examined, and the working principles of the CA algorithm were studied. In the "Processing" (Url-3) programming interface, the GoL application was reproduced using the "Java" programming language (Figure 4). This study is vital in learning the CA algorithm's features to be defined in computer language.

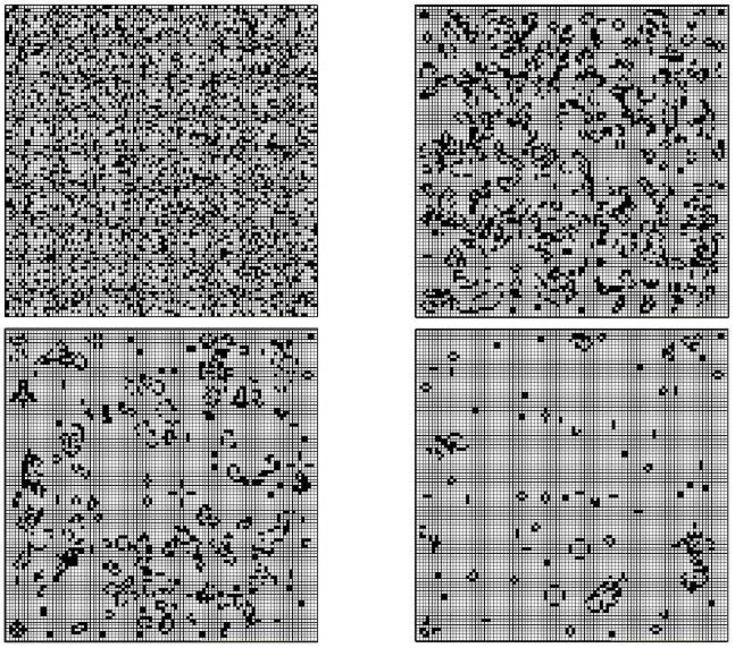

Figure 4. A screenshot from “Game of Life” algorithm in Processing.

3.2. VISIONS OF CHAOS

This application (Url-1) runs algorithms such as Fractals, L-systems, Multi-agent systems, Cellular Automata, and Diffusion Limited Aggregation. It is a versatile program that is capable of running various generative algorithms (Figure 5). In addition to 1D, 2D, 3D, and 4D applications of CA, there are methods in which different neighborhoods, different vitality states, and different rules can be applied. There is a user interface where these features can be defined. While it is easy to use, 3D models and video output are its positive features. Its negative feature is that the algorithm has a limited choice of a sphere, cube, or a filled environment as the initial form. This disadvantage makes it difficult to use the program as a design tool. In the work to be done, it is aimed to produce an interface that allows the user to determine not only the rules and CA type but also the initial state, and in this way, get rid of randomness and make his design.

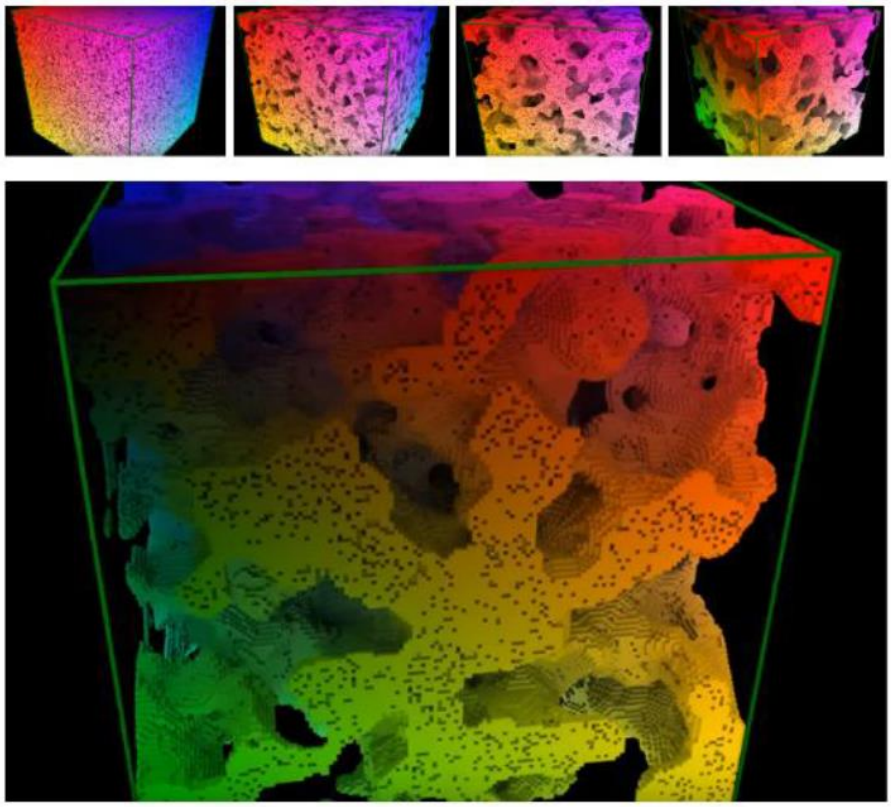

Figure 5. Screenshots from Visions of Chaos with 3D Cellular Automata. (Url-1)

3.3. RABBIT (GRASSHOPPER PLUG-IN)

It is included in the Grasshopper3D, which is a plugin of the Rhinoceros3D program (Url-2). Running the CA algorithm inside a design program means better user control when using this algorithm for design purposes. In addition to graphically defining the initial form of the algorithm, it is also possible to intervene in the environment in real-time. Rabbit plugin includes 2D CA algorithm and 3D CA algorithms Stacked Cellular Automata (SCA - Stacked Cellular Automata). SCA is 3-dimensional geometry obtained by superimposing each generation of 2-dimensional CA. Rabbit is a good example of using 2D CA and its 3D extended version SCA as a design tool. However, this method is insufficient because it does not contain other varieties of CA. This study aims to create a Grasshopper3D plugin in which different methods of CA can be defined.

3.4. COMPARISON

The purpose of trying these three programs before writing a script for 3D CA algorithm in Grasshopper is to learn how the algorithm works in multiple environments and conditions. While writing a 2D CA algorithm in Processing was easier than the 3D version, its aid to the research was the understanding of how the algorithm works.

“Visions of Chaos” (VoC) helped visualizing 3D cellular automata and also how the parameters of the algorithm worked. However, its downsides are also revealed while using it, like not being able to control the initial shape. Using Grasshopper to simulate 3D CA algorithm is thought to solve these problems. Rabbit, which is a Grasshopper plug-in, is capable of solving 3D CA problems. However, this 3D interaction is actually 2,5D, because of how the plug-in works. As a conclusion, a 3D CA algorithm with the working system of VoC in Grasshopper is written.

4. 3D Cellular Automata Plug-in as a C# Script in Grasshopper

4.1. THE ALGORITHM

The algorithm is defined as a Grasshoper3D plug-in (Figure 6). The plug-in written in C# scripting language. The algorithm is planned to have user-defined parameters. These parameters are:

Rules: Each rule defines a new format generation system in CA algorithms. While some rule sets expand from a minor point, some rule sets can result in an entire format diminishing to an optimum state. These rules can be discovered and serve different purposes in design.

Neighborhood: Changing the definition of neighboring cells provides diversity in the development of the system.

Cell states: At the basic level, there are two alternative states of cells in CA, live and dead. The transition of a cell from a live state to a dead state occurs in a generational change. Alternatively, the viability state of a cell can be defined by a number. For example, a cell is dead when it is "0" and alive when it is "1". If the maximum number of states of CA is 4, cells can be found in states "0,1,2,3". When a living cell in the "1" state dies, it first changes to the "2" state, then to the "3" state, then to the "0" state. It can switch from a "dead" state to an "alive" state only when it is "0". In the "2"

or "3" state, it is considered dead in the calculations of neighboring cells. Another example can be taken Rock-Paper-Scissors CA. In this case, the rules between cells change according to the type of neighbor cells.

Initial conditions: In classic CA applications, the startup format is usually defined. The difference in shape finding comes from the random differentiation of the states of the cells that define the initial shape. However, this randomness must be controllable for a designer.

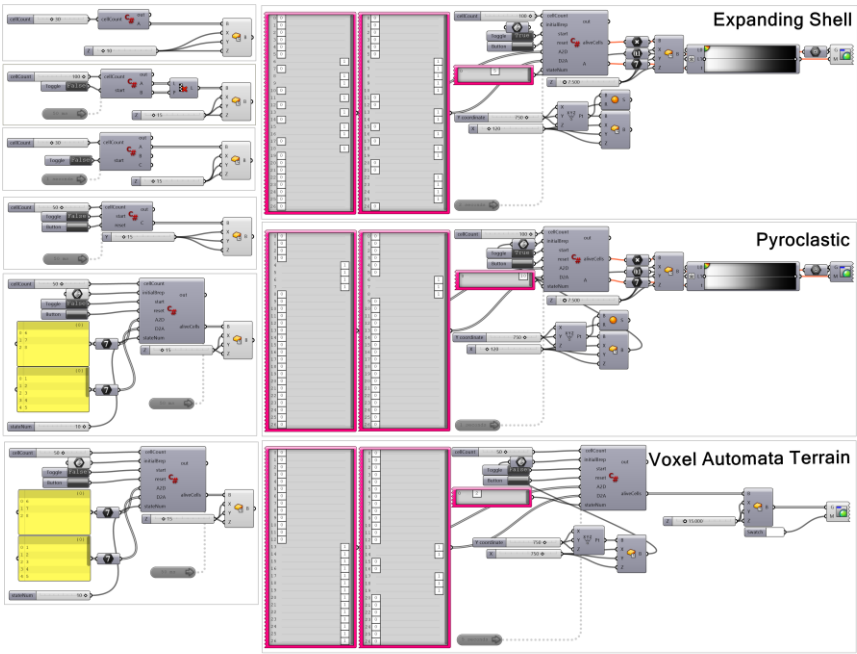

Figure 6. 3D CA algorithms using the plug-in; Expanding Shell, Pyroclastic, Cloud.

4.2. USING THE ALGORITHM

The presented 3D CA plug-in is capable of creating multiple generative systems, based on the variation in initial geometry, rules and model formation. The plug-in is tested with four different algorithms; which are named Expanding Shell, Pyroclastic, Cloud, and Voxel Terrain Automata.

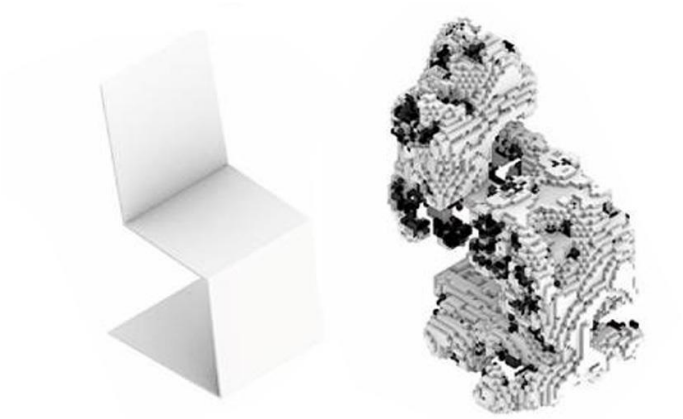

Figure 7. Initial condition (Left), generated model using 3D CA (Right).

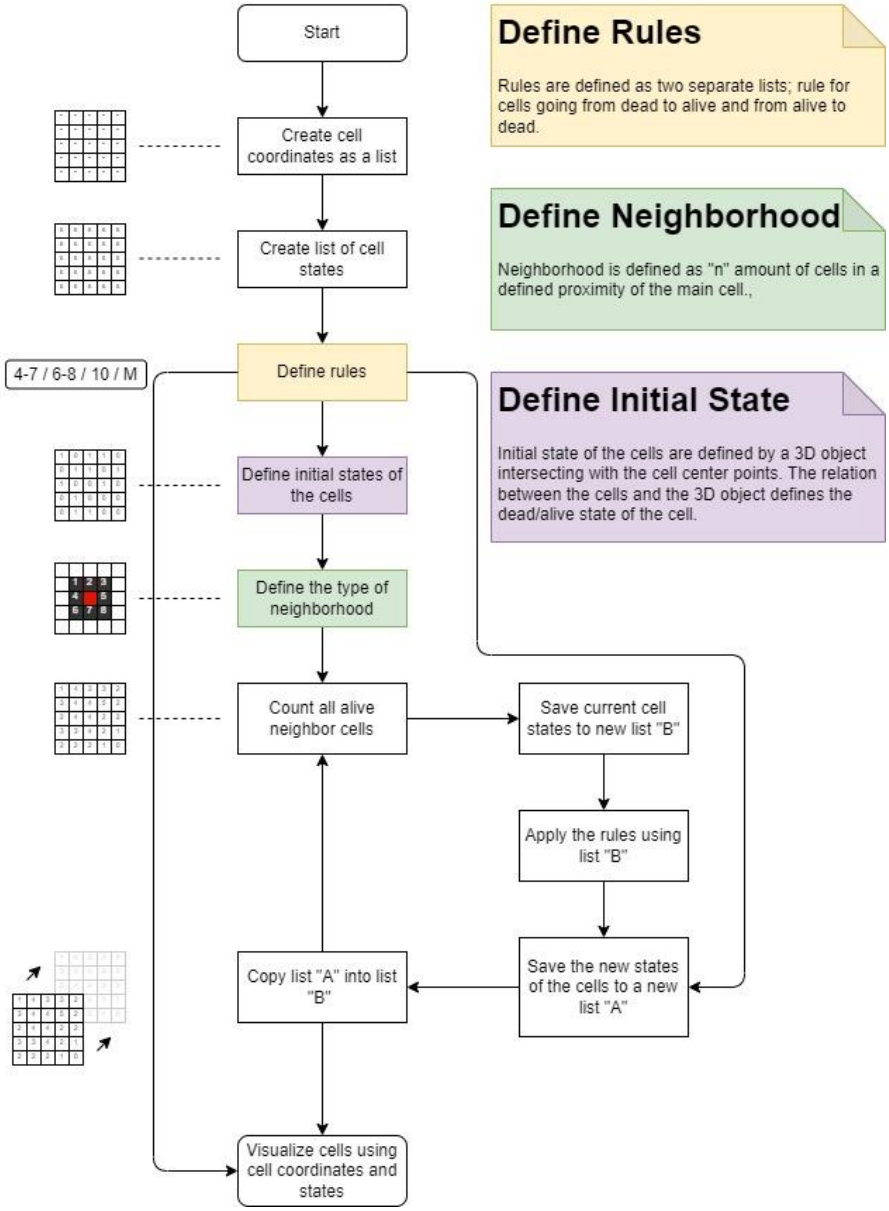

Figure 8. 3D CA algorithm flow chart.

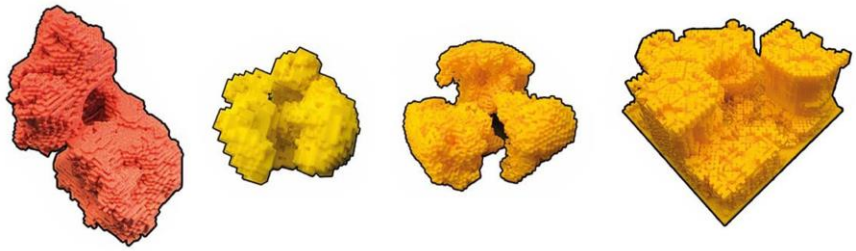

Figure 9. Resulting 3D objects. *From left to right; Expanding Shell, Cloud, Pyroclastic, Voxel Terrain Automata.*

5. Conclusion and Future Possibilities

With the presented Grasshopper3D plug-in "proGeny", new productive systems can be discovered by experimenting with the rules of various cellular automata algorithms, their neighborhoods, and the viability of cells. Through the use of these systems, new form finding experiments can be done which result in emerging forms.

The aspects of this program that are open to development can be listed under the following main headings:

Visual interface: Although Grasshopper's visual interface is sufficient to start these experiments, a more user-friendly interface can be added using C#.

User interaction: In Grasshopper3D, interaction with the computer, keyboard, and mouse is defined. However, other Grasshopper3D plugins have examples (Firefly, Quokka) like Kinect or LeapMotion. User interaction can reach a different dimension through motion sensors, Arduino, and various sensors.

AR/VR applications: Visual outputs of the products obtained with the developed program can be taken on the computer screen. As a design tool, AR/VR applications can help experience this design process in the same environment as other factors affecting design.

In today's world, where digital design has become widespread, it is seen that the role of the designer is gradually replaced by the role of "designer of tools" or "designer of systems". Within the scope of this study, a tool called "progeny" that the designer can use in the design process has been developed. Using the program, the user can generate a design system on various versions of the CA with the rules, initial format, and neighborhood parameters that he has determined and can use this system in the design process. Since it is an application with development potential, it can provide opportunities for new research topics.

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DIGITAL FRAMEWORK TO OPTIMIZE VISUAL COMFORT USING KINETIC FACADES

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Abstract. Visual comfort is one of many aspects of human comfort that should be considered in architectural spaces. Visual comfort is an architectural necessity and could be achieved and optimized in spaces through controlling facades' opening. This could be achieved by applying kinetic facades, which is one of the trends in the field of responsive architecture. However, the research' s aim is optimizing visual comfort using kinetic facades in educational spaces. This optimization will improve the environmental quality of the educational space. In this research architects will achieve easily more effective kinetic facades to have better visual comfort by enhancing daylight quantity and quality using luminous environmental parameters' measurement tool. In this research a series of scripts will be applied on various kinetic facades' alternatives. These scripts will be based on a relation between different daylight and kinetic parameters. Thus, the outcome is to develop an Add-on, as a digital plugin, that will be presented through a friendly Graphical User Interface (GUI).

Key words: *Visual comfort, daylight, educational spaces, kinetic facades, Add-on.*

ملخص. الراحة البصرية هي واحدة من العديد من جوانب راحة الإنسان التي يجب مراعاتها في الفراغات المعمارية. تعتبر الراحة البصرية ضرورة معمارية ويمكن تحقيقها وتحسينها في الفراغات من خلال التحكم في فتحات واجهات المبانى. يمكن تحقيق ذلك من خلال تطبيق الواجهات المتحركة، والتي تعد واحدة من الاتجاهات في مجال العمارة المتجاوبة. ومع ذلك، فإن هدف البحث هو تحسين الراحة البصرية باستخدام الواجهات المتحركة في الفراغات التعليمية. سيؤدي هذا التحسين إلى تحسين الجودة البيئية الفراغات التعليمية. في هذا البحث، سيحقق المعماريون واجهات حركية أكثر فاعلية بسهولة للحصول على راحة بصرية أفضل من خلال تحسين كمية وجودة الإضاءة الطبيعية باستخدام أداة قياس المتغيرات البيئية المضيئة. في هذا البحث، سيتم تطبيق سلسلة من البرامج النصية الحوسبية على بدائل مختلفة للواجهات المتحركة. ستستند هذه البرامج النصية إلى العلاقة بين متغيرات الواجهات المتحركة ومتغيرات الإضاءة الطبيعية المختلفة. وبالتالي، فإن نتيجة البحث هي تطوير مكون برنامج إضافى رقمي يتم تقديمه من خلال واجهة مستخدم رسومية سهلة الاستخدام.

الكلمات المفتاحية: *الراحة البصرية، الإضاءة الطبيعية، الفراغات التعليمية، الواجهات المتحركة، مكون برنامج رقمى إضافى.*

1. Introduction

Achieving comfort in a space is related to physical environments, in addition to psychological issues, mood and social factors (Kamholz & Storer, 2009). Visual, audio, thermal and hygienic are all factors that could affect the human comfort in a space. This research will tackle just visual factor.

Optimizing visual comfort is considered an important factor in human comfort, by using stained glass, blinders and various types of shading devices, which were manually controlled. In addition, kinetic architecture especially kinetic facades have been emerged through the past decade in the field of architecture and visual comfort (Al Horr et al., 2016). Thus, this research focuses on achieving visual comfort in educational spaces, especially in universities library

The research problem is that various software can do environmental simulation to achieve visual comfort in a space. Few of them can simulate kinetic facades at different situation. Thus, the aim of this research is to create and evaluate an Add-on software to enhance a digital tool, to facilitate the simulation and optimization process for architects, when using kinetic facades which in turn will optimize visual comfort through a Graphical User Interface.

The research methodology will start by doing a literature review about visual comfort and kinetic parameters in educational spaces focusing on illuminance and glare, then exploring ladybug and honeybee as digital environmental tools. Proposing and Add-on that can be universally applied and used, the next step is verifying and evaluating the developed Add-on and applying it at BAU university

library, in Tripoli campus, as a case study. The last step is enhancing the (GUI) of the proposed Add-on after evaluation.

2.Daylight and kinetics system in universities library

Lighting can reinforce action and perception, according to the illumination Engineering Society of North America (IES). Productivity, human health and energy efficiency are all affected by daylight (El-Dabaa, 2016).

- Energy efficiency: more efficient daylight reduces the need for artificial light, resulting in lower energy consumption.
- Functional efficiency: sufficient lighting improves spatial and functional efficiency of space, not only in the direct use such as writing but also in term of revealing color and form that promote functional efficiency.
- Human productivity and health: According to Tomassoni adjusting daylight amount in a location improves user mood and productivity. Because psychological well-being, body temperature and brain activity are all influenced by the light in a certain architectural context, studies reveal that those who work at night have a significantly higher negative mood that those work during the day (Tomassoni et al., 2015). If the daylight amount is insufficient, their neutral system may be disrupted, leading to a feeling of exhaustion.

The European Norms (EN) set the universal standards for light planning in indoor work environments, which were adopted by the European Committee for Standardization (CEN). These guidelines aid in achieving human visual comfort in a variety of settings and functions (EN, 2011). Sufficient lighting is required for both quantitative and qualitative components of comfortable daylight.

As a result, the research focuses primarily on the visual comfort category, which comprises numerous characteristics for establishing the luminous environment, such as luminance and glare, which are further investigated.

2.1. LUMINOUS ENVIRONMENT PARAMETERS

The primary elements affecting daylight and artificial light, such as illuminance, glare, luminance distribution, directionality of light, variability of light, flicker, color rendering, and color appearance of the light, determine the luminous environment (EN,2011).

It is remarkable that glare and illuminance are two of the most important parameters for having comfortable daylight and sufficient daylight quantity and quality, according to European Standards (EN). Thus, the two parameters considered in all of the research are illuminance and glare.

- Glare

When bright spots develop in the visual field, glare occurs. Glare that is distracting might lead to accidents and tiredness. As a result, various criteria must be considered in order to minimize unacceptable glare, such as Daylight Glare Probability (DGP), a method that considers both "illuminance at eye level and individual glare sources of high brightness to predict the fraction of unsatisfied persons" (EN,2011). DGP is divided into four categories: not perceived glare, perceived but not disturbing glare, disturbing glare, and intolerable glare. The first two are deemed suitable, while the final two are considered unsuitable.

- Illumination

Illuminance has an impact on people's visual comfort and how quickly they perceive visual activities. The European Standards established illuminance values based on the type of work environment and requirements for performance and comfort (EN, 2011). Illuminance levels should be higher than or comparable to those specified in European standards. Illuminance values should be calculated at particular spots, which should be produced using a grid system with equal sides. The ratio of length to breadth varies between 0.5 and 2. In addition, the number of grid points and the distances between them should be provided based on EN standards from 2011.

2.2. KINETIC FAÇADE & IMPORTANCE

The layer located between inside and outside a building is called building envelope, which could be static or dynamic. Blinders or shadings located on a building façade could be kinetic, which mean the movement, while kinetic architecture mean the building design produced by a movement. In addition, kinetic architecture is one of the most significant trends in architecture, since it is a revolution from static to dynamic (Al Horr et al.,2016). From 1970 to the present, many researchers have discussed kinetic architecture, including Zuc and Clark in 1970, Michael A. Fox in 2003, Chuck Hberman in 2005, Robert Kronenburg in 2007, Kostas Terzidis in 2008, and others (Barozzi, 2016). Furthermore, Kostas Terzidis suggested in 2008 that adding motion to a building is vital since it affects the design, aesthetic, and performance of the structure. As

a result, kinetic architecture is more than simply about moving buildings; it's also about bridging the gap between nature and the built environment in terms of environmental variability.

Furthermore, depending on the system's function, kinetic architecture takes on several forms (Rossi et al., 2012). It could, for example, be used on building facades, building structures, and landscapes, among other things. The research will target kinetic facades that could be controlled automatically in response to outdoor environmental changes such as daylight. Kinetic facades could be found in many examples in the world, such as Abu Dhabi Investment Council HD in Abu Dhabi, Kiefer Technic Showroom in Austria, the University of Southern Denmark (ADU), Arab World Institute in Paris, and other.

3.Daylight Simulation Plugins (Ladybug and Honeybee)

For environmental simulation, various simulation plugins have been utilized; however, this study uses the ladybug and honeybee plugins in grasshopper3D for Rhino since they are validated and built on validated energy and daylighting engines, EnergyPlus, Radiance, and Daysim (Sadeghipour Roudsari and Pak, 2013). Python, one of the most powerful programming languages, is used to script Ladybug and Honeybee (Ladybug Tools | Ladybug", 2020). Ladybug allows users to import standard EnergyPlus Weather files (EPW) into Grasshopper, as well as other diagrams and studies such as sun path, radiation rose, wind rose, shadows studies, view studies, and others.

Following an examination of the existing plugins, the following features have been identified as having the potential to provide better, more flexible, and user-friendly performance that will eventually answer to research objectives:

- Kinetic simulation automation: present plugins waste a lot of time because when architects simulate dynamic yearly shading, they have to work under certain constraints: each instance must be done independently and continuously by the user. As a result, it is necessary to simulate diverse kinetic scenarios automatically over time.
- Adding a time range: the simulation given by the existing plugin is only for a fixed time annually. As a result, a long-time range is required to automatically replicate different periods of time throughout the year.
- Output graphical interface: the existing plugins only include graphs for static shading cases as outputs, but no graphs for kinetic shading situations, such as graphs for shadings at different angles.

- Multi-task simulation: Furthermore, the present plugin only works with one simulation type, such as illuminance; it is not feasible to mix different simulation types, such as glare and illuminance, at the same time.

4. Proposed Add-on's Framework

A new Add-on's framework is proposed aiming address the mentioned four points in order to enable automatic daylight simulation for kinetic facades by determining the best kinetic shading mechanism for achieving optimal daylight in areas at various angles and times, as well as glare and illuminance simulation. The proposed Add-on structure is illustrated in the following graph, that includes the Add-on's steps and codes.

As illustrated in Figures 1 and 2, the proposed Add-on is split into three primary phases: first, input phase (fixed and variable parameters), second, optimization phase, and third, output phase.

4.1. INPUT PHASE

To start any simulation, inputs are needed. In the proposed Add-on, there are fixed and variables inputs. Each one is divided to various sub-inputs as follows and shown in Figure 3.

Three types of fixed inputs parameters are supposed to exit, which are:

- Environmental parameters: containing the orientation of the building and the weather file that is required to collect hourly solar radiation for a specific area.
- Architectural space parameters: containing all simulated space data, such as room size, dimensions, proportion, area, opening ration and opening placement.
- Kinetic parameters: containing the related data to kinetic units, such as speed, geometry and weight

Furthermore, the variable inputs are split into two categories:

- Kinetic parameters: these include rotation, open and shut, and other kinetic shading motion parameters.
- Time/date parameters: simulation period includes hours, days, and months throughout the year.

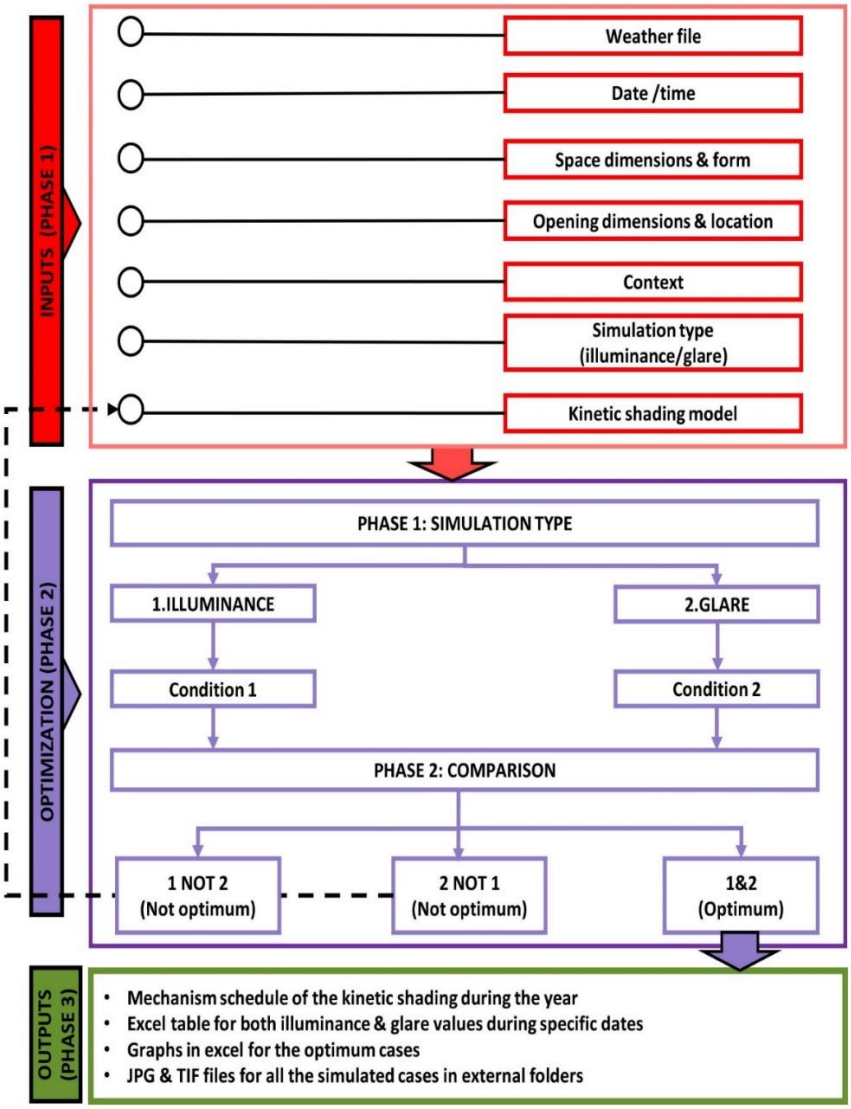


Figure 1, Diagrams shows the general Add-on framework divided into three main phases

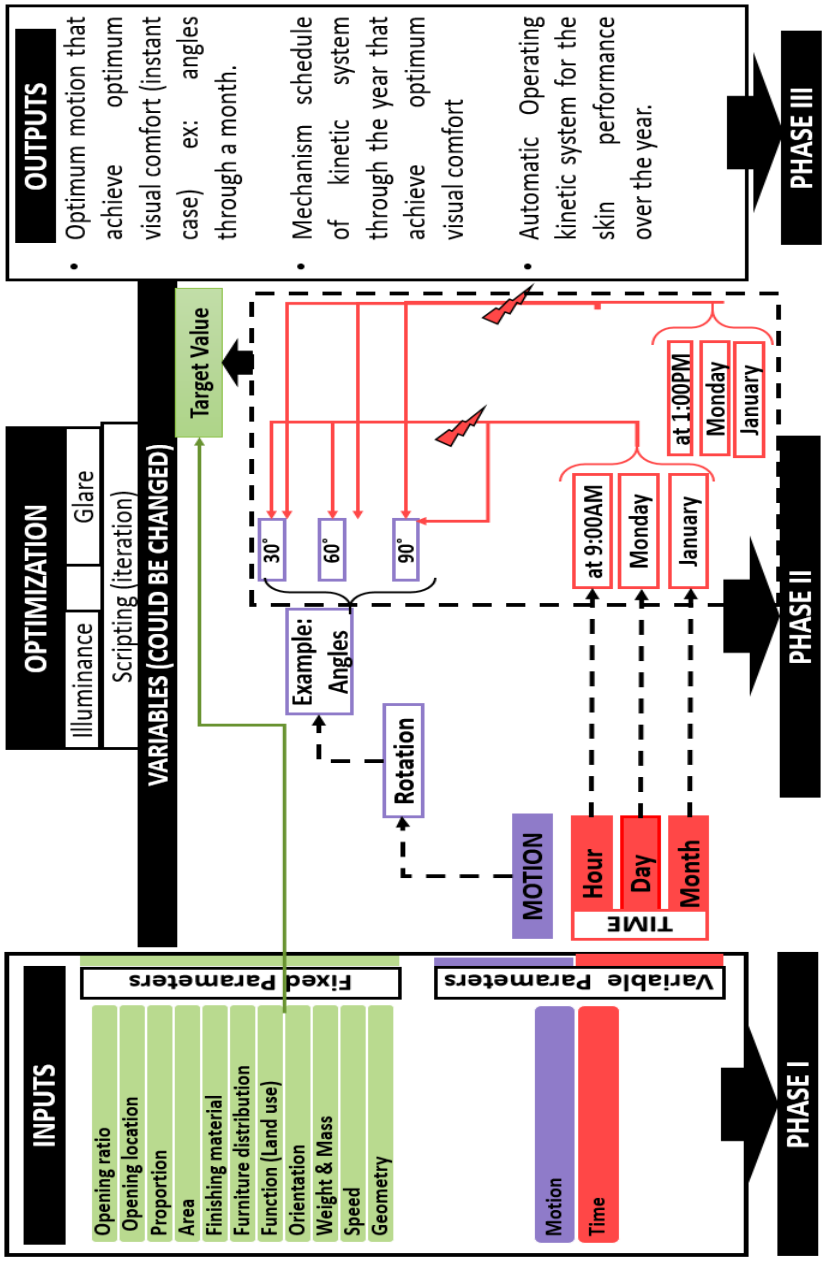


Figure 2. Diagram that shows the detailed Add-on framework including inputs, operation and outputs

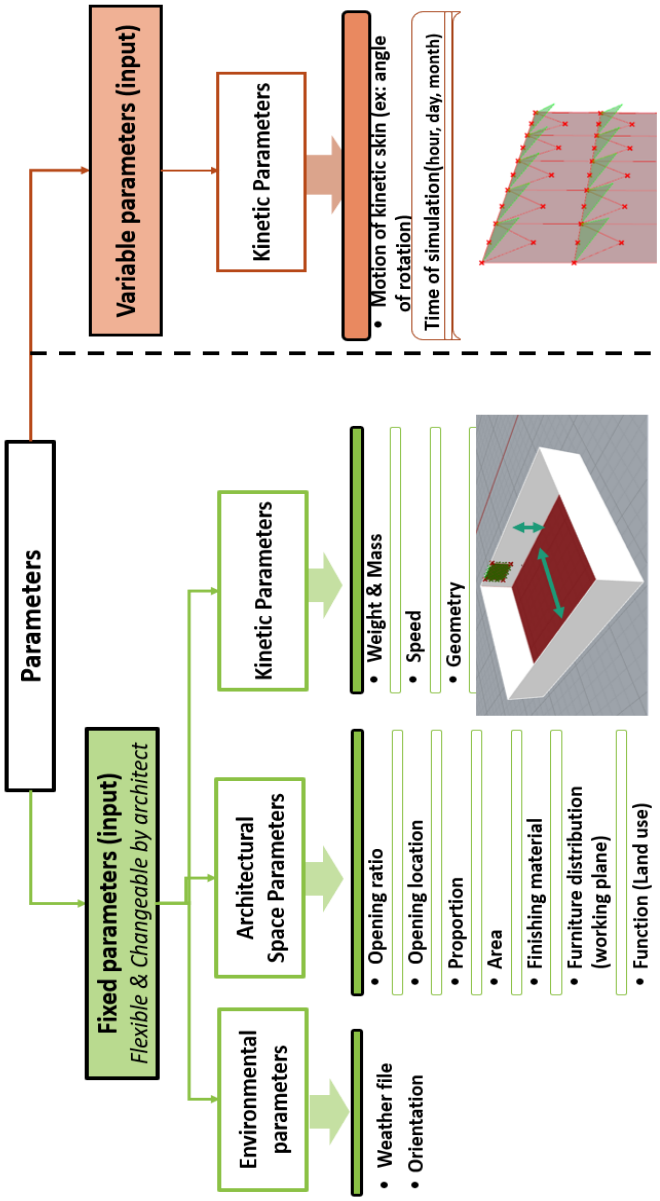


Figure 3. Diagram that shows both fixed and variable inputs for the developed add-on plug in

4.2. OPTIMIZATION PHASE

The optimization phase, which includes both illuminance and glare simulations, is illustrated in Figure4. Each operates differently in order to achieve the best results over a period of time. The automation date/timing range was built using an automated script, so the user does not have to constantly update the simulation time and date. The optimization goes via an automated optimization loop towards two primary checking gates to achieve optimum visual comfort and daylight. The first gate verifies that the illuminance values are within the intended range, while the second verifies that the glare inside the DGP range is appropriate. The findings of both gates will then be compared, and the final optimization results will be checked. The outputs will be displayed in the next phase if the results were optimal, but if they were not, the user must modify the kinetic shading models' variables and simulate again.

4.3. OUTPUT PHASE

Following the optimization process, the output should look like this:

- Values for both glare and illuminance at the same time in Grasshopper 3D.
- Illuminance and glare values on an Excel sheet and table.
- Kinetic shading mechanism schedule in an excel table for each of the optimum scenarios' individual simulation time and date.
- Excel graphs for the best kinetic shading mechanism for visual comfort and optimal daylight at a given moment.
- Identifying the best scenarios for each simulation (in text).
- All simulated cases in defined scenarios are saved as TIF and JPG files in external archives.

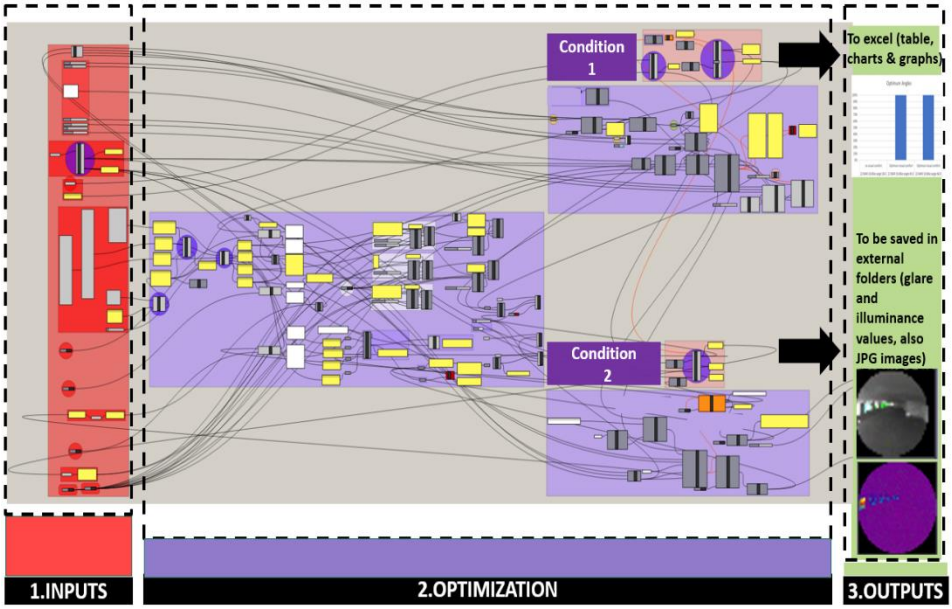


Figure 4. Add-on plugin phases using ladybug and honeybee in Grasshopper for Rhino

Different programming languages can be used to construct a script; python is the programming language used in this research. To construct this add-on, various scripts are written inside the Grasshopper3D software environment, each script serving a specific role, as shown in Figure 5. The following is a list of the seven written scripts:

1. Script 1 contains simulation type, which seeks to select the simulation type by including a check list for several types of simulations to run, such as illuminance, glare simulation, and both will perform the simulation, while when it is set to false, the simulation will stop
2. Script 2 displays the angel values, which allow the user to choose the angles that will be used in the simulation. The second script's inputs are a list of angle values that can be checked or inserted by users, with the output being the selected or written angels that will be utilized in the simulation.

3. Script 3 is the animation slider value is used to calculate the value of a series of simulations run for various inputs such as angles and time. A list of months, days, hours, and angels are entered as inputs.
4. Script 4 is about date and angels, which aims to identify the required period of time and the angels' values for the simulation, including a list hours, days and month, and angels' values, which are inserted into the x, y, z, and v variables inputs, as well as the animation slider value, which is implanted into the u variable input for activating the simulation.
5. Script 5 displays the illuminance target value, which is used to specify the illuminance value required in a certain area.
6. Script 6 is the illuminance condition, which is the procedure for determining whether or not the amount of illuminance is sufficient.
7. Script 7 offers optimization conditions that aid in determining the sequence in which the simulation logic should go in order to achieve the best kinetic shadings situation in a given amount of time. The condition for both illuminance and glare to provide optimum visual comfort in a certain function and location is included in this script.

5. Add-on Graphical User Interface (GUI)

As illustrated in Figure 6, all of the components utilized in this Add-on have been clustered and combined to make the GUI more user-friendly. As a result, nine components have been replaced by 51 components as a final GUI:
Component 1: simulation inputs is used to collect all simulation inputs, such as the kinetic shading system, geometrical space components, weather file, and simulation period.
Component 2: illuminance simulation, which is used to simulate illuminance.
Component 3: glare simulation, which is used to carry out the glare simulation.
Component 4: simulation type, which is used to turn on or off the simulation.
component 5: list value for choosing between illuminance, glare, or both types of simulation.
Component 6: function type, which allows you to choose between different space functions such as library, classroom, and so on.
Component 7: optimization tags, which are used to define the best results by demonstrating simulation values.
Component 8: create cases for automating the simulation for a variety of kinetic situations in a row.
External excel sheet data (component 9) is used to keep a record of all simulation results.

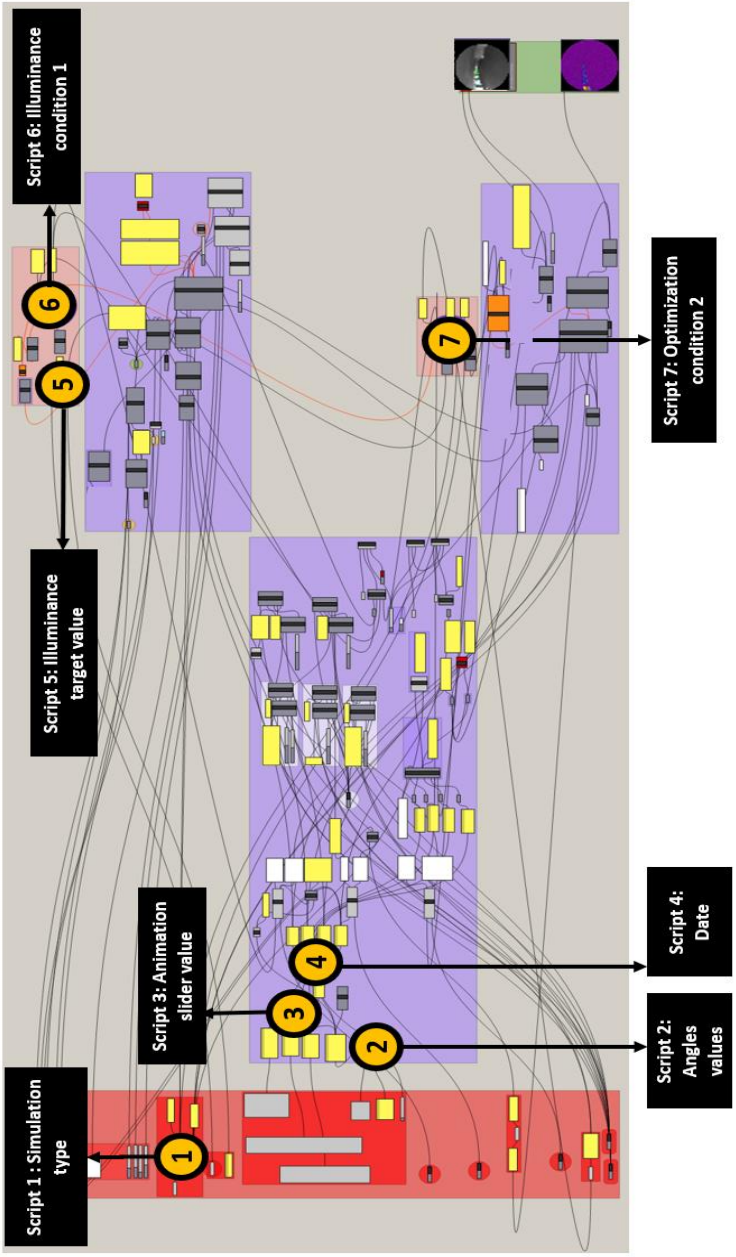


Figure 5. Six scripts created in the proposed add-on

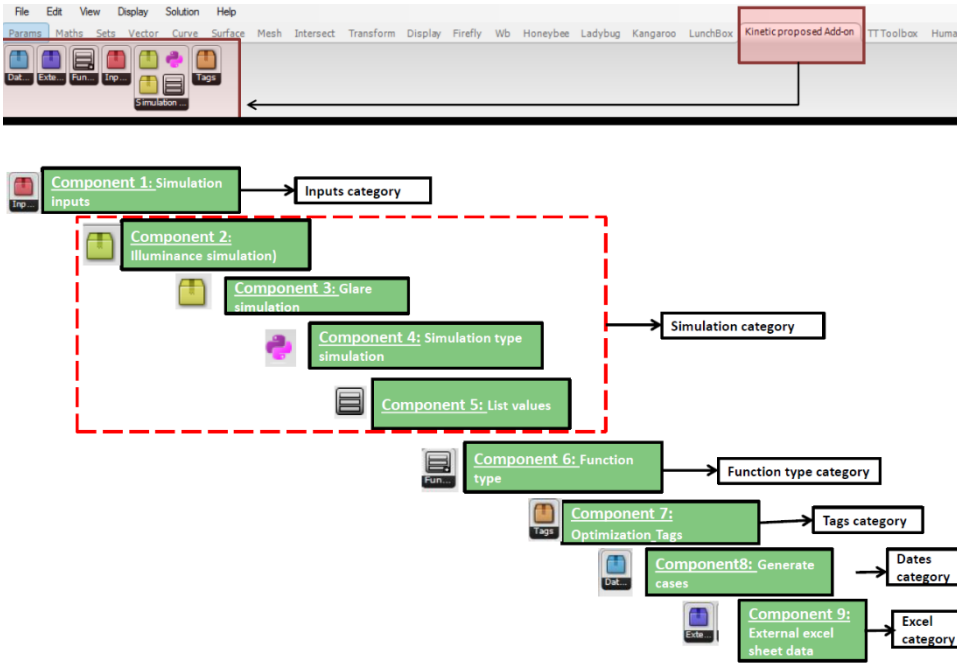


Figure 6. Add-on components through GUI

5.1. PROPOSED ADD-ON APPLICATION

Many people spend the majority of their time in educational settings. Natural lighting is vital for students' wellbeing and mental health; hence it should be considered while increasing their visual task performance. However, it may be unsuitable in areas where glare is noticeable. As a result, there is a requirement for users, particularly students, to have a suitable amount of natural daylight while practicing their visual skills in a pleasant and relaxing atmosphere (Bakri, 2014).

In university libraries, daylighting has a significant impact on users' perceptions, satisfaction, and behavior. Libraries are regarded an important element of university, where there is a strong emphasis on self-learning, with the library playing a vital role in providing students with access to information, documentation, and data references, among other things. Furthermore, the library's architecture and daylighting may increase usage and encourage students to use it during their free time rather than only during exams.

An application is need it to be applied on educational space to verify and test the proposed Add-on. Thus, the selected space is the library of BAU University, located in Tripoli, North Lebanon, as shown in Figure 7 and 8.

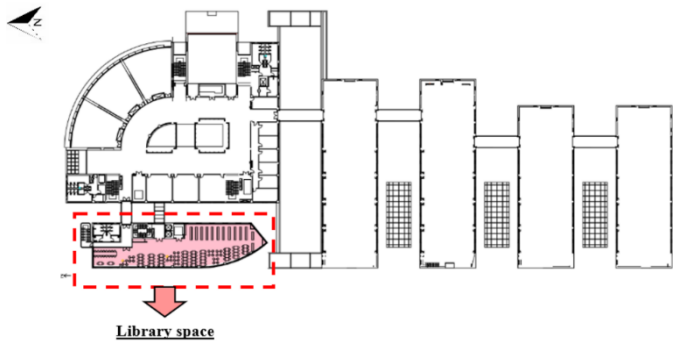


Figure 7. Library location in BAU University

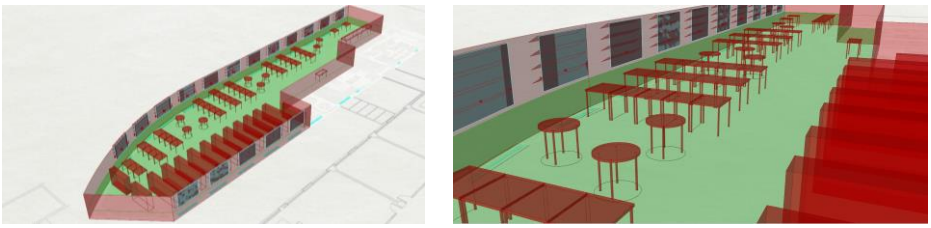
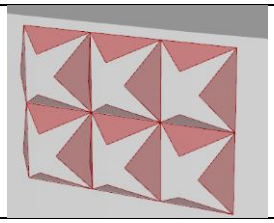
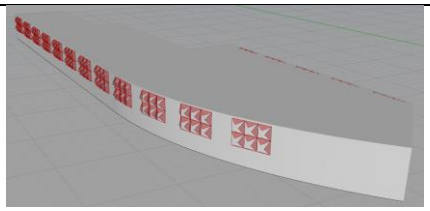


Figure 8. Table location (task area) inside the library

A kinetic shading system was implemented as a simulation on the library's windows using Grasshopper for Rhino software, as indicated in table 1. The simulation method begins by inserting variables and fixed inputs, such as kinetic units' geometry, mechanism, space, and opening dimensions, and so on, in order to have a better control over the shade. The goal illuminance value is automatically adjusted to 500 lux after selecting the function for the examined space, in our case the library. Then choosing dates, such as months, days, and hours. Additionally, choosing the angles of the mechanism that will change during the kinetic shading simulation. As a result, rather than simulating each case individually, all cases at various dates and angles will be simulated automatically. After all of the inputs have been entered, the optimization process will begin with illuminance and glare simulations. Under an overcast sky, illuminance and glare must be calculated. A 0.5*0.5m grid is used, and a working space of 0.85m is supplied.

TABLE 1 The three kinetic shading types used in this thesis

Kinetic shading Case number	**Kinetic shading units**	**Kinetic shading on library's windows**
Case 3 Square		

5.2. EVALUATING THE SUGGESTED ADD-ON'S PERFORMANCE

The proposed Add-on could be utilized for the entire year, 12 months, but three months were chosen to test its performance in different seasons and reduce simulation time. The three months chosen are June, which has the longest day of the year, known as Summer Solstice, December, which has the shortest day of the year, known as Winter Solstice, and March, which has day and night lengths that are equal, known as Vernal Equinox, and is very similar to September, which is known as Autumnal Equinox. Three days were chosen from each month, 20, 21, and 22, as they reflect daylight length critical points (weather.gov, 2020). Case 3: The Add-on was used at three different times during the working day. Using case 3, the Add-on was applied to three different angles (30, 45, and 60) during working hours (10:00AM, 13:00PM, and 16:00PM), resulting in DPG and illuminance values, as shown in Figures 9 and 10. Illuminance and DPG values are automatically calculated and saved externally for each example during the simulation process, both numerically and graphically.

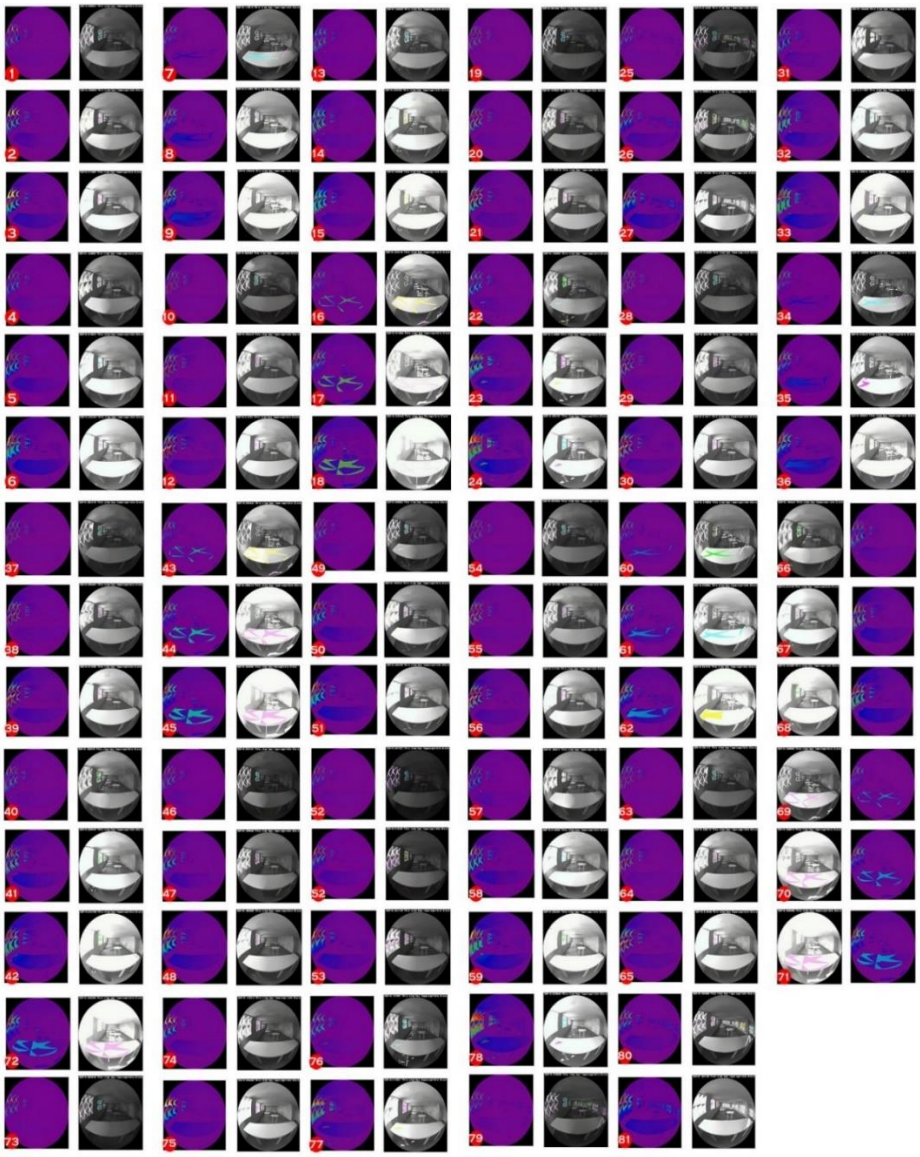


Figure 9. 81 DPG results values after doing glare simulation using the proposed Add-on at three different months, time and angles for case 3

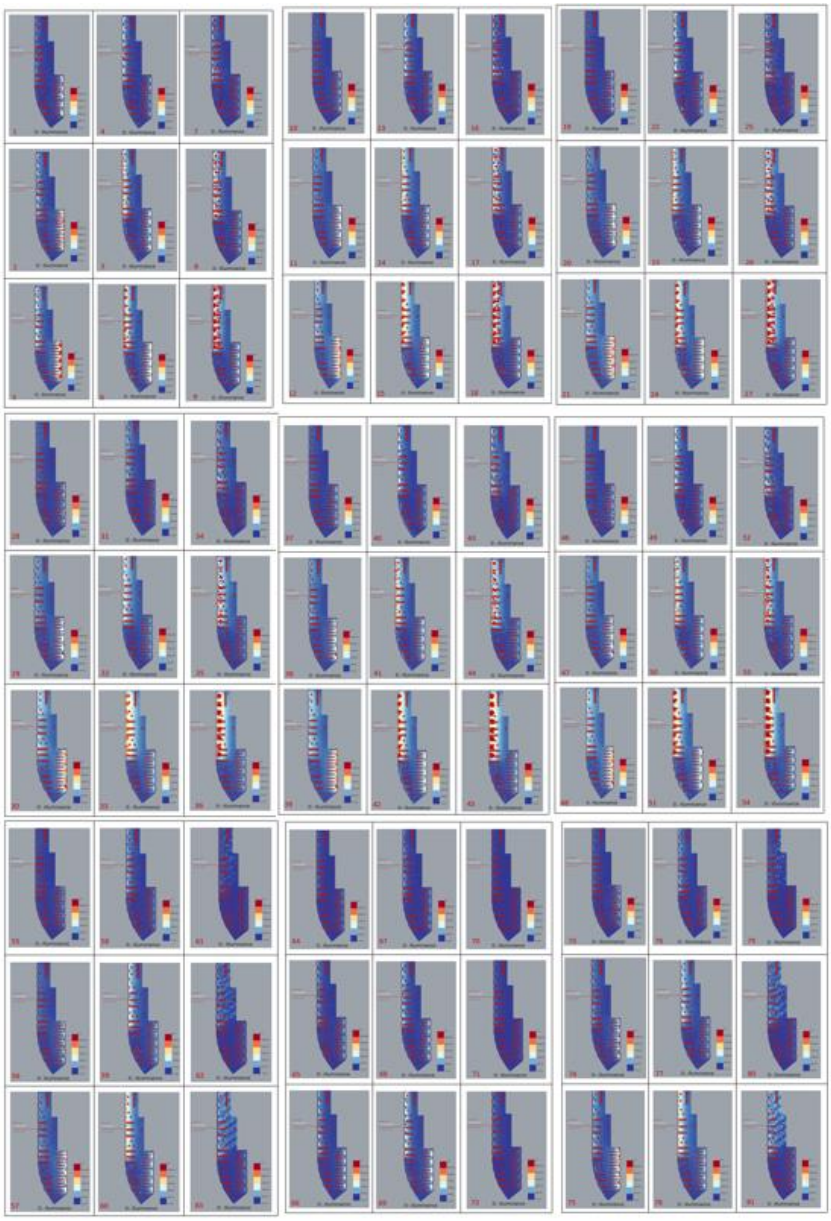


Figure 10. 81 illuminance values as results after doing glare simulation using the proposed Add-on at three different months, time and angles for case 3

5.3. RESULTS AFTER ADD-ON APPLICATION

This application has emphasized the optimum glare and illuminance conditions. This allows the user to check angles in terms of efficiency and visual comfort not only in the graphical interface, but also quantitatively in an external excel sheet for all values, highlighting the best scenarios, as shown in table 2. The user can now specify the ideal mechanism of the kinetic units based on these optimum outcomes at various simulated dates.

Table 2, shows excel sheet as output after glare and illuminance simulation during three months, using the proposed Add-on and highlighting the optimum results

	Date	visiual comfort results	glare (DGP)	Illuminance value(LUX)	Optimum Angles
1	20 MAR 10:00at angle:30	no visual comfort	0.099251	156	0
2	20 MAR 10:00at angle:45	no visual comfort	0.206883	272	0
3	20 MAR 10:00at angle:60	no visual comfort	0.215862	406	0
4	20 MAR 13:00at angle:30	no visual comfort	0.154906	160	0
5	20 MAR 13:00at angle:45	no visual comfort	0.210017	296	0
6	20 MAR 13:00at angle:60	no visual comfort	0.224101	424	0
7	20 MAR 16:00at angle:30	no visual comfort	0.176012	146	0
8	20 MAR 16:00at angle:45	no visual comfort	0.211465	326	0
9	20 MAR 16:00at angle:60	Optimum visual comfort	0.230538	558	1
10	21 MAR 10:00at angle:30	no visual comfort	0.079326	270	0
11	21 MAR 10:00at angle:45	no visual comfort	0.204766	391	0
12	21 MAR 10:00at angle:60	Optimum visual comfort	0.215511	549	1
13	21 MAR 13:00at angle:30	no visual comfort	0.185508	279	0
14	21 MAR 13:00at angle:45	no visual comfort	0.217262	452	0
15	21 MAR 13:00at angle:60	Optimum visual comfort	0.238024	654	1
16	21 MAR 16:00at angle:30	no visual comfort	0.186698	162	0
17	21 MAR 16:00at angle:45	no visual comfort	0.212512	340	0
18	21 MAR 16:00at angle:60	Optimum visual comfort	0.230821	586	1
19	22 MAR 10:00at angle:30	no visual comfort	0.087958	322	0
20	22 MAR 10:00at angle:45	no visual comfort	0.20728	378	0
21	22 MAR 10:00at angle:60	Optimum visual comfort	0.217165	554	1
22	22 MAR 13:00at angle:30	no visual comfort	0.180517	218	0
23	22 MAR 13:00at angle:45	no visual comfort	0.214938	379	0
24	22 MAR 13:00at angle:60	Optimum visual comfort	0.233297	558	1
25	22 MAR 16:00at angle:30	no visual comfort	0.219805	239	0
26	22 MAR 16:00at angle:45	Optimum visual comfort	0.239964	517	1
27	22 MAR 16:00at angle:60	Optimum visual comfort	0.257214	909	1
28	20 JUN 10:00at angle:30.0	no visual comfort	0.088343	351	0
29	20 JUN 10:00at angle:45.0	no visual comfort	0.205419	464	0
30	20 JUN 10:00at angle:60	Optimum visual comfort	0.215124	785	1
31	20 JUN 13:00at angle:30.0	no visual comfort	0.184939	226	0
32	20 JUN 13:00at angle:45.0	no visual comfort	0.22013	442	0
33	20 JUN 13:00at angle:60	Optimum visual comfort	0.240098	722	1
34	20 JUN 16:00at angle:30.0	no visual comfort	0.273715	383	0

35	20 JUN 16:00at angle:45	Optimum visual comfort	0.311305	955	1
36	20 JUN 16:00at angle:60	Optimum visual comfort	0.37045	1510	1
37	21 JUN 10:00at angle:30.(	no visual comfort	0.087278	329	0
38	21 JUN 10:00at angle:45.(	no visual comfort	0.205407	457	0
39	21 JUN 10:00at angle:60	Optimum visual comfort	0.215283	759	1
40	21 JUN 13:00at angle:30.(	no visual comfort	0.192676	245	0
41	21 JUN 13:00at angle:45.(	no visual comfort	0.220412	449	0
42	21 JUN 13:00at angle:60	Optimum visual comfort	0.241788	674	1
43	21 JUN 16:00at angle:30.(	no visual comfort	0.264555	361	0
44	21 JUN 16:00at angle:45	Optimum visual comfort	0.299515	871	1
45	21 JUN 16:00at angle:60	Optimum visual comfort	0.355032	1371	1
46	22 JUN 10:00at angle:30.(	no visual comfort	0.097177	339	0
47	22 JUN 10:00at angle:45.(	no visual comfort	0.208715	466	0
48	22 JUN 10:00at angle:60	Optimum visual comfort	0.21875	794	1
49	22 JUN 13:00at angle:30.(	no visual comfort	0.194552	249	0
50	22 JUN 13:00at angle:45.(	no visual comfort	0.221116	456	0
51	22 JUN 13:00at angle:60	Optimum visual comfort	0.241366	694	1
52	22 JUN 16:00at angle:30.(	no visual comfort	0.256093	305	0
53	22 JUN 16:00at angle:45	Optimum visual comfort	0.288675	770	1
54	22 JUN 16:00at angle:60	Optimum visual comfort	0.340368	1225	1
55	20 DEC 10:00at angle:30.(	no visual comfort	0.041554	117	0
56	20 DEC 10:00at angle:45.(	no visual comfort	0.177024	227	0
57	20 DEC 10:00at angle:60.(	no visual comfort	0.206619	342	0
58	20 DEC 13:00at angle:30.(	no visual comfort	0.159032	132	0
59	20 DEC 13:00at angle:45.(	no visual comfort	0.210389	248	0
60	20 DEC 13:00at angle:60.(	no visual comfort	0.226797	367	0
61	20 DEC 16:00at angle:30.(	no visual comfort	0.015288	57	0
62	20 DEC 16:00at angle:45.(	no visual comfort	0.083954	110	0
63	20 DEC 16:00at angle:60.(	no visual comfort	0.174284	169	0
64	21 DEC 10:00at angle:30.(	no visual comfort	0.023141	54	0
65	21 DEC 10:00at angle:45.(	no visual comfort	0.120648	103	0
66	21 DEC 10:00at angle:60.(	no visual comfort	0.18909	153	0
67	21 DEC 13:00at angle:30.(	no visual comfort	0.056932	80	0
68	21 DEC 13:00at angle:45.(	no visual comfort	0.192275	156	0
69	21 DEC 13:00at angle:60.(	no visual comfort	0.205766	235	0
70	21 DEC 16:00at angle:30.(	no visual comfort	0.007302	20	0
71	21 DEC 16:00at angle:45.(	no visual comfort	0.018137	40	0
72	21 DEC 16:00at angle:60.(	no visual comfort	0.047178	61	0
73	22 DEC 10:00at angle:30.(	no visual comfort	0.037619	97	0
74	22 DEC 10:00at angle:45.(	no visual comfort	0.178375	182	0
75	22 DEC 10:00at angle:60.(	no visual comfort	0.204498	281	0
76	22 DEC 13:00at angle:30.(	no visual comfort	0.147367	121	0
77	22 DEC 13:00at angle:45.(	no visual comfort	0.210027	228	0
78	22 DEC 13:00at angle:60.(	no visual comfort	0.226946	344	0
79	22 DEC 16:00at angle:30.(	no visual comfort	0.018633	62	0
80	22 DEC 16:00at angle:45.(	no visual comfort	0.103483	124	0
81	22 DEC 16:00at angle:60.(	no visual comfort	0.183106	199	0

After the simulation, the following graphs and charts are provided as graphical outputs:

- Optimum outcomes chart: in case 3, out of 81 states, there are 20 optimum states, as shown in Figure 11.
- Glare graph: this graph represents all of the DPG values for the 81 states in relation to optimal values, as displayed in Figure 12.
- Illuminance graphs: that represents the illuminance values for 81 states for specified dates, times, and angles, as illustrated in Figure 13.

Figure 11. Chart for the optimum solutions after illuminance and glare simulations during three months, using the proposed Add-on

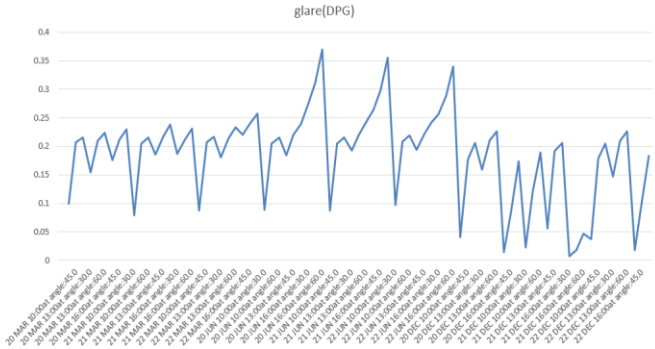


Figure 12. Chart for the glare values (DPD) after simulations during three months, using the proposed Add-on

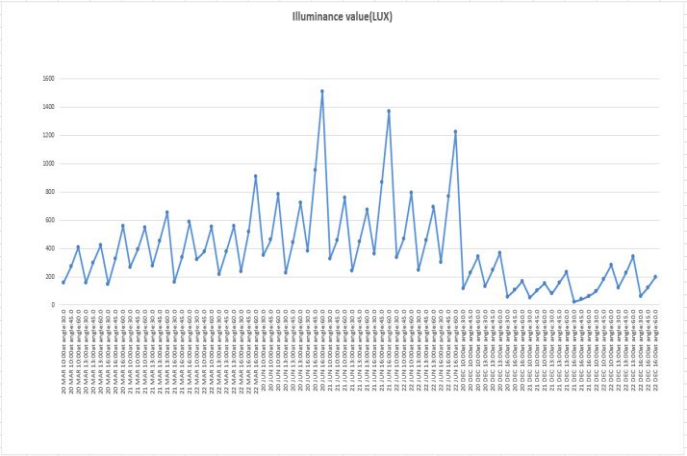


Figure 13. Chart for the illuminance values after simulations during three months, using the proposed Add-on

6.Conclusion and recommendation

As a conclusion, after testing and verifying the proposed Add-on, new values are obtained when using this Add-on which are the following:

- A clear representation of optimum values of kinetic shading parameters connected to both illuminance and glare, using graphs, charts, and data sheets, where the glare range is increased from inappropriate to suitable by a percentage ranging from 51 percent to 76 percent.
- The ability to do parallel comparisons between multiple situations at the same time.
- A user-friendly Graphical User Interface (GUI) that was created for all designers from various background.
- For the proposed kinetic shading, several simulations run automatically, and both illuminance and glare simulations can run in simultaneously. With many simulations running in succession at different dates, hours, and kinetic unit mechanisms, simulation time is nearly half that of the present plugin.
- All simulation results are preserved in external files, both graphically and mathematically, so users can review any case outcomes at any time.
- The created Add-on can be generally applicable to be used not only in educational spaces, but also in various other typologies

This research has indicated the need for additional development in future study by achieving its goals to a considerable extent:

- Extend the use of the proposed Add-on to other types of functions besides educational areas.
- Expanding the Add- on to include all forms of kinetic systems, not simply the rotating mechanism.
- Expanding the Add-on to accommodate more visual comfort characteristics besides glare and illuminance.

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AFFORDABLE COMPUTATION FOR ARCHITECTURE

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Abstract. Current architectural requirements prioritize the need to minimize the ecological footprint. By taking advantage of computational design approaches like Algorithmic Design (AD), architects can enhance their design processes with analysis, optimization, and visualization mechanisms, which are critical to explore design solutions that meet this need. However, these mechanisms are also highly time- and resource-consuming, often implying a quality tradeoff or the acquisition of High-Performance Computing (HPC) machines. The latter are not yet affordable for most design studios but, fortunately, they can be contracted as a service. This paper evaluates the impact of computation as a service in architecture and, more specifically, the remote use of HPC for AD, with the aim of reducing the time and costs associated with computationally expensive processes. A set of experiments were made involving analysis, optimization, and rendering of a selected case study. Results indicate that HPC services are advantageous, particularly when performing embarrassingly parallelizable tasks such as rendering. However, some challenges remain, namely the required expertise.

Keywords: *Algorithmic Design; High-Performance Computing; Design Optimization; Performance Analysis; Visualization.*

ملخص. تعطي المتطلبات المعمارية الحالية الأولوية للحاجة إلى تقليل البصمة البيئية. من خلال الاستفادة من مناهج التصميم الحسابي مثل التصميم الخوارزمي، يمكن للمعماريين تعزيز عمليات التصميم الخاصة بهم من خلال آليات التحليل والتحسين وتقنيات الرؤية، والتي تعد ضرورية لاستكشاف حلول التصميم التي تلبي هذه الحاجة. ومع ذلك، فإن هذه الآليات أيضًا تستهلك الكثير من الوقت والموارد، مما يعني في كثير من الأحيان مقايضة الجودة أو الاستحواذ على آلات الحوسبة عالية الأداء. وبالرغم من عدم توفر آلات الحوسبة عالية الأداء

في متناول معظم استوديوهات التصميم حتى الآن لحسن الحظ يمكن التعاقد عليها كخدمة. تقيّم هذه الورقة تأثير "الحوسبة كخدمة" في الهندسة المعمارية ، وبشكل أكثر تحديدًا، الاستخدام عن بُعد لآلات الحوسبة عالية الأداء فى التصميم المعمارى، بهدف تقليل الوقت والتكاليف المرتبطة بالعمليات الحسابية باهظة الثمن. تم إجراء مجموعة من التجارب التي تشمل التحليل والتحسين التمثيل لدراسة حالة مختارة. وقد أشارت النتائج إلى أن خدمات آلات الحوسبة عالية الأداء مفيدة، لا سيما عند أداء مهام متوازنة بشكل محرج مثل العرض. ومع ذلك، لا تزال هناك بعض التحديات وتحديدا الخبرة المطلوبة.

الكلمات المفتاحية: *التصميم الخوارزمى، آلات الحوسبة عالية الأداء، تحسين التصميم، تحليل الأداء، تقنيات الرؤية.*

1. Introduction

Architecture must respond to the ever evolving social and environmental demands, such as the growing awareness on the industry's ecological footprint (Boeck et al., 2015; Dillen et al., 2020). By taking advantage of new digital tools and computation-based design approaches, architects have been increasingly exploring design solutions that meet these demands (Kolarevic, 2005). Algorithmic Design (AD) is one such approach (Caetano et al., 2020) that facilitates the integration of analysis and optimization mechanisms since early design stages. This not only provides architects with a better grasp of their designs' behavior (Figliola and Battisti, 2021; Henriksson and Hult, 2015; Oxman, 2008), but also critically helps them orient the design process in a more informed manner.

Nevertheless, analysis and optimization tasks are typically highly time- and resource-consuming, often implying a quality tradeoff. A straightforward solution for this problem is the use of High-Performance Computing (HPC) resources (Isard et al., 2007; Lin et al., 2021). Core count is one of the determining factors of computer performance and, while the first Central Processing Unit (CPU) invented only had one core to run one tasks, today we expect computers to work on multiple tasks simultaneously. To do so, as well as to handle resource-intensive programs, CPUs have evolved towards multi-cores. Portable computers these days typically have CPUs with four to eight cores, which allows for the computation of around 10^{11} operations per second. High-end desktop workstations go further by combining two or four CPUs in one machine, which elevates the number of allowed operations per second to around 10^{13}. Supercomputers take this concept to the next level by offering hundreds or thousands of CPUs, reaching 10^{17} operations per second.

Unfortunately, only a small fraction of architectural studios worldwide can afford the kind of HPC described above, which limits the latter's potential benefits for nowadays architectural practice, particularly, in solving design optimization problems, which are critical to reduce the ecological impact of the industry. To promote better architecture for all, improving life quality

while mitigating the industry's environmental footprint, computation must become affordable to anyone and anywhere. With this goal in mind, this research presents the results of a field report evaluating the potential performance benefits of HPC for AD.

2. Methodology

HPC is advantageous to reach architectural solutions with higher indoor environmental quality and reduced ecological footprints but the access to HPC machines is still limited. This research addresses this problem by evaluating the remote use of HPC in current AD practices using the following methodology:

1. Investigating HPC methods and their potential applications in architecture.
2. Identifying the benefits and challenges of remote HPC for architectural design.
3. Performing a set of experiments for multiple design tasks using a supercomputer to (a) validate the proposed hypothesis regarding time and cost gains, and (b) find ways to surpass the challenges encountered.
4. Analyzing the advantages obtained and challenges faced during the experiments and proposing guidelines for future use.
5. Drawing conclusions on the findings and forecasting future research paths.

In the following sections we elaborate on each of these tasks.

3. Computation in Architecture

The emergence of computation-based tools triggered new design approaches, such as AD (Caetano et al., 2020), that combine the computational power of machines with the architects' creative potential (Terzidis, 2004). Due to its algorithmic nature, AD allows automating repetitive and time-consuming design tasks, facilitates design changes, and increases design flexibility. Therefore, in addition to reducing the time and effort spent in testing new solutions, and thus increasing design space exploration, AD makes it possible to deal with higher levels of design complexity involving multiple design constraints.

Nevertheless, given the considerable computational demands of the required analysis, optimization, and image synthesis tools (Belém, 2019; D'Agostino et al., 2021; Kosicki et al., 2020), addressing the previous

constraints often requires having programs running for weeks in HPC workstations, which is not compatible with most projects' deadlines. Furthermore, access to HPC is still limited due to high acquisition and maintenance costs, as well as space requirements.

A possible solution is to allow designers to benefit from HPC remotely. To that end, using AD is critical, as it allows us to algorithmically describe the different design tasks, thus facilitating their manipulation and translation into HPC machines. Our thesis is that, soon, the use of remote computing will feel as natural as other common services (Schubert et al., 2010), like water, gas, television, and internet and this work contributes to the implementation of this reality in the architectural context.

4. Computation as a Service

Providing HPC as a service presents itself as a possible solution to eradicate the current inequality in access to computation resources worldwide and make it affordable to a wider audience. Distributed HPC allows users to run programs on a grid of remote machines from the comfort of their homes, and it is already being used for rendering and gaming on the cloud (Armbrust et al., 2009). Blender, Autodesk, and Google Stadia, for instance, allow users to remotely use computer farms for specific tasks.

Nevertheless, many of the available HPC resources run on operating systems that are quite different from those typically used by architects, such as Windows or MacOS. As such, HPC often requires converting design data and processes to match the specificities of its environment. Moreover, HPC processes tend to be script-based, not providing immediate feedback nor supporting user interaction via Graphical User Interface (GUI). This means that the description of the converted processes must be, first, entirely algorithmic; second, carefully planned to avoid mid-process errors; and third, adapted to the computing environment used (e.g., distributed computing or grid computing). Contrastingly, traditional architectural processes have a visual-based nature, thus largely deviating from the language understood by HPC machines.

Unlike traditional architectural processes, AD already relies on algorithmic descriptions and thus it is a step closer to supporting architectural design in HPC environments. However, it still requires the adaptation of the algorithms since, in most cases, to benefit from a supercomputer, one must parallelize the work, distributing computational tasks through the available computing nodes. Typical AD processes are composed of a plethora of tasks related to design exploration, analysis, optimization, and visualization, and these tasks can range from embarrassingly parallelizable to entirely sequential. Therefore,

different parallelization solutions must be considered for each case (Pereira, 2022).

5. Parallel Computing

Parallel computing is a type of computation that benefits from multiple processors to solve a problem, performing many calculations simultaneously (Quinn, 1994). Parallelization, in turn, is the act of processing data in parallel, instead of serially, therefore allowing several problems to be solved independently and simultaneously. Two main parallelization options currently exist: (1) distributing the algorithmic instructions through the available hardware by using multi-threading and multi-processing or (2) using distributed (or cloud) computing strategies.

Multi-threading is the simplest parallelization option, and it supports running multiple tasks on multiple executing threads simultaneously on a single multi-core machine, i.e., a machine that has more than one processing unit, providing easy access to shared memory. Multi-processing also involves a single machine, but each task is implemented by an isolated process and, thus, does not typically share memory with others. Therefore, exchanging data between processes is not as efficient. In both cases, scalability remains an issue since we are limited to the computing power of a single machine.

Distributed computing involves running multiple processes on different machines. Since it uses a network of machines, this strategy offers greater scalability. However, as the machines are physically separated from each other, exchanging data involves a slow communication process.

To run processes efficiently with parallel computing, data exchange should be minimized, which suggests design tasks that are entirely independent from one another. Figure 1 illustrates several embarrassingly parallelizable cases where no dependencies between separate processes exist.

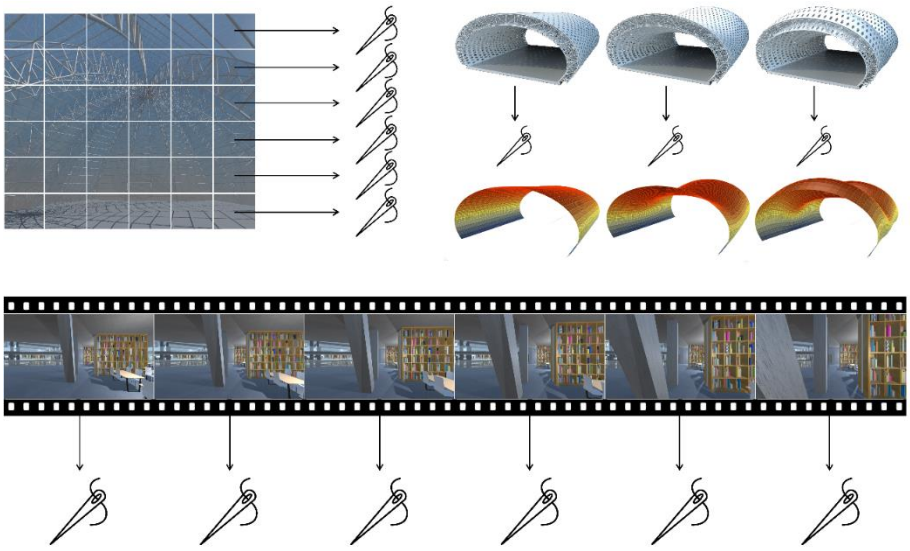

Figure 1. Embarrassingly parallelizable cases: each pixel of a render image (top left); each frame of a render sequence (bottom); and each simulation in a sensitivity analysis (top right).

Cloud computing is a type of distributed computing that delivers computational services remotely through the internet (Armbrust et al., 2009). It is thus a potential solution to the existing inequality of access to HPC, allowing users to benefit from the computation power of a grid of machines anywhere on Earth with internet access. By only requiring the use of personal computers as terminals from where instructions are launched and results collected, cloud computing constitutes an affordable option that has the potential to approximate the status of other daily life services, such as water, gas, television, and internet. It is also a promising solution to enable and democratize the use of analysis, optimization, and image synthesis processes, towards a more socially and environmentally conscious architecture.

6. Challenges of HPC for AD

HPC currently has two main challenges: (1) the need to send the instructions in a batch-processing style and (2) the need to carefully plan the distribution of the tasks to perform. This section elaborates on these two issues, proposing guidelines to overcome them.

6.1. BATCH PROCESSING

HPC currently entails batch processing, which means computing tasks are submitted to the remote computing service, returning the results only after completion. A similar scenario occurs in AD, which involves, first, planning a sequence of instruction for the computer to perform; then, describing them in a program; and, lastly, forcing their execution by running the program.

During the execution of simple design-related instructions, model re-generation is usually fast enough to give a false sense of interactivity, i.e., allowing us to visualize each program change reflected on the 3D model almost immediately. As such, the execution method lying underneath often goes unnoticed. However, the same is not true for the type of processes that benefit from HPC. As the execution time is typically longer, the interactivity illusion often fails, offering little to no visual feedback on the course of the process. This means that mistakes are only discovered at the end of the process, or when an error breaks it midway. Given that these processes may last for days or even weeks, it is critical to minimize the chances of errors.

To that end, users should carefully plan parallelization jobs before sending them to HPC services, performing sanity checks, which involve testing and validating every component and stage separately, and making limited runs at a smaller scale. In most cases, the time invested in these validations pays off; their relevance proportionally growing with the size of the computation task.

Another challenge of batch processing lies in the architects' typical lack of experience with textual programming. Due to the smoother learning curve and typical interactivity, visual programming offers a more democratized access to computational methods at small scales, allowing architects with little to no programming experience to rapidly achieve interesting results. However, it tends not to scale to large construction projects without the aid of textual scripting (Janssen, 2014; Leitão et al., 2012; Ma et al., 2021), therefore not supporting the processes that potentially benefit from HPC. To that regard, textual programming is the *de facto* tool for large-scale development.

6.2. ALLOCATING JOBS

Parallelized approaches require job allocation, that is, deciding how to map tasks to the HPC hardware. While some tools, such as POVRay and Accelerad, already know how to handle job allocation, in other cases, this falls under the programmer's responsibility. In that case, it typically requires executing commands at the level of the operating system, a task that typically lies outside of the architect's comfort zone.

Additionally, when the task involves the modeling tools architects typically use, such as AutoCAD or Rhinoceros, the situation becomes worse because they are usually not compatible with HPC operating systems. A

possible solution is to create virtual machines running the needed operating system but there are other problems. As these tools are mainly conceived for single-user/single-threaded use, they can hardly steer parallel processes by themselves. There are workarounds for this, such as having several instances of the tools running concurrently, but other challenges may arise with this solution, such as concurrent file writing or license limitations. While the first can, once more, be solved with virtual machines, the latter has no solution besides buying more licenses.

Following the same logic, when multithreaded tools, such as POVRay, are not using all the available hardware resources, we can also force the execution of multiples instances to increase the parallelization. In all these cases, however, the programmer must plan the division of labor among the tool's instances and must ensure the parallelization does not surpass the available resources.

7. Evaluation

This section investigates the potential of using HPC resources to perform different AD tasks through practical experiments using the Khepri AD tool (Sammer et al., 2019) due to its portability between different design, analysis, and optimization tools. For that, we modeled a structural case study in Khepri and selected, among the supported tools, those that already support batch processing, namely Frame3DD and POVRay. From the experiments developed, we present three relevant ones encompassing analysis and rendering (section 7.4) and optimization (section 7.5). In the following sections, we elaborate on (1) the adopted AD workflow for remote HPC, (2) how we overcame the challenges of HPC (particularly those regarding batch processing and job allocation), and (3) the time gains in each case.

7.1. CASE STUDY

The performed experiment addresses the design space exploration of a simple truss structure inspired by Gaudi's catenary curves (Figure 2 left), whose legs can be interconnected using different truss schemes (Figure 2 right). The truss is made of Bamboo and is placed on a slab with a randomized outline, which means it does not have an axis of symmetry and, therefore, presents an interesting resistance test case. In this case study, we were interested in simulating and optimizing its structural performance, as well as in developing render images of possible design variations.

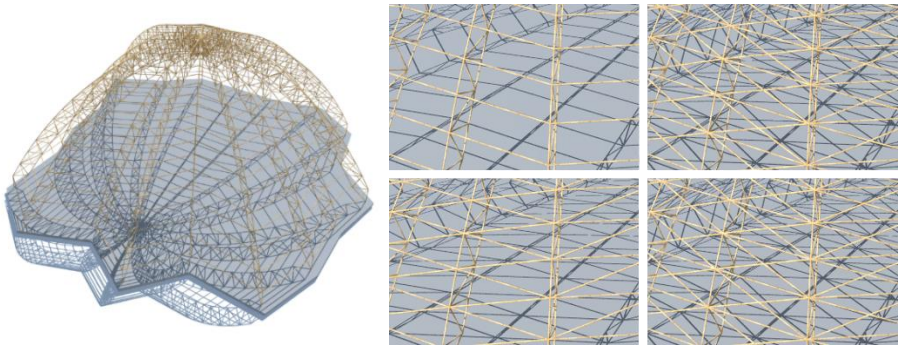

Figure 2. Gaudi-inspired truss structure with randomized outline (left) and detail of different truss schemes (right).

7.2. HARDWARE CONDITIONS

The evaluation was conducted on a supercomputer containing four computing nodes, each providing 96 AMD EPYC 7552 cores, running at 2.2 GHz and accessing 512 GB of RAM. In total, the partition allowed 384 simultaneous execution threads, using 2 TB of memory. Although these capabilities were constrained by the supercomputer's topology and the available resources at each moment, they still represent a significant amount of computing power when compared to current commodity hardware, which typically supports only 8 execution threads using 16 GB of RAM.

7.3. BATCH PROCESSING

There are large differences between the hardware of the supercomputer and that of a typical laptop, but the differences in their software are even bigger. As the supercomputer uses the Linux-based CentOS 7 operating system, which mostly operates in batch mode, the scripts sent to it must carefully describe the intended executions and the resources needed. Moreover, it does not provide immediate feedback, nor does it support any program requiring either user interaction or a GUI.

To help deal with these challenges, we used the job scheduling system of the popular open-source cluster management tool Slurm. Since not all software available for Linux can directly run on a supercomputer, we also installed the exact same operating system on a local virtual machine. This allowed us to more easily recompile the software and, only after successfully testing them on our own virtual machine, move it to the supercomputer.

The AD tool used in the case study, Khepri, is based on the Julia programming language, which supports multi-threading and distributed computing, provided by the Distributed standard library as well as external packages, such as MPI.jl and DistributedArrays.jl, Khepri, however, is not

thread-safe, meaning that it is not prepared for parallel execution. Hence, we were particularly interested in testing its distributed computing capabilities.

7.4. USING MULTITHREADED SOFTWARE

Design space exploration is one of the simplest applications of HPC in AD. In this case, the idea was to study the impact of the design parameters in the performance of the above-mentioned truss structure.

Our first experiment tested a vertical load of increasing magnitude (from 0 to 100N) applied to all non-supported truss nodes. For each load case, the structure was analyzed using Frame3DD and the computed truss node displacements were used to show the shape of the truss under load in the render produced by POVRay (Figure 3).

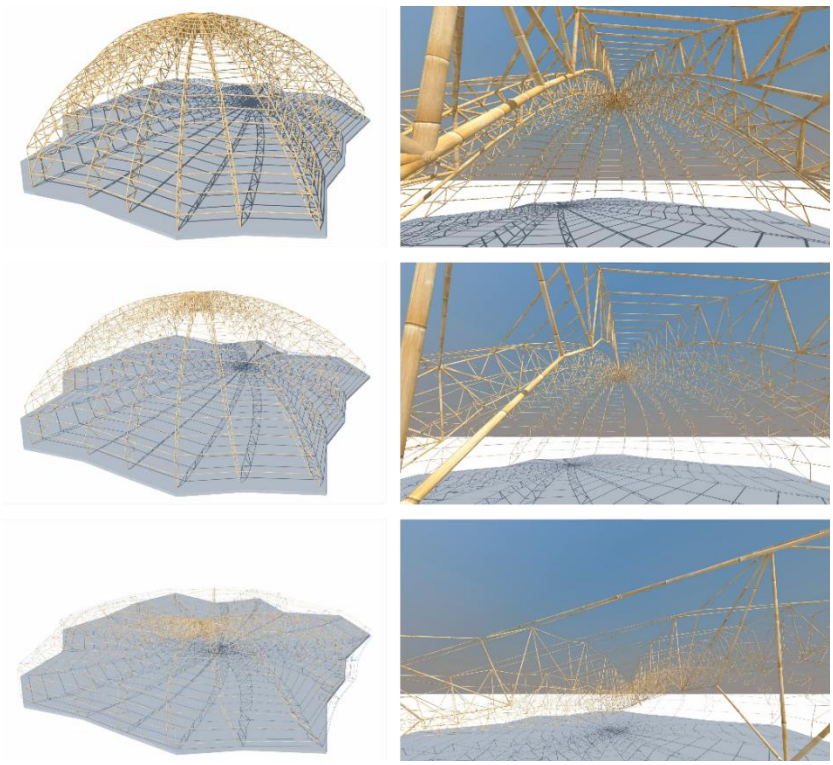

Figure 3. Renders of the truss under different loads.

Each structural analysis was entirely sequential, so we could not benefit from multiple threads on a single evaluation. However, the most time-consuming task in this process was not the analysis itself, but rather the rendering of the result afterwards - a task that is highly parallelized. For rendering in POVRay we took full advantage of the 96 CPUs available on each node. The

parallelization process is schematized in Figure 4. The evaluation of 200 different load cases together with the Full HD rendering of the results took 1h46m to complete. In a typical PC, the same experiment would have taken approximately 14 hours.

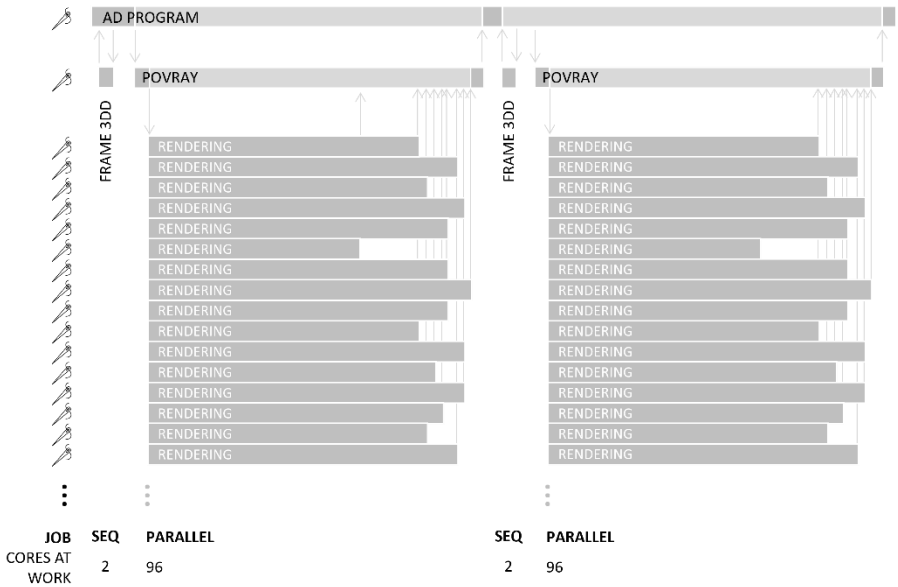

Figure 4. The AD program is sequentially launching analysis processes in Frame3DD and rendering processes in POVRay. POVRay, as a multithreaded tool, automatically distributes the task among the available cores.

In the next test, we measured the scalability of POVRay, by rendering image sequences of the 3D structure in two sizes (1024x768 and 1920x1024) and with different materials (Figure 5) while increasing the number of CPUs on each test. Figure 6 shows the time spent for each case and for different numbers of threads. To eliminate possible fluctuations in the load of the computing node, we present the average of three repeated tests.

Once more comparing to commodity hardware, while in our experiments the time per image when using 96 cores was 30.5 and 110.3 seconds for the small and large resolution image, respectively (Figure 6 top), in a typical PC we would likely be limited to eight threads. Still using a supercomputer, the time per image using eight threads was 214 and 857 seconds for the small and large resolution image, respectively, which represents an 8X slowdown. On a desktop, depending on the hardware, this slowdown can be even bigger.

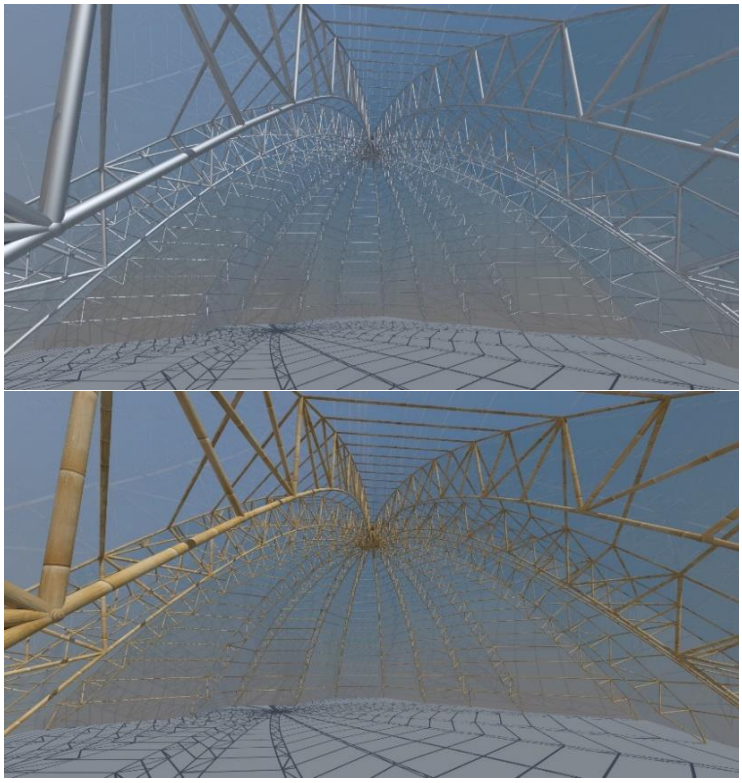

Figure 5. Renders of the truss with different materials: streel and glass (top), and bamboo and glass (bottom).

Now focusing on HPC, in general, there are relevant speedups up to the upper limit of threads. Although it pales in comparison to the initial gains, from 80 threads to 96 threads there is still a significant reduction in the high-resolution image. Based on this analysis, we can determine the number of threads we should use. As is visible in Figure 6 (bottom), for the rendering task with the smaller resolution, it only paid off to use up to 80 threads, obtaining an almost 40X speedup when compared to using just one thread. After that, the gains were marginal. In the case of the larger resolution one, despite the fluctuations, not only were we able to reach a speedup of almost 65X, but the trend line also evidenced the potential for achieving even bigger speedups. In fact, POVRay can take advantage of 512 threads, which means we were still a long way from the limit.

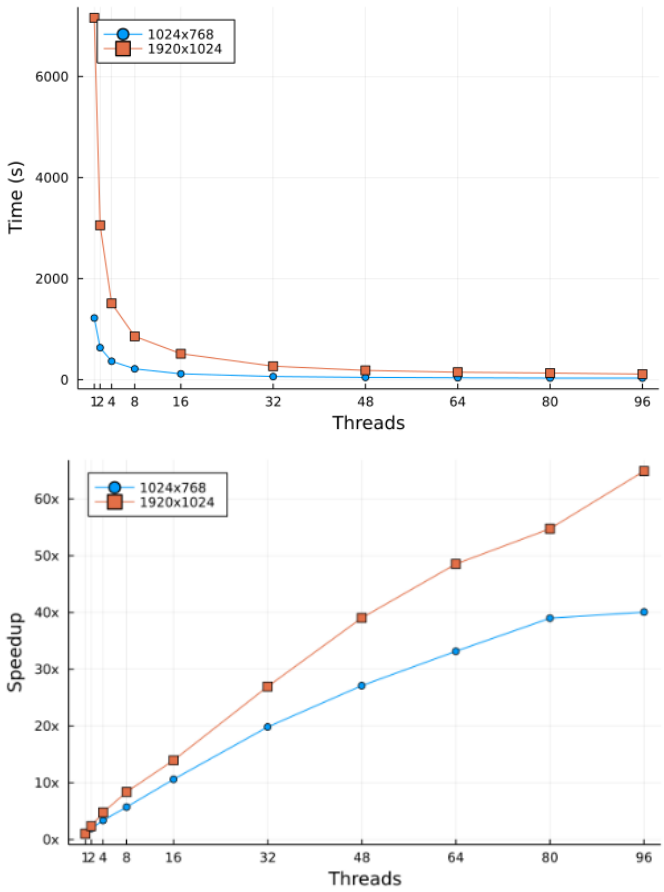

Figure 6. On top, the trend lines for the mean time spent in rendering for different numbers of processes (threads) for the two image sizes (1024x768 and 1920x1024). On the bottom, the speedup obtained from the same data set.

7.5. LAUNCHING CONCURRENT PROCESSES

To measure the potential gains that parallelization could provide to optimization problems, we evaluated a non-parallelizable objective function: the optimization of the truss' structural performance, measured by the maximum displacement of the nodes. To that end, we selected the variable to optimize during the experiment – a vector containing the X and Y coordinates of the truss' center node, where all the arches join - and kept all remaining design variables unchanged, including the truss' height.

To evaluate the objective function, we used the structural analysis tool Frame3DD. To optimize this function, we used two different parallelized optimization strategies from the BlackBoxOptim library: Exponential Natural

Evolution Strategy (xNES) and Separable Natural Evolution Strategy (sNES). BlackBoxOptim supports multi-threading and multi-processing, allowing the optimization algorithm to evaluate many candidate solutions at the same time. Since Khepri is not yet thread-safe, we opted for multiple independent processes.

To evaluate the scalability of the optimization process, we performed several experiences with a varying number of working cores. We followed the BlackBoxOptim guidelines, setting up a master process responsible for running the optimization and worker processes responsible for evaluating candidate solutions (Figure 7).

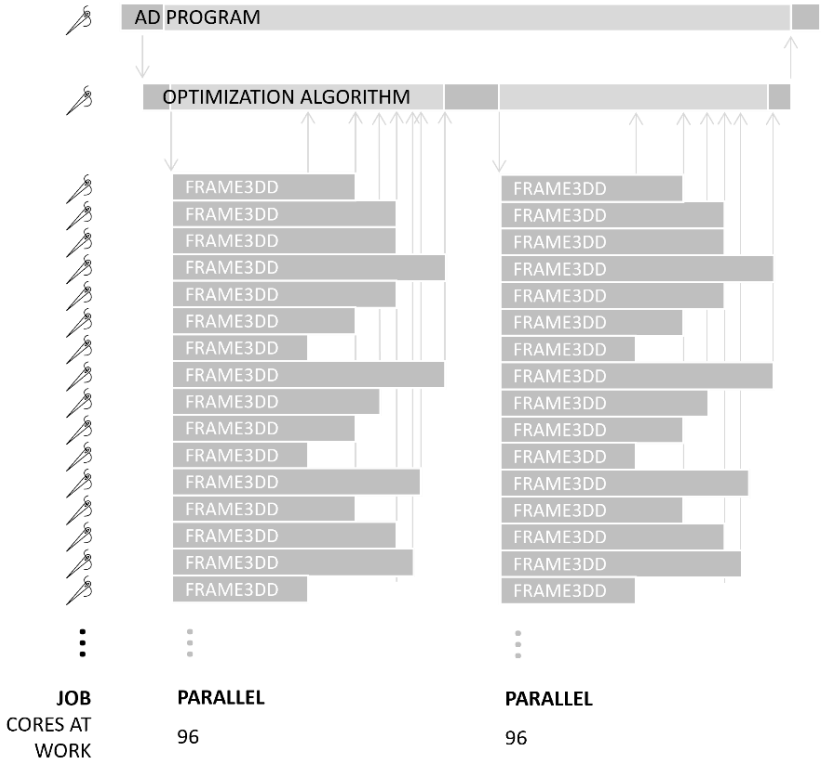

Figure 7. The optimization algorithm functioning as the master process, launching parallel Frame3DD processes to evaluate candidate solution batches.

For reproducibility purposes, we fixed the seed of the master process' random number generator, allowing us to repeat the experiments with a different number of workers while ensuring the same solution is reached after the same number of steps. We performed three independent runs for each test to smooth out the noise, set an initial population size of 500, and allowed the

optimizations to do a maximum of 5000 objective function evaluations. Figure 8 presents the mean time spent in the optimization with different numbers of processes for both algorithms.

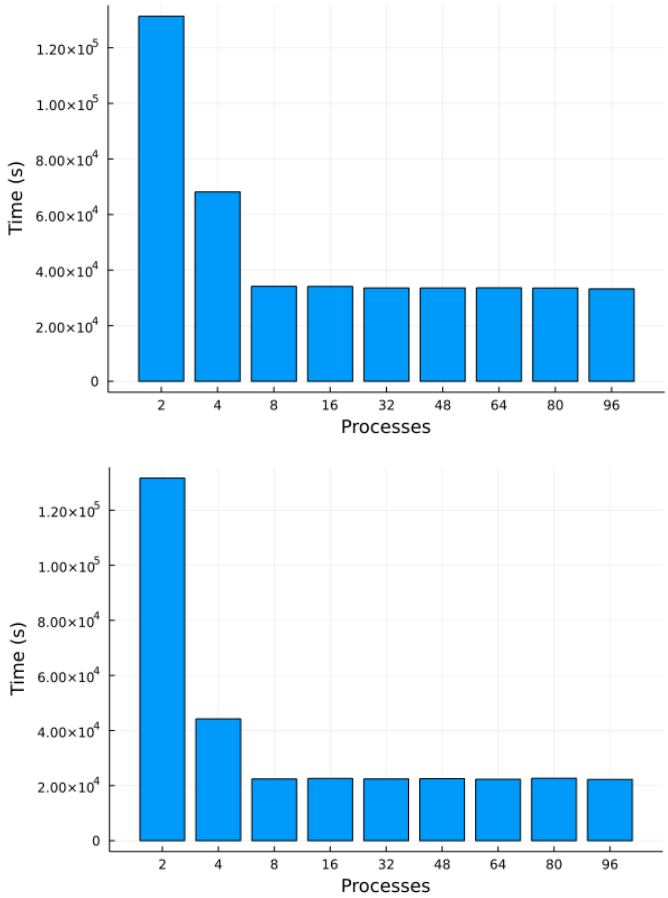

Figure 8. Time spent in the optimization process of the truss structure for different numbers of processes using xNES (top) and sNES (bottom).

Results show that the optimization clearly benefited from the parallel evaluation of candidate solutions but only up to eight concurrent processes. It seems that the BlackBoxOptim library is not yet fully capable of exploring a large number of computing resources. Unlike the previous experiments, the gains of the supercomputer do not surpass those of a normal laptop.

8. Discussion

This section discusses the results of the evaluation, reflects upon the way the two main HPC challenges were handled, the lessons learnt in the process, and the time and cost gains of the experience.

Regarding the first topic, results show that accessing HPC resources is advantageous for architectural design practice, particularly when performing embarrassingly parallel tasks such as rendering. In these cases, we concluded that HPC provides large computational gains (the greater the number of processes, the greater the speedups achieved), and even greater gains are expected with higher numbers of threads than those tested in these experiments. In design optimization tasks, however, the speedups obtained were not as impressive. The results lead to the conclusion that for the specific optimization algorithms and for the problem addressed in this research there is no need to use more than eight processes.

There is, however, a silver lining: if it does not compensate to launch more than eight processes for a given optimization algorithm, we can use the remaining computing resources to evaluate other algorithms. This is particularly beneficial, for instance, when addressing the No Free Lunch theorem (Pereira and Leitão, 2020), which states that no optimization algorithm is better than all others in all cases. The consequence is that multiple algorithms need to be tested and HPC allows these tests to be done simultaneously, thus taking no longer than running the slowest of them.

The two main challenges of HPC, batch processing and job allocation, were surpassed in these experiments with a high dose of manual labor. Some of the parallelization solutions presented were achieved only after several trial-and-error loops, leaving us with a list of lessons for future use:

1. HPC resources provide little to no compatibility with the tools architects typically use: tools requiring GUIs can hardly run in HPC environments and even batch-oriented tools frequently need to be adapted. Furthermore, lack of administrative privileges impedes software installations on HPC environments. Workarounds need to be found.
2. Not all software or design tasks can benefit from HPC resources. The structural analysis tool used (Frame3DD) is one example that could not benefit from multiple CPUs because the software was not parallelized. A specific parallelization strategy must then be devised for each case.
3. Even in the processes that directly benefit from parallelization, the performance improvements achieved are variable. For instance, while the rendering tasks considerably benefited from supercomputing resources, the optimization tasks using parallelized algorithms only

benefited up to a point. These limits should be tested and known before launching large processes since failing to consider them may constitute a waste of resources.

4. It only pays off to parallelize if the time it takes to start the parallel tasks is significantly smaller than the time needed to complete those tasks. Otherwise, instead of speeding up the computation, we might end up slowing it down.

Finally, we circle back to the goal of this paper - affordable computation for architecture - by discussing the cost of these experiments. Despite the huge computational power of the supercomputer we used in this evaluation, its operational costs are rated at 0,01€ core*hour. This means that even when using all available resources (4 nodes with 96 cores each), we pay less than 4€ per hour, which is an enormous cost reduction when compared to the acquisition and running costs (electricity and maintenance) of a personal workstation or, in any case, the sort of workstation required to handle the demanding computations presented in reasonable time (Isard et al., 2007).

9. Conclusion

Algorithmic Design (AD) allows architects to enhance their design processes by facilitating the integration of analysis and optimization since early design stages. However, these tasks are typically highly time- and resource-consuming, which makes them difficult to apply on the typical hardware available to architects. High-Performance Computing (HPC) is a tempting solution to these problems.

In this paper, we presented a field report evaluating the potential benefits of remote HPC for AD workflows. The work outlines the two main issues associated with HPC for AD, batch processing and job allocation, and describes how we overcame them in the process of parallelizing algorithmic design, analysis, optimization, and visualization.

Our results show that remote HPC can considerably reduce the time and costs associated with computationally expensive processes, making AD approaches accessible to users with limited resources. However, some challenges remain as expertise is required to surpass the issues associated with HPC. Future research paths should focus on parallelization strategies that can facilitate the planning, testing, and launching of processes for architects.

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GENERATIVE DESIGN FOR A SUSTAINABLE URBAN MORPHOLOGY

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Abstract. The present work concerns the applications of generative design for sustainable urban fabric. This represents an iterative process that involves an algorithm for the generation of solar envelopes to satisfy solar and density constraints. We propose in this paper to explore a meta-universe of human-machine interaction. It aims to design urban forms that offer solar access. This being to minimize heating energy expenditure and provide solar well-being. We propose to study the impact of the solar strategy of building morphosis on energy exposure. It consists of determining the layout and shape of the constructions based on the shading cut-off time. This is a period of desirable solar access. We propose to define it as a balance between the solar irradiation received in winter and that received in summer. We rely on the concept of the solar envelope defined since the 1970s by Knowles and its many derivatives (Koubaa Turki & al., 2020). We propose a parametric model to generate solar envelopes at the scale of an urban block. The generative design makes it possible to create a digital model of the different density solutions by varying the solar access duration. The virtual environment created allows exploring urban morphologies resilient both to urban densification and better use of the context's resources. The seasonal energy balance, between overexposure in summer and access to the sun in winter, allows reaching high energy and environmental efficiency of the buildings. We have developed an algorithm on Dynamo for the generation of the solar envelope by shading exchange. The program makes it possible to detect the boundaries of the parcels imported from Revit, establish the layout of the building, and generate the solar envelopes for each

variation of the shading cut-off time. It also calculates the FAR[1] and the FSI[2] from the variation of the shading cut-off time for each parcel of the island. We compare the solutions generated according to the urban density coefficients and the solar access duration. Once the optimal solution has been determined, we export the results back into Revit environment to complete the BIM modelling for solar study. This article proposes a method for designing buildings and neighbourhoods in a virtual environment. The latter acts upstream of the design process and can be extended to the different phases of the building life cycle: detailed design, construction, and use.

Keywords: *Solar envelope, Smart virtual environment, Seasonal energy balance, Urban morphology, Generative Design.*

ملخص. يقدم هذا البحث تطبيقا لتصميم توليدي للنسيج الحضري المستدام. ويتمثل في عملية تكرارية تتضمن خوارزمية لتوليد المغلفات الشمسية لتلبية متطلبات التقاط الطاقة الشمسية والكثافة الحضرية. نقترح في هذا البحث استكشاف بعد الميتافيرس للتفاعل بين الإنسان والآلة بهدف تصميم الأشكال الحضرية التي تمكن من التقاط الطاقة الشمسية لتقليل نفقات الطاقة الحرارية وتوفير الرفاهية للإنسان. نقترح دراسة استراتيجية لتشكيل المبنى حسب التعرض للطاقة الشمسية وذلك بتحديد تخطيط وشكل الإنشاءات بناءً على وقت إيقاف التظليل وهو فترة التقاط الطاقة الشمسية المرغوب فيها. إذ أن هذه الفترة الزمنية مستنتجة عن توازن بين أوقات الطاقة الشمسية الملتقطة في الشتاء وفي الصيف. نعتمد على مفهوم الغلاف الشمسي المقترح منذ السبعينيات من قبل رالف نولز ومشتقاته العديدة (قوبعة التركي وآخرون، ٢٠٢٠). نقترح نموذجًا برامتريا لتوليد مغلفات شمسية ضمن الكتلة الحضرية. يتيح التصميم التوليدي إمكانية إنشاء نموذج رقمي لمختلف حلول الكثافة الحضرية من خلال تغيير مدة إيقاف التظليل. تسمح البيئة الافتراضية التي تم إنشاؤها باستكشاف الأشكال الحضرية التي ترمي لهدفي التكثيف الحضري والاستخدام الأفضل للموارد المتاحة. يتيح توازن الطاقة الموسمي، بين اجتناب التعرض المفرط لأشعة الشمس في الصيف والرغبة فيها في الشتاء، الوصول إلى جودة طاقية عالية وكفاءة بيئية للمباني. لقد اقترحنا خوارزمية لتوليد الغلاف الشمسي عن طريق تبادل التظليل عبر برنامج دينامو. تمكن الخوارزمية من إنشاء ارتكاز المباني الافتراضية على شكل مغلفات شمسية وذلك حسب اختلاف وقت إيقاف التظليل. وقد قمنا بمقارنة الحلول حسب معايير الكثافة الحضرية ومدة التقاط الطاقة الشمسية. بمجرد تحديد الحل الأمثل، نقوم بتصدير النتائج إلى برنامج ريفيت لإكمال التصميم. تقترح هذه المقالة طريقة جديدة لتصميم نمذجة المباني والأحياء في بيئة افتراضية. تندرج هذه البرمجية في بداية عملية التصميم ويمكن أن تمتد إلى المراحل المختلفة من دورة حياة المبنى: التصميم التفصيلي والبناء والاستخدام.

الكلمات المفتاحية: *الغلاف الشمسي، البيئة الافتراضية الذكية، توازن الطاقة الموسمي، التشكل الحضري، التصميم التوليدي.*

1 Floor Space Area is the ratio between the sum of the floor's areas and the plot area.

2 Floor Space Index is a floor occupation coefficient corresponding to the ratio between the buildable floor area and the plot area.

1. Problematic and approach

The solar rights appeared in the late 1970s through the concept of the solar envelope described by Knowles between 1968 and 1971 (Knowles, 1974, 1980). This morphological concept guarantees this right by allowing solar access to a building without shading its neighbours at specific times. These times, called the cut-off-time, define the period for which solar access is desirable. Shadows are inscribed within a virtual spatial boundary, called the shadow fence, which defines the shadow projection boundary of the massing. The cut-off time and the shadow fences are the two constraints of morphological definition of the solar envelope. Koubaa Turki and al. (2020) have drawn up the state of the art of the various works relating to the determination of these two constraints. Until 2020, the works on determining these constraints represent 15% of publications on the solar envelope, 60% of which are dedicated to the study of cut-off time and 40% to the study of shadow closure.
We have noticed an interest in determining the cut-off time maximizing solar gain in winter (Capeluto & Plotnikov, 2017; Knowles, 1981; Morello & Ratti, 2009). On the other hand, few studies propose studying both winter and summer energy gain (Raboudi & Ben Saci, 2014; Vartholomaios, 2015). With global overheating, the impact of solar gains in summer is increasingly important. Indeed, air conditioning often becomes necessary for spaces with high solar gain in summer. That is why we propose the notion of seasonal energy balance of contributions between winter and summer, taking into account neighbouring buildings. The objective is to propose a method for designing virtual morphologies that ensure a compromise between desirable solar irradiation in winter and undesirable one in summer.

2. Determination of the cut-off time

2.1. DETERMINATION OF THE CUT-OFF TIME IN THE STATE OF THE ART

The cut-off time is determined, initially, according to the periods of useful insolation or solar energy collection. Knowles (1981) proposed to calculate the useful periods of solar access by weighting the incident solar radiation at several times of the day, by the sinus of the angle of the sun altitude. We have listed several research studies about cut-off time determination researches; depending on periods of useful insolation (1981), received solar gains (Vartholomaios, 2015) and depending on energy consumption (Bruce, 2008). The cut-off time was also determined according to the thermal comfort of the exterior space (Sorayaei & Sorayaei, 2017) or that of the interior space (Capeluto & Plotnikov, 2017). Three quarters of the studies determining the cut-off time relate to solar collection. Indeed, advances in energy calculation

models, in particular Radiance (Ward, 1994) and Energyplus (Crawley et al., 2001) have made it possible to refine the determination of the cut-off time according to energy capture (Capeluto et al., 2006; Capeluto & Plotnikov, 2017; Koubaa Turki et al., 2018; Raboudi & Ben Saci, 2014; Vartholomaios, 2015).

Most cut-off time determination studies focus on desirable solar access in winter. However, this period corresponds to overheating hours in summer. Niemasz et al. (2013) studied the application of the solar envelope on land located in seven cities in North America. The authors evaluated the energy consumption of these envelopes. They noticed that this model has an advantage on energy consumption for heating against a considerable deficit for climates requiring cooling loads.

Hence the question: What would be the optimal solar access period in winter and summer and not only during the winter period?

We propose, in this research, to maximize the direct solar irradiation received in winter and to minimize the direct solar irradiation received in summer. The model proposes a virtual environment of urban morphologies resilient both to urban densification and solar access.

2.2. METHOD FOR DELIMITING THE SHADING CUT-OFF TIME

We define, for a given place, the shading cut-off time (denoted T_o) by calculating the sum of the direct solar irradiation in winter (denoted Rd_h) and the sum of them in summer (denoted Rd_e) received per hour on 1m² of vertical surface. We calculate these irradiations in winter and summer by different orientations of facades with a rotation step of 22.5°.

We are interested in a solar neighbourhood approach to maximize the capture of direct solar irradiance in winter and minimize it in summer.

We calculate the direct solar irradiation received during the winter per hour from sunrise to sunset on the different orientations. We refer to the Pareto principle (1967) to define the retained time period. We propose that the time period retained in winter be around 20% of the hours of the day which corresponds to at least 80% of the total irradiation. We are looking for the time slot that provides this percentage of daily solar gain in winter for all orientations such as:

$$\sum Rdh\ To \geq 80\% \sum Rdh \text{ daily for the winter} \quad (1)$$

We calculate the direct solar irradiation received on the different orientations in summer during the time slots satisfying this condition in winter.

We propose the energy balance factor, (denoted Q), which characterizes the ratio of these two irradiations and qualifies the relationship of the direct solar irradiation received in winter and in summer. It is calculated by the ratio between the sum of the direct solar irradiation received in winter and that

received in summer. We consider a range of shading cut-off times satisfying the previous condition with:

$$Q = \sum Rdh\ To / \sum Rde\ ti \text{ such that } \sum Rdh\ To \geq 80\% \sum \text{Daily } Rdh \quad (2)$$

We choose the shading cut-off time which has a maximum coefficient corresponding to a high solar irradiation rate in winter and a low one in summer.

3. Experimentation and results

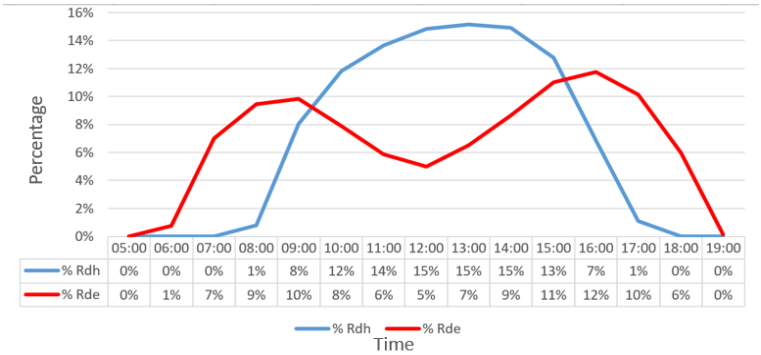
We present an application example on an urban block of three plots (A, B and C) located in Lac of Tunis (Figure 1).

Figure 1. Satellite photo of the urban block composed of three plots A, B and C located at the Lac of Tunis (latitude 36°50'31.22"N, longitude 10°16'48.75"E).

3.1. DETERMINING THE SHADING CUT-OFF TIME FOR TUNIS

We define the shading cut-off time by calculating the sum of the direct solar irradiation[3] received per hour on 1m² of vertical surface in winter (from 21 December to 21 March) and summer (from 21 June to 21 September) by different orientations of facades with a rotation step of 22.5°. Then, we deduce the hourly percentage compared to the daily sum in the two seasons (Figure 2).

3 With Insight in Revit for energy simulation using DOE 2.2 and EnergyPlus.



	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
% Rdh	0%	0%	0%	1%	8%	12%	14%	15%	15%	15%	13%	7%	1%	0%	0%
% Rde	0%	1%	7%	9%	10%	8%	6%	5%	7%	9%	11%	12%	10%	6%	0%

Figure 2. Percentages of direct solar irradiation received in winter and in summer on one square meter of facade for different orientations with a step of 22.5° in Tunis compared to the daily sum (in kWh/m²).

We observe that, from 7:00 to 9:00, and from 16:00 to 18:00, direct solar irradiation is negligible compared to the total irradiation in winter. The cumulative percentage of irradiation from 10:00 to 15:00 is 83.2% compared to the total sum of the irradiance received in winter.

Then, we calculate the cumulative sum of solar irradiation received for several ranges of shading cut-off times in winter and the corresponding cumulative sum in summer. We deduce the percentages from the daily sum and the energy balance factor Q (Figure 3).

The cumulative percentage of irradiation (Figure 3) from 10:00 to 15:00 is 43.75% compared to the total amount of irradiation received in summer. This led to fixing the shading cut-off time To = [10:00, 15:00]. This duration corresponds to 25% of the day's hours. For this period, the Q is 0.56. This is the maximum ratio satisfying the required condition of solar access in winter and corresponding to the minimum solar gain in summer.

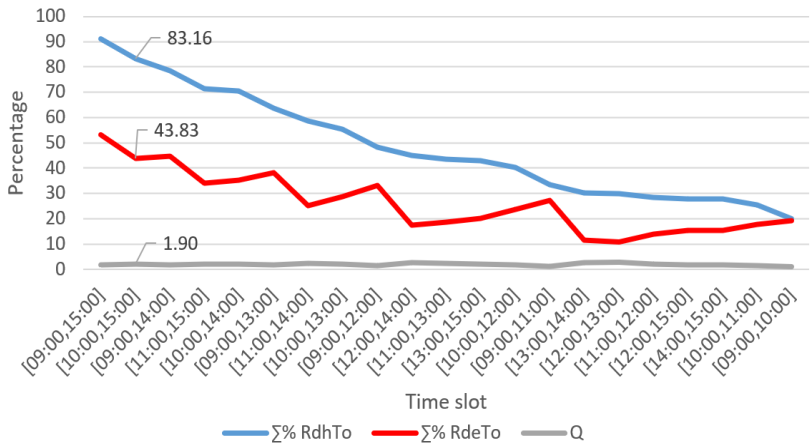


Figure 3. Percentage of cumulative values of solar irradiation per cut off time.

3.2. GENERATION OF SOLAR ENVELOPES

We propose a workflow based on Revit environment. We use Dynamo for parametric algorithm that we be involved on generative design by Refinery. The selected solution is exported to Revit for solar analysis.

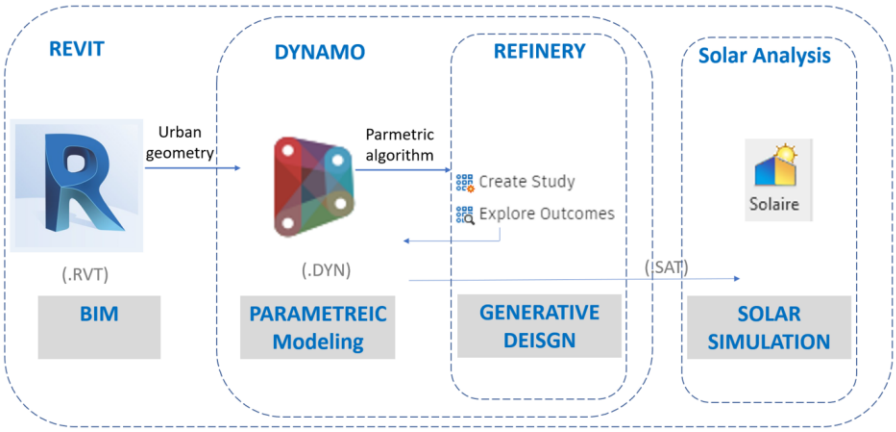


Figure 4. Workflow of BIM, Parametric modelling, Generative Design study and Solar analysis.

The generative design makes it possible to study the different urban density solutions by varying the shading cut-off time. We have developed an algorithm on Dynamo (Figure 5) for the generation of the solar envelope by shading exchange using Boolean operations (Stasinopoulos, 2000). The program makes it possible to detect the boundaries of the parcels imported from Revit, in order to determine the layout of the building and the generation of the solar envelope for each variation of cut-off time. So, we can deduce the maximum height of the buildings that ensure the solar access conditions. It also calculates the FAR and the FSI from the variation of the cut-off time for each parcel of the island.

Finally, we compare the solutions generated according to the urban density coefficients (FSI and FAR) and the solar access duration.

The inputs are the location of the site, a start time cursor t1 and an end time cursor t2 of the shading cut-off time interval [10:00,15:00]. The output results are the FAR and FSI urban density indices and the shading cut-off time duration.

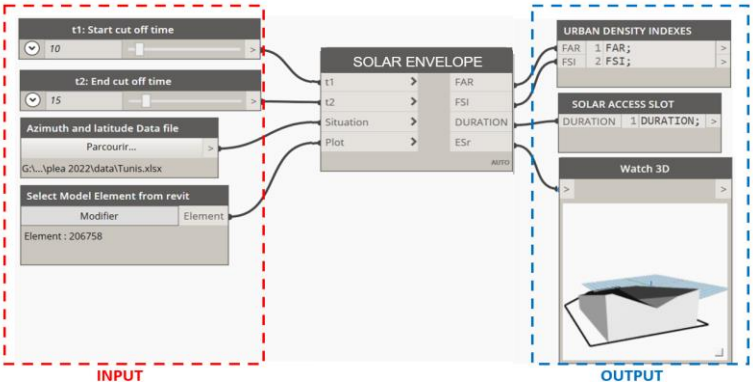


Figure 5. Dynamo solar envelope component.

The cross product on Refinery (Di Filippo et al., 2021) makes it possible to obtain 21 variants for each plot (Figure 6). The multidimensional representation below allows us to see the implications for all the variables considered.

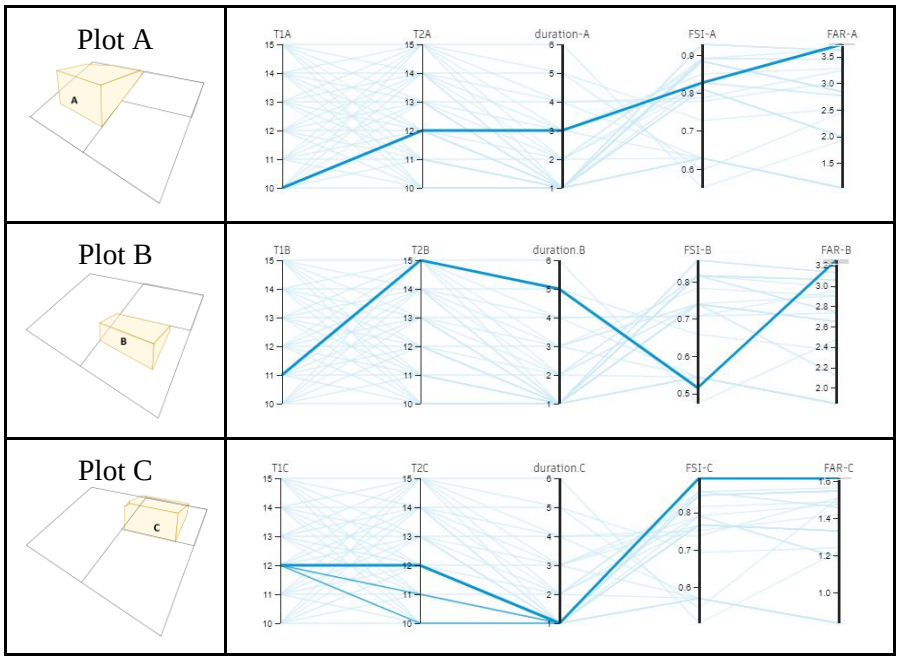


Figure 6. Parameters diagrams of solutions obtained for each plot (A, B, C) corresponding to the various urban density of shading cut-off time.

We examine the results by two studies where the goals are to (1) maximize the FAR and (2) maximize the solar access duration (Figure 7).

(a) (b)

Figure 7. Simulation of results in real context for (a) maximum FAR and (b) maximum duration.

Firstly, we propose to study the best solution that maximizes the FAR for each plot (Table 1).

TABLE 1. Results for a maximum FAR and a minimum 3 hours duration of cut-off time for the three plots.

	Plot A	**Plot B**	**Plot C**
FSI	0.827	0.515	0.892
FAR	3.732	3.251	1.617
Duration	3	5	1
Cut-off time	[10:00h,12:00]	[11:00,15:00]	12:00

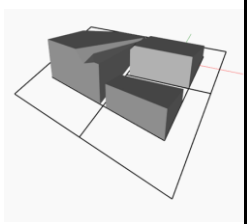
For the goal of maximum FAR, plot A has the best result with a gain of 12.8% and 56.67% compared to respectively plot B and plot C.
Secondly, we propose the goal of having a maximum duration of cut-off time for the three plots (Table2).

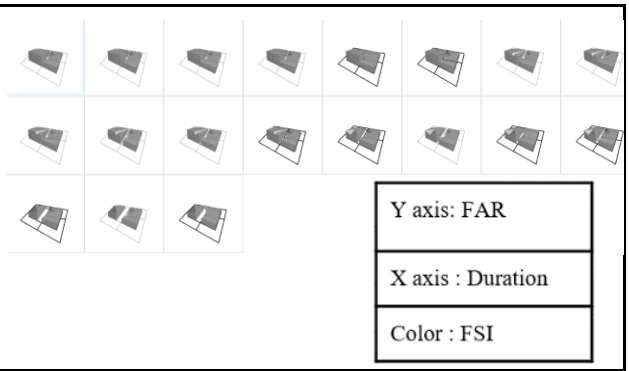
TABLE 2. Results for a maximum duration of shading cut-off time on the three plots.

	Plot A	**Plot B**	**Plot C**
FSI	0.55	0.473	0.503
FAR	1.928	2.473	1.223
Duration	6	6	6

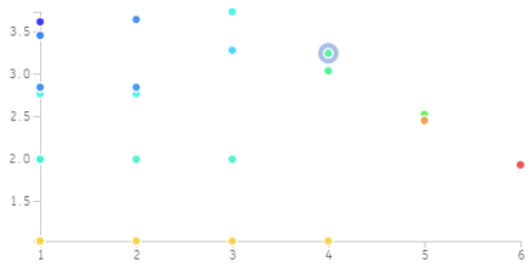
Cut-off time	[10:00,15:00]	[10:00,15:00]	[10:00,15:00]

Plot B can guarantee a better FAR with a gain of 22.08% and 50.54 % compared to respectively plot A and plot C.
So, we can have a range of optimal solutions satisfying the two previous conditions. Figure 8 represents the three diagrams relating to the three plots that represent optimal solutions relating urban density and solar access constraints. We represent on the x axis the solar access duration, on the y axis the FAR and in color variation for the FAR.

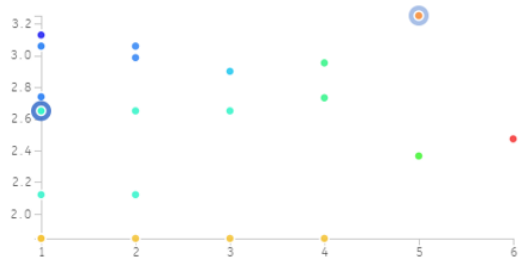




Plot A



Plot B



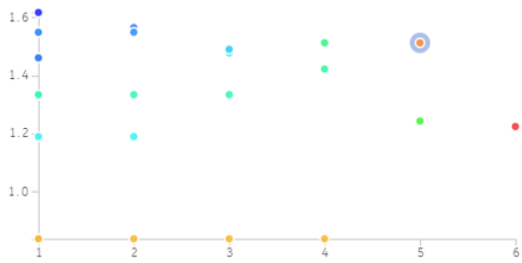
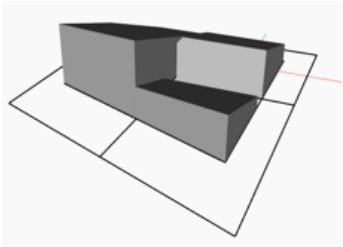
Plot C	

Figure 8. Optimal solutions for maximum FAR and maximum duration.

4. Discussion

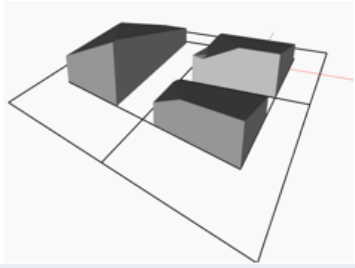
This paper proposes a resilient approach to optimize urban density and solar access by studying the optimal duration and FAR. It proposes a method for determining urban morphology by controlling the solar access duration. Varying the period of the shading cut-off time makes it possible to explore different urban densities (Figure 9) while guaranteeing solar access over a useful solar access time slot.

The aim of this approach is to exploit the solar morphological potential of each plot. The position, shape and size of the plot impact the FAR and the solar access duration. The study of the maximum FAR and the duration of solar access makes it possible to obtain the best solutions for each plot. The multi-objective approach would be necessary in this case.



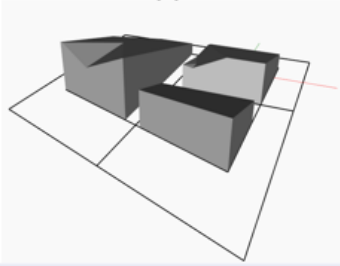
MAX FAR			
	A	B	C
FSI	0.827	0.515	0.892
FAR	3.732	3.251	1.617
DUREE	3	5	1
To	[10:00h,12:00]	[11:00,15:00]	12:00

(a)



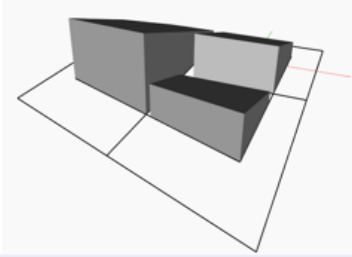
MAX DURATION			
	A	B	C
FSI	0.55	0.473	0.503
FAR	1.928	2.473	1.223
DUREE	6	6	6
To	[10:00,15:00]	[10:00,15:00]	[10:00,15:00]

(b)



5 HOURS			
	A	B	C
FSI	0.727	0.515	0.543
FAR	2.521	3.251	1.512
DUREE	5	5	5
To	[10:00,14:00]	[10:00,15:00]	[11:00,15:00]

(c)



3 HOURS			
	A	B	C
FSI	0.827	0.741	0.816
FAR	3.732	2.9	1.49
DUREE	3	3	3
To	[10:00,12:00]	[10:00,12:00]	[11:00,13:00]

(d)

Figure 9. Examples of generated solar envelopes.

The model makes it possible to maximize the FAR (Figure 9-a). Plot B has maximum FAR with a duration of five hours of solar access. Besides, the maximum FAR for plot C allows only one hour of solar access.

For maximum duration (figure 9-b), plot A doubles its duration but decreases its FAR of 43.33% compared to the first study. Besides, plot B has one additional hour of solar access impacting its FAR with a reduction of 23.93%. Plot C has 5 additional hours but its FAR decreases only of 24.36%.

By unifying the solar access duration to 5 hours of solar access (Figure 9-c), Plot A and C show a loss of 32.44% and 6.4% in FAR compared to the maximum FAR.

For 3 hours of solar access (figure 9-d), B and C show a loss of 10.79% and 7.85% in FAR compared to the maximum FAR.

The comparison of the results obtained with the current urban regulation of Tunis shows a clear improvement by using this model. We notice that this

approach improves the maximum height indicated by the urban regulation. It can increase until 30m (Figure 10) compared to 17m as indicated by the actual urban regulation. The model allows building higher buildings guaranteeing solar access. This strategy optimizes the distribution of shade between neighbouring buildings in winter. This allows to increase the FAR for between 46% (for plot B) to 53% (for plot A).

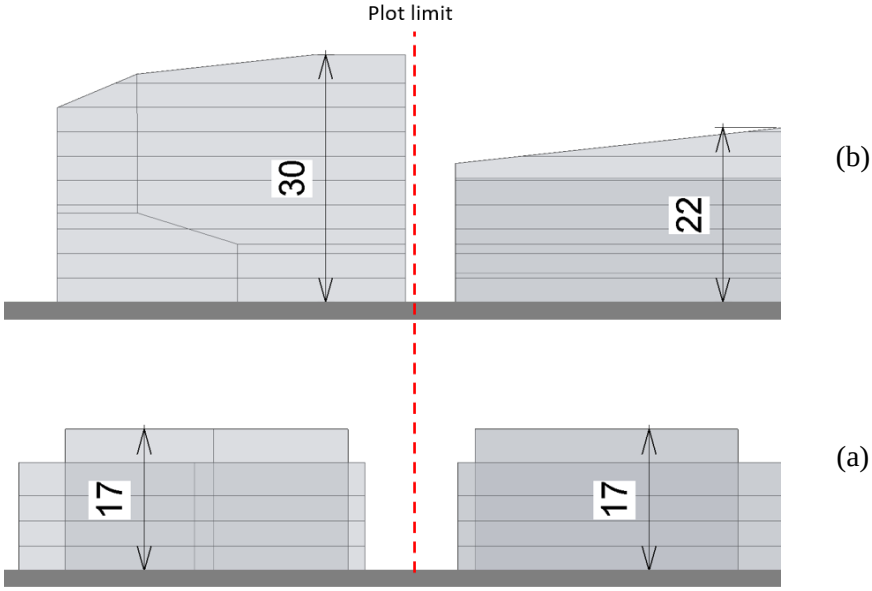
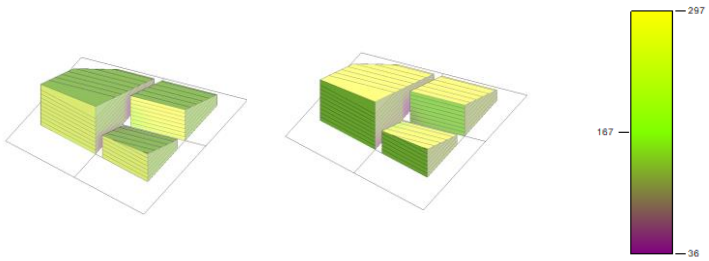


Figure 10. Height of buildings:(a) actual regulation and (b) for maximum FAR.

We evaluate the solar energy for the generated solar envelopes. We calculate the solar energy received on them at the shadow cut-off time for winter and summer (Table 3).

TABLE 3. Solar energy received on the solar envelope with maximum FAR in Winter and summer at the shadow cut-off time (kWh/m²).

	Winter	**Summer**	**Rd_h / Rd_e**
Plot A	98	187	0.524
Plot B	98	191	0.513
Plot C	101	185	0.545
A+B+C	99	186	0.532



We notice that Plot A and plot B have the same energy in winter (98 kWh/m²) but plot B has an excess of 2% in summer compared to plot A. Plot C has 3% more energy in winter than A and B. Besides, in summer it has the least exposure. It represents the best solution from an energy balance point of view.

5. Conclusion

We proposed a parametric model to generate solar envelopes for sustainable urban fabric. The generative design makes it possible to generate a digital model of the different density solutions by varying the solar access duration. Generative design can offer advantages to traditional urban planning processes, given its capability to manage complexity by optimizing heterogeneous preselected criteria. The virtual environment created allows exploring urban morphologies resilient both to urban densification and better use of the context resources.

This paper aims to optimize the solar envelope model by improving the shading cut-off time determination. We suggest defining it by a balance between the solar irradiation received in winter and that received in summer. The method proposed establishing the shading cut-off time to adjust the urban morphology to climatic conditions of solar access.

The goal of this approach is to exploit the morphological potential of each plot according to the climatic context of the project. The position, shape and size of the plot impact the FAR and the solar access time. The variation of the shading cut-off time allows manipulation of urban density while ensuring solar access over a useful solar access time slot. Plot A shows better results in density but the worst one for energy evaluation. Besides, plot C is the better solution for energy balance but it is limiting urban density. This is due to the form and location of the plots.

The proposed approach makes it possible to guarantee better use of the solar resource on the building envelopes. Here, we have calculated the solar resource a posteriori. However, we can consider this variable as a parameter to select the optimal urban morphology. The study of the maximum FAR and received energy according to the shading cut-off time provides optimal

solutions for each plot. The multi-objective approach would be necessary in that case.

We propose, in perspective, to refine the determination of the shading cut-off time according to the use and energy consumption. This being to adjust the morphology of the optimal solar envelope to the actual needs of the building. For example, assuming the installation of energy capture devices, if the shading cut-off time interval makes it possible to reach energy values that exceed the needs of a construction, the shading cut-off time could be reduced in favour of the neighbour.

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DAY 2 - PARALLEL SESSION 2

TOPIC 3 - PARAMETRIC DESIGN AND DIGITAL FABRICATION

BEYOND FLAT SURFACES

Parametric Derivations of Historical Islamic Geometric Designs

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Abstract. This paper sets out to identify a guiding methodology and define algorithms to extend the existence of Islamic geometric designs beyond flat surfaces. The paper discusses two computational approaches to deriving various non-flat geometric compositions: Euclidean Point Extrusion and Curved Surface Fitting. The paper examines historical precedents, conducts an in-depth analysis of patterns employed to generate those elements, then establishes a computational process to explore the potential of translating 2D Islamic Geometric Designs into 3D non-flat surfaces.

Keywords: *Islamic Geometric Design, Computations, Muqarnases, Domes, Parametric Design.*

ملخص. تهدف هذه الورقة إلى تحديد منهجية إرشادية وتعريف الخوارزميات لتوسيع وجود الأنماط الهندسية الإسلامية إلى ما وراء الأسطح المستوية. تناقش الورقة نهجين حسابيين لاشتقاق مجسمات هندسية مختلفة غير مسطحة: بثق النقطة الإقليدية وتركيب الأسطح المنحنية. تدرس الورقة الامثلة التاريخية، وتجري تحليلًا متعمقًا للأنماط المستخدمة لتوليد تلك العناصر، ثم تقدم عملية حسابية لتحويل الأنماط الهندسية الثنائية الأبعاد إلى أسطح غير مسطحة ثلاثية الأبعاد.

الكلمات المفتاحية: *التصميم الهندسي الإسلامي ، الحوسبة ، المقرنصات ، القباب، التصميم البارامتري.*

1. Introduction

Patterns are one of the main defining characteristics of Islamic art and architecture. Typically, Islamic patterns can be classified into floral and

geometric patterns. Islamic Geometric Patterns (IGP) are commonly constructed from geometric elements that show four recognizable characteristics: symmetry, interlacing, flow, and unboundedness (Burckhardt, 2009, Abas et al., 1995). Various materials were used to produce Islamic geometric patterns, such as brick, wood, brass, and plaster. Geometry in Islamic art and architecture flourished and evolved over time (Abdullahi & Embi, 2013). Major innovations occurred between the 10th and the 16th centuries (Bonner, 2017; Abas et al., 1995). Historical evidence suggests that mathematicians and artisans collaborated regarding the perfection of geometries (Ozdural, 2000).

The vast majority of Islamic geometric designs exist on two-dimensional, flat surfaces. However, some of the later geometries were found on a non-flat surface, such as the geometries found on some Mamluks domes in Egypt or Karatay Madrasa in Konya. Those compositions show the different levels of proficiencies with some unique geometrical construction.

This paper aims to establish a taxonomy of three-dimensional Islamic geometric design and propose a computational approach to explore the design laten space in 3D.

2. Precedents

The recently completed Cambridge Mosque shows another example of the creative use of geometry in Islamic architecture (figure 1, left). The ceiling design of the Mosque is based on Islamic Geometric Patterns, yet the constructional components of the free-form wood ceiling morphed in certain places forming columns (Barfield, 2021). Another example that shows the creative employment of Islamic geometric patterns is the Louver Abu Dhabi which also features geometric patterns that are placed on top of the dome (figure 1, right) (Burry, 2010). Although these two projects employed Islamic geometric designs on non-flat surfaces, still, these two projects show two different approaches to deriving three-dimensional forms. Both approaches can be traced back to historical precedents.

Muqarnas, a vaulting decorative component, shows some of the earliest attempts to employ Islamic geometric design to generate a three-dimensional composition from two-dimensional design blueprints, as shown in the Topkapi and the Tashkent Scroll (figure 2) (Necipoğlu, 1996). Karbandi is another possible employment of geometric designs to derive forms beyond flat surfaces, such as the ribbed dome that exists at the Great Mosque of Cordoba (figure 3). Unlike Muqarnas, the geometry is curved as if it is being projected into a round surface (Mohammadi et al., 2018).

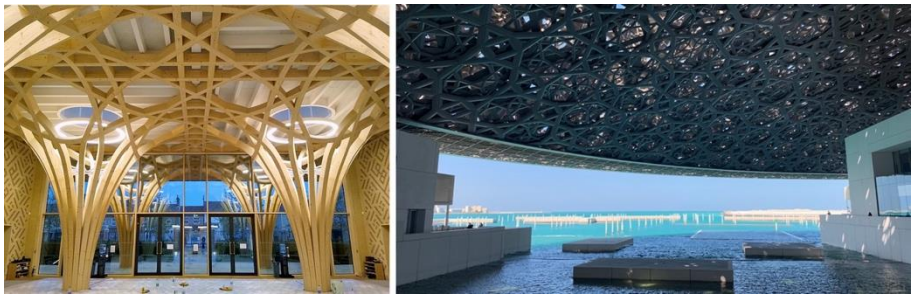

Figure 1. Contemporary examples of IGP on non-flat surfaces. Left: Cambridge Mosque (Image credit: Wikimedia). Right: Louver Abu Dhabi (Image credit: authors).

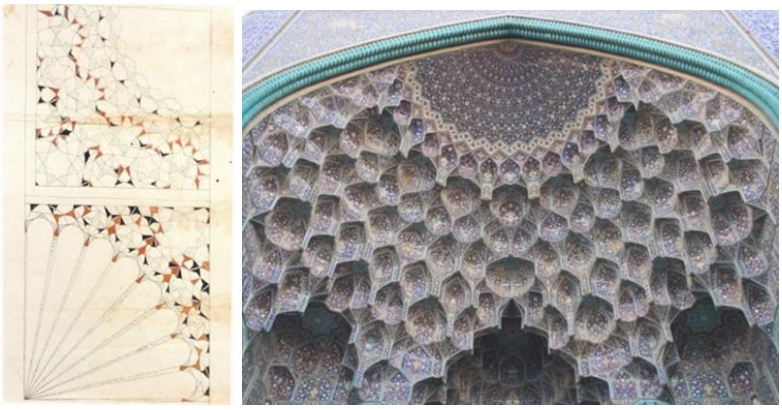

Figure 2. Left: page from the Topkapi scroll showing a 2D blueprint of a Muqarnas (Image credit: Wikimedia). Right: Muqarnas in the Iwan of the Shah Mosque in Isfahan, Iran (Image credit: Wikimedia).

Figure 3. The interior part of the dome of the Great Mosque of Cordoba (Image credit: Wikimedia).

The dome of the Karatay Madrasa (constructed in 1251 CE, Konya) features a geometric pattern that was morphed to cover the dome's interior (figure 4, left). Another remarkable example exists in Cairo at the dome of Sultan Qaytbay Funerary Complex (constructed in 1472-1474 CE) (figure 4, right). The dome is covered with several star patterns that were designed to fit the dome (Cipriani, 2005).

This quick overview of historical and contemporary precedents aims to develop an understanding of the variety of existing non-flat geometric designs by which two-dimensional geometric designs were employed to derive forms beyond flat surfaces.

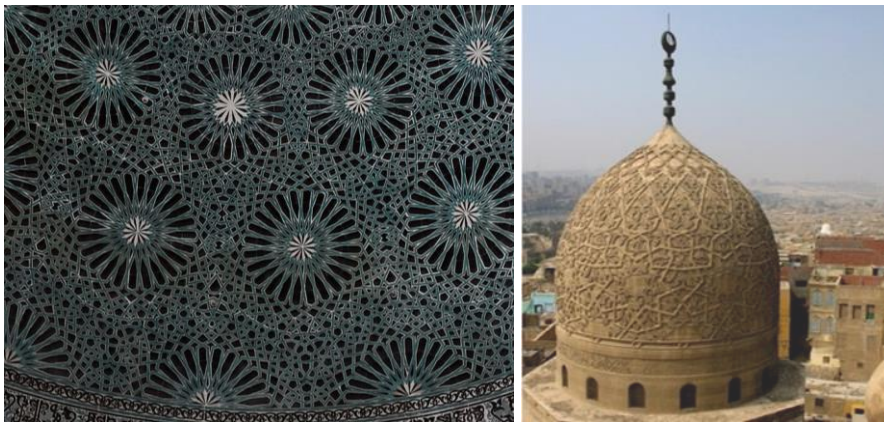

Figure 4. Historical examples of the employment of Islamic geometric patterns on non-flat surfaces. Left: the dome of the Karatay Madrasa (Image credit: Wikimedia). Right: the dome of the Sultan Qaytbay Funerary Complex (Image credit: Wikimedia).

3. Anatomy of the Islamic Geometry

Generally, Islamic Geometric Designs (IGD) consist of points connecting to form line/s and/or polyline/s replicated using symmetry to fill a specified space. Typically, Islamic geometric designs show some or all of the following recognizable characteristics: symmetry, flow, unboundedness, flow, and interlacing (Abas & Salman, 1995). Islamic Geometric designs morphologically relate to each other, and it is possible to morph designs to transform from one historically existing design to another (Alani, 2017).

Three types of symmetry structures were identified in Islamic geometric designs: rosettes, periodic, and quasi-periodic structures. Figure 5 below shows an example of three points that were connected with each other using a single polyline and experimented with to create designs using the above-mentioned three structural orders.

Rosettes patterns are formed by applying rotational symmetry to a particular geometric composition around a specified axis. This type of patterns can have a number of axes that goes from 1 to ∞ (Shubnikov 1974). Rosettes patterns have two types: cyclic and dihedral; cyclic is formed by applying rotations to the geometric compositions, while dihedral includes using reflection geometry in addition to the rotational symmetry.

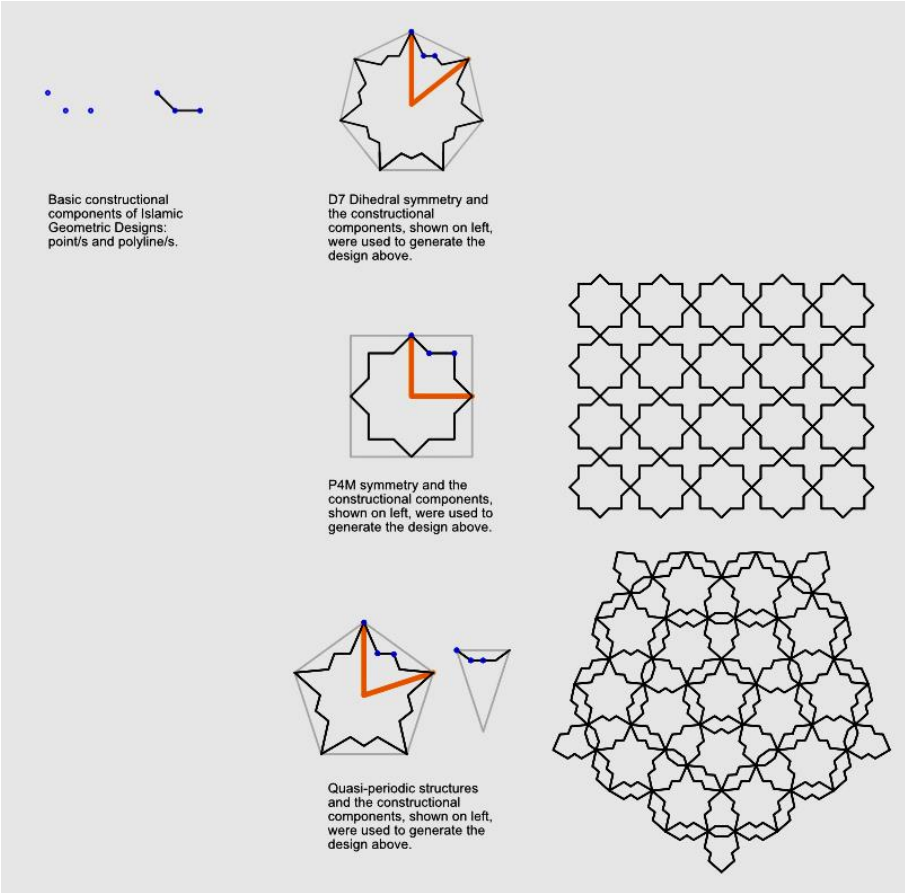

Figure 5. shows the possible designs that can be derived from the same polylines by changing the employed symmetry (from top to bottom: rosettes, periodic, or quasi-periodic structural order).

Periodic patterns are formed through the employment of the wallpaper symmetry group to replicate geometric compositions to fill space while leaving no gaps. Islamic architecture employed the 17 possible types of the wallpaper symmetry group to create the enormous diversity of geometric

designs; in fact, the seventeen possible types of wallpaper symmetry group have been identified in Alhambra palace alone (Pérez-Gómez 1987).

On the other hand, quasi-periodic patterns are also tessellated structure capable of filling the space while leaving no gaps; however, it does not employ regular translational symmetry and typically includes more than one shape (Chorbachi & Loeb 1992, Al Ajlouni 2012).

This paper codifies this definition of Islamic geometric design and explores computational processes to derive geometric forms that go beyond flat surfaces.

4. Migrating Flat Surfaces

The vast majority of Islamic geometric designs exist in Euclidean two-dimensional space. However, several examples of Islamic geometric designs are found on non-flat surfaces. This section discusses two methods by which Islamic geometric designs can be employed to derive three-dimensional compositions: Euclidean Point Extrusion (EPE) and Curved Surfaces Fitting (CSF).

4.1 EUCLIDEAN POINT EXTRUSION:

Euclidean Point Extrusion method derives three-dimensional compositions from two-dimensional Islamic geometric designs by manipulating the points' z-coordinate with no changes to the x- and y-coordinates. The challenge in deriving the forms in this method lies in setting the value of the z-coordinate and filling any gaps that may result with appropriate forms.

Muqarnas is an exemplar case of the EPE method. Figure 6 shows an example of this method with a simple design.

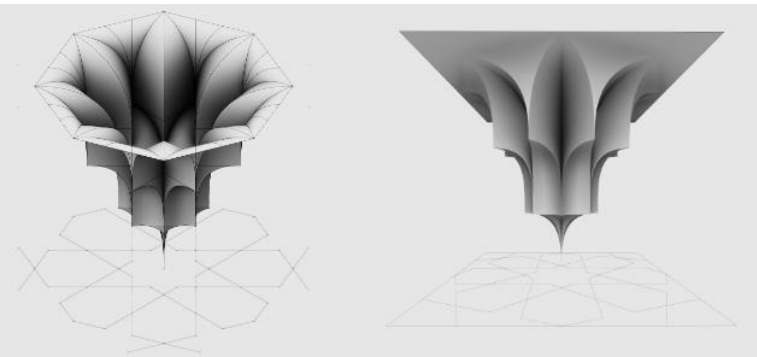

Figure 6. Square-based, Islamic geometric design was employed to generate the muqarnas-like form shown above through the manipulation of the z-coordinate of the points on different geometric patterns.

4.2 CURVED SURFACES FITTING:

The Curved Surfaces Fitting method aims to fit a two-dimensional Islamic geometric design into various non-flat surfaces. It can be further categorized into two sub-categories: Curve Directional Projection and Curve Mapping. Both subcategories require a Hosting Surface (HS) to project or map the design.

4.2.1. Curve Directional Projection

Similar to the EPE method, the curve projection method also extrudes points in the z-coordinates with no changes to the x- and y-coordinates. However, the value of the z-coordinates is determined by the HS. Additionally, the curves that connect design points are generated by solving the intersection of the extruded design with the HS. Thus, the curves inherit the HS curvature while conducting no changes to the x- and y-coordinates. Note that the resulting geometry will no longer follow Euclid's Postulates as it will inherent some of the hosting geometry characteristics; for instance, the sum of the triangle angles is no longer 180 degrees) (figure 7).

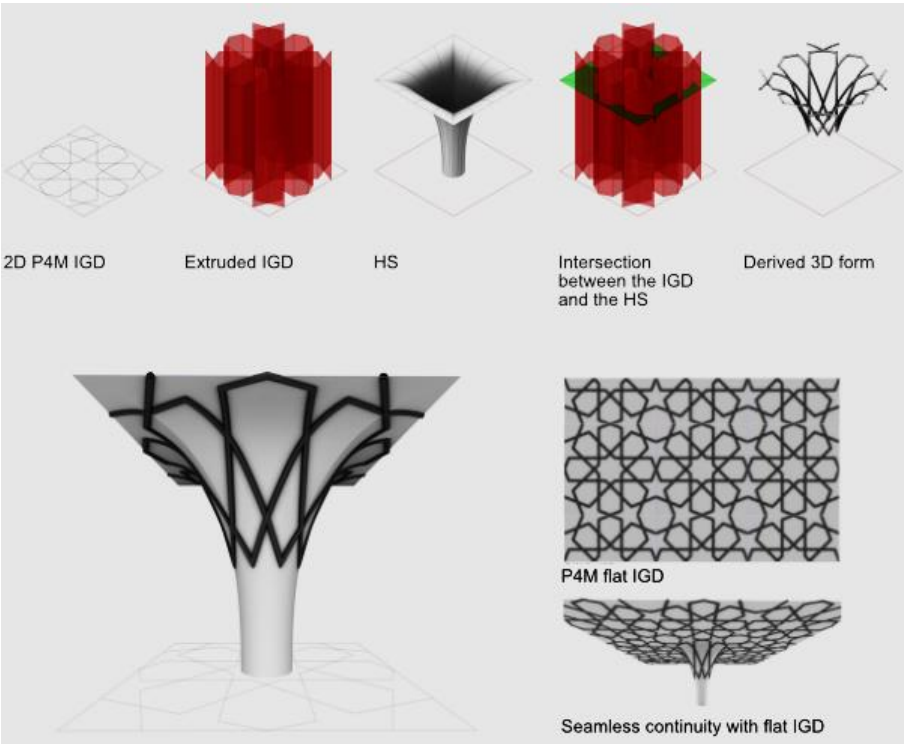

Figure 7. Left: shows example of a projected 2D Islamic Geometric Design on a curved surface. Right: tiling the derived form with the original 2D Geometric Design.

4.2.2. Curve Mapping

Depending on the design problem, the curve projection method could be limiting. Consider the hemisphere shown in figure 8 (bottom left), which shows an Islamic geometric design projected into a dome-like HS. The figure clearly shows that the design is strongly distorted at the bottom boundary of the HS. This limitation is addressed by the Curves Mapping method.

The curves Mapping method would conduct significant changes to x-, y-, and z-coordinates of the design points and changes to the respective curves. That is, the points will be located in a position that is relative to their original position in the two-dimensional design. Creating such forms would require extracting and flattening the HS's isoparametric curves (ISO curves). In most cases, the HS is not a developable surface. Thus, this method requires establishing a two-dimensional flat equivalent of the HS using the ISO curves. Then, the design is to be placed and fit within the flattened equivalent space and then mapped back to the HS (figure 8).

5. Three-Dimensional Parametric Exploration

The selection of a method to derive three-dimensional geometry depends on the design problem. For instance, if the goal is to design a dome, Curve Mapping would deliver an appropriate outcome. Figure 9 shows the computational process for deriving non-flat Islamic geometric designs. The process starts with selecting a particular Islamic geometric design to be passed to a selected migration method and deriving an output. There are two groups of parameters to work with in this flow: IGD parameters and migration method parameters.

The Islamic geometric designs parameters are the symmetry type, points count, point coordinates, and polyline intersections, all of which can explore the latent design space of a 2D Islamic geometric designs. The migration method parameters differ based on the employed method. For instance, the parameters in the Euclidean Point Extrusion are the Z-coordinates of the points and the shape of point connections. However, the parameters in the Curve Projection and Curve Mapping are primarily based on the shape of the HS. When combined together, the two sets of parameters allow exploring the latent design space of Islamic geometric designs on a non-flat surface (figure 10).

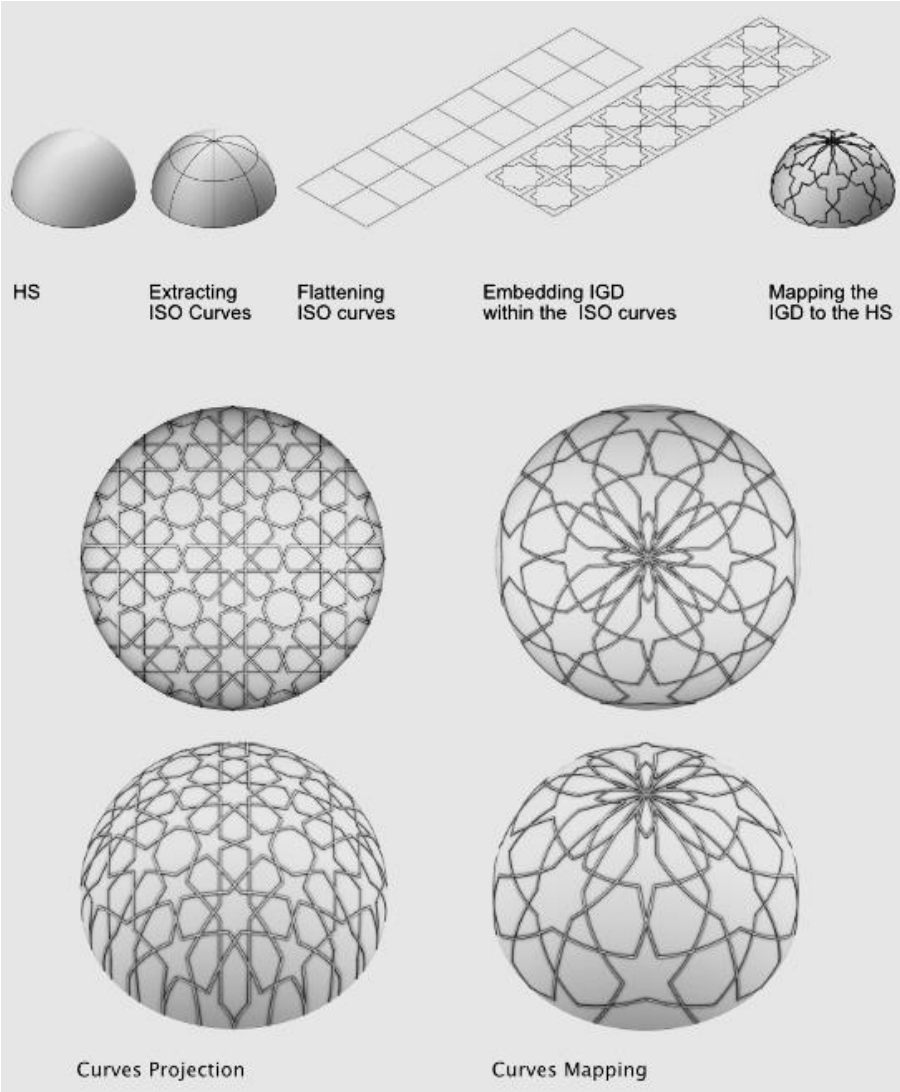

Figure 8. Curves Mapping method applied to a dome-like HS. Top: shows the process of unrolling the equivalent surface, inserting the desired design within, and mapping back the design to the hemisphere. Bottom left: perspective view illuminates the distortion occurring at the bottom edge of the HS when using the Curve Projection method. Bottom right: using Curves Mapping to fit a design into the hemisphere.

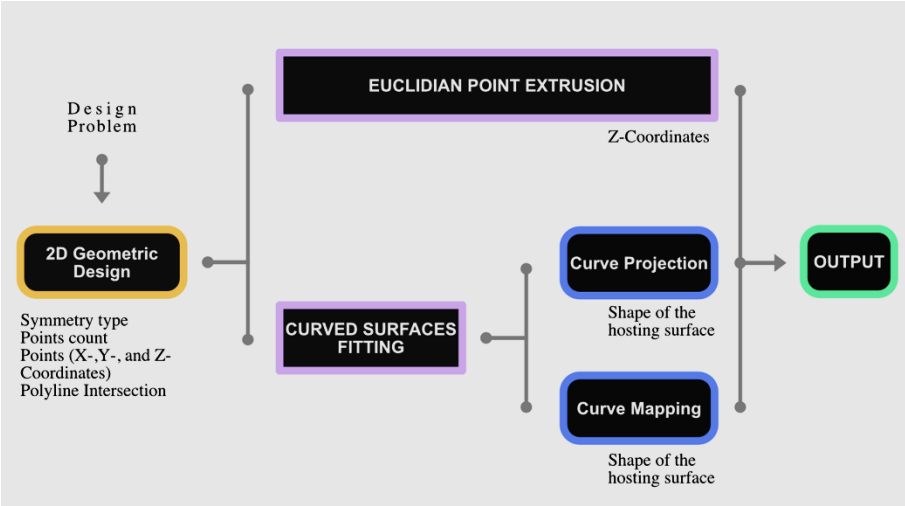

Figure 9. Computational process for exploring the latent design space of Islamic geometric design on non-flat surfaces.

6. Discussion

In all of the explored scenarios, the 2D Islamic geometric designs played a foundational role in creating the designs beyond flat surfaces. Therefore, designers' sensibility is crucial as it will affect the outcome significantly. The Euclidean Point Extrusion method allows for an additional layer for the designer to be creative in connecting design parts and filling the gaps resulting from the extrusion process. In the Curved Surfaces Fitting method, designers' creativity primarily resides at the 2D level, and the HS and all changes need to be conducted there.

Historically, Islamic architecture embedded a firm understanding of geometry that served functional and aesthetical purposes (Burckhardt, 2009). Categorizing the corpus of existing designs and identifying generative processes of such designs is necessary to understand historical designs and provide a platform to develop Islamic architecture progressively. Consequently, the aim of this study is twofold: first, the paper aims to investigate Islamic geometric designs on non-flat surfaces and categorize the different possible ways by which Islamic geometric designs can exist on non-flat surfaces; secondly, the paper seeks to unveil computational approaches by which such structures can be generated, visiting, in the process, uncharted territories to expand the search for novel forms.

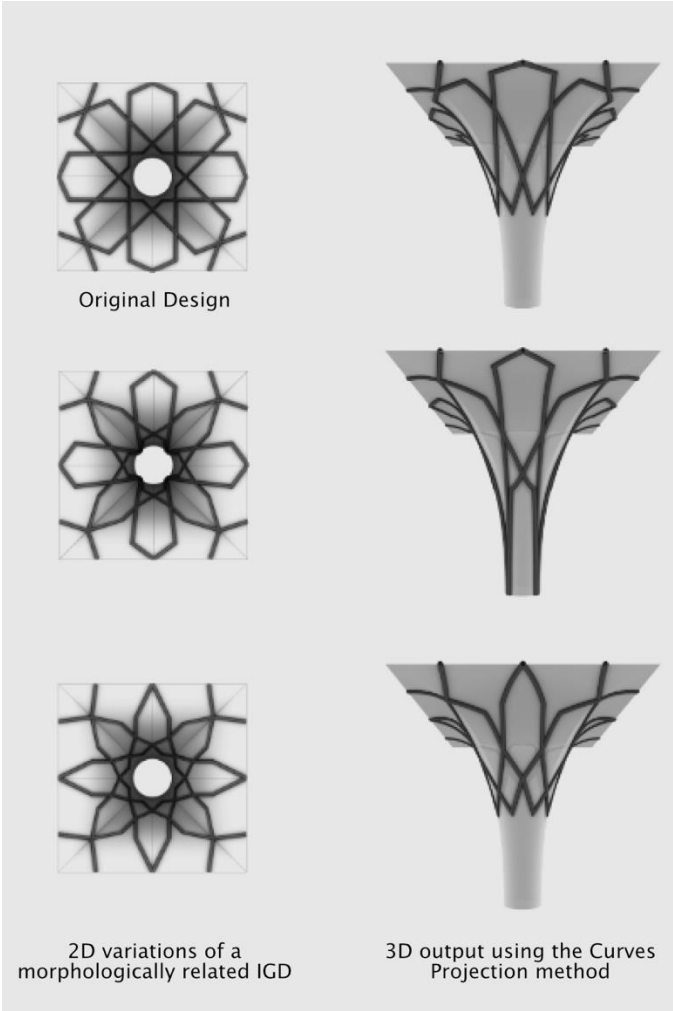

Figure 10. Design variations were created using a fourfold Islamic geometric design and the Curve Projection method.

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ADAPTING DIGITAL ARCHITECTURE VOCABULARY TO REFORMULATE GEOMETRIC COMPOSITIONS OF ISLAMIC FAÇADES

Case Study: Proposed Model for Islamic Façade through Digital Vocabulary

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Abstract. Islamic architectural facades characterized by many distinguished vocabularies that formed its character; as arches, ornaments, al-Muqarnas and mashrabeya etc. However, during the modern era, the Islamic heritage regions faced many changes and transformations of its character, either by new buildings that were built according to modern or unplanned styles, or by random and unplanned developments. However, recently and with the beginning of the twenty first century and with the great breakthrough in the digital tools and techniques, it facilitates new horizons in the architectural form generation. Accordingly, the research focuses on how to investigate the positive impacts of digital technologies on Islamic Architecture. In addition to how to utilize the digital thoughts, vocabulary, and techniques to create and develop a heritage inspired vocabulary that can compromise with the traditional Islamic architecture theme. Through this, the research aims to achieve a systemization of digital design strategies to facilitate the generation of Islamic-inspired façade, to create a new Islamic architecture that can be applied within Islamic heritage regions to connect the modern buildings which located in these regions with the existing Islamic reference. To achieve that, the research starts with studying and discussing the main elements that formed the Islamic facades, to stand on the methods of formations of each element and its function of the Islamic façade, whether it is an intrinsic function or aesthetic function. Consequently, standing on the main digital theories that lead to new architectural vocabulary that can homogenate with Islamic vocabulary, through studying the concept of each digital theory, accordingly how it can be applied theoretically to create a modern façade with an Islamic spirit. The research ends with a case study for

a proposed modern building that resembles most of the recent buildings in Al-Azhar Islamic region in Cairo, and how through applying some selected digital theories can result in developing and renovating this facade to match the heritage Islamic surrounding in a new digital way.

Keywords: *Digital architecture, Islamic vocabulary, Heritage Regions, Digital Era, Architectural Paradigm.*

ملخص. تتميز الواجهات المعمارية الإسلامية بالعديد من المفردات المميزة التي شكلت طابعها مثل العقود والزخارف والمقرنصات والمشربيات وما إلى ذلك. ولكن مناطق التراث الإسلامي واجهت خلال العصر الحديث العديد من التغييرات والتحولات في طابعها، إما من خلال المباني الجديدة التي تم بناؤها على الطراز الحديث أو غير المخطط لها أو تلك التى بنيت بشكل عشوائي. ومع ذلك، في الآونة الأخيرة ومع بداية القرن الحادي والعشرين فقد وفرت التطورات الهائلة في الأدوات والتقنيات الرقمية آفاقًا جديدة في أدوات التشكيل المعماري. وبناءً عليه، يركز البحث على كيفية تقصي الآثار الإيجابية للتقنيات الرقمية على العمارة الإسلامية، بالإضافة إلى كيفية الاستفادة من الأفكار الرقمية والمفردات والتقنيات لإنشاء وتطوير مفردات مستوحاة من التراث يمكن أن تتعارض مع موضوع العمارة الإسلامية التقليدية. من خلال ذلك، يهدف البحث إلى تحقيق منهجية لاستراتيجيات التصميم الرقمي لتسهيل توليد واجهة مستوحاة من العمارة الإسلامية ، لإنشاء عمارة إسلامية جديدة يمكن تطبيقها في مناطق التراث الإسلامي لربط المباني الحديثة الموجودة في هذه المناطق مع مرجعيات مفردات العمارة الإسلامية. ولتحقيق ذلك يبدأ البحث بدراسة ومناقشة العناصر الأساسية التي شكلت الواجهات الإسلامية للوقوف على أساليب تشكيل كل عنصر ووظيفته للواجهة الإسلامية، سواء كانت وظيفة جوهرية أو وظيفة جمالية، وبالتالي الوقوف على النظريات الرقمية الرئيسية التي تؤدي إلى مفردات معمارية جديدة يمكن أن تتجانس مع المفردات الإسلامية، وذلك من خلال دراسة مفهوم كل نظرية رقمية، وبالتالي كيف يمكن تطبيقها نظريًا لخلق واجهة حديثة بروح إسلامية. ينتهي البحث بدراسة حالة لمبنى حديث مقترح يشبه معظم المباني الحديثة في منطقة الأزهر الإسلامية في القاهرة، وكيف يمكن من خلال تطبيق بعض النظريات الرقمية المختارة أن يؤدي إلى تطوير وتجديد هذه الواجهة لتتناسب مع المحيط التراثي الإسلامي بطريقة رقمية جديدة.

الكلمات المفتاحية: *العمارة الرقمية، مفردات العمارة الإسلامية، المناطق التراثية، العصر الرقمى، الطراز المعمارى.*

1. Introduction

As the 21st century has conveyed new era for architecture, so searching for creative and innovative forms became one of the most motivating focuses to contemporary architects in recent years, and computer has played essential role in achieving this new paradigm in architecture. Digital architecture is considered the architecture of the 21st century and distinguished by its extremely varied manifestations and characteristics that simulate various principles and theories. Complexity in masses and shapes to fluidity, moreover geometric shapes that known as parametric geometry and many others, in which the relationship among them are examined and

applied through computer software. Despite this, remains the absence of mutual discourse methodology between digital and traditional approaches to create a modernized vocabulary has challenged contemporary historical Architecture, while the digital architecture theories with the role of computer can assure the simulation of historical rich ideas, vocabulary and characteristic (Nejad et al., 2014).

By concentrating firstly on the design of Islamic façade with its unique and distinctive way, through studying the main elements that formed the identity of Islamic facades, in which its features were designed to support different aspects starting from psychological, ecological, societal and religious demands convenient to all the requirements of that era. (Singh and Saxena, 2021). In this context, the question arises as to find and highlight the link between the design of Islamic façade elements and the design methods of digital architecture and how it can have a great role in the possibility of achieving a new historical architecture with its great and rich vocabulary to reach a new Islamic feature through the wide variations in the digital techniques. In addition to being able to compromises with the traditional Islamic vocabulary, elements and characteristics and can still also have the same imaginative and expressions within the same spiritual traditional Islamic way.

2. Islamic Architecture Facades Elements and Vocabulary:

Formation of Islamic architecture facades utilizes a set of rules and principles that created this vocabulary. Islamic vocabulary combines between fixed (religious beliefs) and variable (the form) principles, that formed the Islamic architecture and assure its distinctive characteristics. For example, from the religious beliefs that affected the form in Islamic architecture was the privacy principle, which is one of the most important principles that affected the form through many aspects specially the external openings that led to covering external openings with different treatments. Consequently, it’s important to determine the main elements that formed the Islamic facades and its basic principles to stand on deep understanding for Islamic elements and vocabulary to reach a conscious attitude and full awareness of their meaning and way of designing, to enhance rethinking and reformulating Islamic compositions through digital techniques. (Hillenbrand, R. 2003),

2.1. GEOMETRIC ORNAMENTS

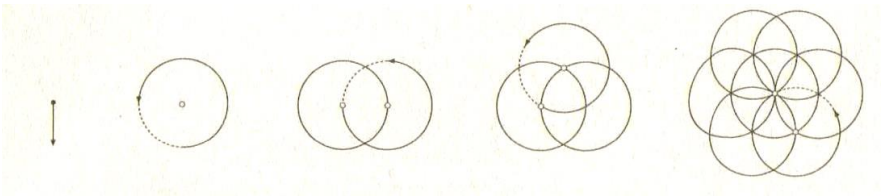


Figure 1. From unity to cell through circle center interlocking (Sutton 2007, 3)

Islamic ornaments are one of the main elements that formed Islamic architecture identity and ideology. When we analyze its composition, we can in Islamic pattern the most notable and basic theme in forming its geometry find that repetition. Islamic ornament formation methodology is mostly based on one or two basic shapes, by interconnecting these basic shapes many diverse and complex patterns can be generated. (Alani, 2015). Origin Start of any of any Islamic geometric pattern shows a kind of symbolism, as example; the center of the circle (Although not visible in itself), the center provides the basis for the rest of the pattern. This center/unity corresponds to the concept of Tawheed in the Islamic tradition, as shown in figure 1. Correspondingly, it is the basic concept and the first pillar of faith. In Islam, God is the absolute power from which the universe originated. Although the names may vary (center, unity, or absolute), in both geometry and Islam, it is the unseen reality that is the most obvious. (Azad, 2020).

Islamic Ornamental designs are mostly generated by the repetition of the basic shapes circle which is the main, square and triangle. Pentagon, octagonal, hexagon decagon, and Islamic stars are from the shapes that also have a significant role in generating Islamic ornaments and patterns, but furthermore most of these shapes can be formed from the interlocking of the Islamic basic shapes. As stated previously, what is significant about Islamic ornaments is repetition that can generate a surface of geometric pattern, as shown in figure 2. (Azad, 2020).

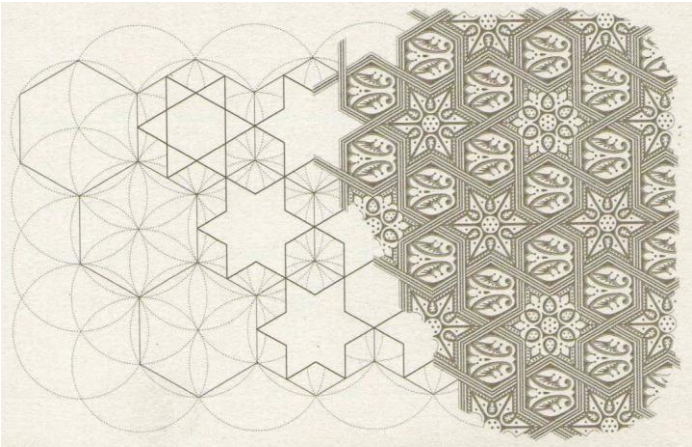


Figure 2. Simple to complex (from circle to hexagon transforms into another shape by joining the midpoints of the hexagons). (Sutton, 2007, 3).

2.2. AL MUQARNAS

Muqarnas is an organization of three-dimensional decorating masses that used in Islamic architecture with various forms. Muqarnas is complicated shapes, geometry, and repeated structures that characterized by symmetry-repetition-diversity-accumulation - diversity in scale. Muqarnas is mostly used in domes, niches, arches in facades to determine the entrance. According to the use of Muqarnas; its size, module in addition to the deepness of its composition is varies and adjusts to the size of the area covered or to the required purpose, Figure 3, for example in ceilings it serves a clear architectural purpose as a transition element from ceilings to walls (e.g. from circle to square or vice versa), or provides the structural delusion and spatial balance of ascending movement in domes. (Bloom, 1988).

Figure 3. On the left Main entrance portal (iwan) of Mosque-Madrassa of Sultan Hassan, Cairo, Egypt. On the right muqarnas vault of entrance portal, Complex of Sultan al-Mu'ayyad, Cairo, Egypt (Sutton, 2007, 3).

The three-dimensional effect of the muqarnas decoration is achieved by interlacing and repetition of patterns. The Muqarnas are made of small 3d pieces or cells which are simple in shape combined in successive layers together produce this complex surface. These cells are the structural blocks on which Muqarnas were built and expanded to fill the area between consequent layer lines, as in Figure 4. Muqarnas 3d cells are roofed like a staircase consists of facets and a flat roof. Both facets together with their roof are called one cell. Adjacent cells, which have their bases on one and the same surface parallel to the horizon, are called one tier, and from tiers to complex surface as stated before. (Von, V, 2006).

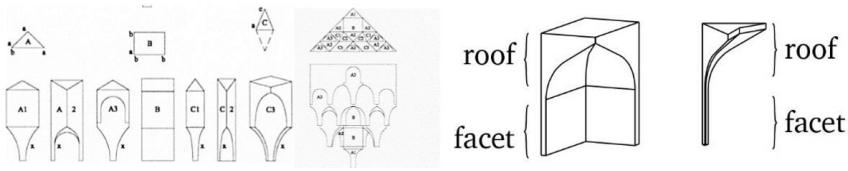


Figure 4. Simple elements of Muqarnas (roof and facet), Plans, Elevations, Sections. (Garofalo, V. 2010).

2.3. ARCHES

The arch in Islamic architecture as an opening or frame has three purposes in its achievement: the first is the functional, to form openings or a set of arrangements of arcades that formed and surrounded Islamic plazas and courts. The second purpose is a structural purpose which may be a load-bearing with a profile based on the segment of a circle or series of segments. The third is the aesthetic and symbolic feature as it can be used as a decorative element in the Islamic facades. Mostly arches in Islamic architecture are used in regular repetition rhythm, shown in figure 5, which appeared in the opening's rhythm of Islamic facades or in the repetition rhythm the arcades. (Edwards, C. and Edwards, D. 1999)

Figure 5. Left photo arches repetition in the Great Mosque of Kairouan, (www.khanacademy.org). Right photo the repetition in arches with different scales in Al-Azhar Mosque entrance, (islamicart.museumwnf.org).

There are different types of Islamic arches as shown in figure 6, the variation in their shapes depend on the number of the arcs segments and the changing the positions of their center. (Almaimani, A., Nawari, N. 2016,)

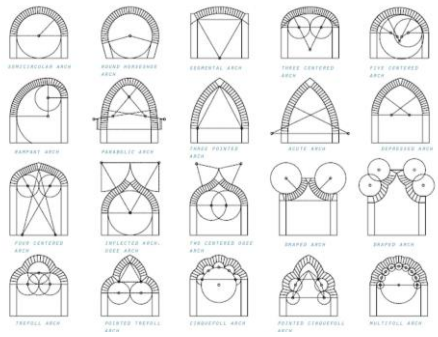


Figure 6. Some of the Islamic arch types (Almaimani, A., Nawari, N. 2016).

2.4. WOODEN TREATMENTS OF ISLAMIC FACADES

Islamic wooden treatments are considered a porous structure that have several distinct types according to their wooden latticework designs differ from region to region, figure 7. Wooden languages in Islam offers a lot of aspects according to human needs that Islamic architecture was concentrating on, (i.e., religion, privacy, environmental, spiritual, and ornaments), which can be further sorted into the following aspects: (Embi. R., Abdullahi. Y., 2012)

- Physical aspects: adding a touch of details in terms of color, aesthetics, and another level of ornaments in the facades.
- Psychological: Achieving a kind of porous through indirect connection between the interior spaces and outdoor spaces.
- Environmental aspects: provide shade from the summer sun while permitting the flow of cool air from the road. This allows for greater air circulation within the room without causing discomfort. The wood itself removes moisture from the air.
- Social and Spiritual needs: The wooden ornaments allow the user to use the space confidently, insure Islamic practices and worship.

Figure 7. Wooden treatments (mashrabeya) in Beit El-Sennari (www.meashots.com).

2.5 DURING THE STUDY OF ISLAMIC FACADES GEOMETRIC COMPOSITIONS, THE RESEARCH HAS REVEALED THAT:

- By decomposing Patterns and motifs in Islamic architectures to its constructional non-repeating components, it's found that it is based on a fundamental unit or cell, which is formed from a starting point or smaller cells. Once the fundamental unit is achieved, a surface geometry can be able to reconstruct.
- Islamic geometric patterns have simple governing rules for creation and have infinite number of possible patterns.
- Islamic formations depend on the repetitive sequences.
- Patterns is used to enhance cultural characteristics, and determining its identity.

  So the research will study digital architecture vocabulary and techniques to develop Islamic elements and vocabulary using parametric algorithms.

3. Reformulating Islamic Geometry Compositions Through Digital Methods and Techniques:

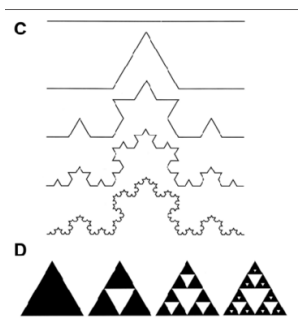
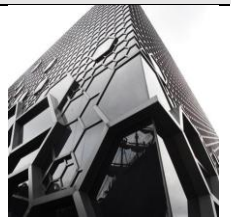
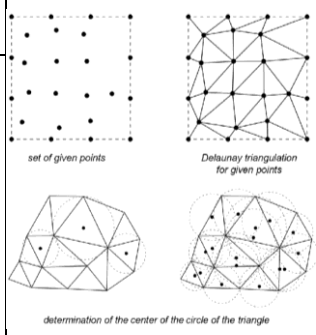
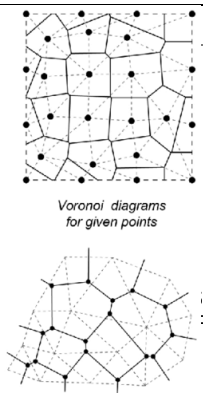
The notable changes in today's architecture are predictable consequences of the sweeping technological advances of the 21th century. The architecture of 21th century or digital architecture is characterized by various features and compositions that resemble Islamic architecture formations which have been studied previously in so many characteristics. Consequently, digital architecture can be exploit in achieving new contemporary architecture that can homogenate and compromise with the Islamic architecture and be a way to develop facades of modern buildings in the traditional Islamic regions. In this context, the research will illustrate the most convenient theories that matches with the Islamic compositions that have been illustrated before.

3.1. FRACTAL GEOMETRY

Fractal geometry is inspired from structural irregularity of nature system. Fractal appears in phenomena of nature system through all its scales, from its particle to cosmological unit. From its examples, the structures of the ground surface, snow crystal shape, discharge phenomenon of electricity, and distribution of the cosmic galactic system, human and plant cells, and many other. Fractal has varied principles and theories that can be useful in applications of new Islamic architecture. Fractal geometry is developed by means of algorithm that developed in cellular formations in a numerical formula, and achieved in a repetitive operation process. Namely, fractal has a creative attribute in which small change in parameters incorporated in creating various complex patterns, with substantial change. (Lee M. 2014).

Many theories and classifications have discussed the fractal types according to varies visions and from these theories, the research will concentrate on three theories that can correspond the Islamic concepts of geometric patterns as studied in the following table:

TABLE 1. Fractal Theories.

Fractal Theories		
Theory name and Concept	**Concept of application method**	**Example**
Fractal Self Similarity It's a repetitive process in which that the figure can be decomposed into some number of disjoint pieces, each of which is an exact copy of the entire figure but may differ in its size. (mellor B, 2013)		 Repetitive hexagon by different scales (Busygina. E. behance)
Delaunay triangulating Fractals It is a triangle mesh that is formed from either a set of random **points** or from a group of adjacent circles in which the vertices of each triangle intersect with the circumference of each circle at different points forming an acute angle triangle. (Rokicki, W. 2016).		 Delaunay Fractals Pattern
Voronoi Fractals		

It's a step more after the Delaunay triangulation through either defining the voronoi cell from a given point, or from the centers of the circles which determine the vertices of the convex polygon of voronoi which form form a new grid of "irregular voronoi diagram " (KNZLE, A. 2020).		Voronoi diagram with different attractor points.
Conclusion	Fractals mostly depend in its design on a starting point to reach a fractal fabric as in Islamic geometric patterns.	

3.2. GEOMETRIC FOLDING

The process of folding is bases on transforming a two-dimensional surface into a three-dimensional sculptural object, which includes three important aspects for the architectural design, creation and performance.

- Folding paper is a design method to build geometric models, by transforming the two-dimensional sketching into a three-dimensional modelling as shown in figure 8, which can give into wide possibilities of unpredicted results.
- Geometric folding is an effective structural model that can support itself due to the stability of its folds.
- Most of geometric folding has an effective adaptability with different environmental aspect. (Hemmerling, 2010)

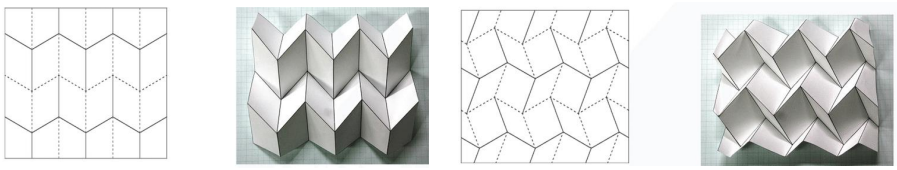


Figure 8. Transforming 2d surfaces into geometric 3d modelling through folding (Lynn, G. 2004)

These spatial parametric patterns and models can be used through different building aspects such as; in form and building mass designing, or as a structure element in building ceilings or columns or as a façade pattern and material. In that respect the morphogenetic process of folding results in a highly useful in detailed design model that provides a high degree of freedom for the designer through different patterns.

3.3. POROSITY

Pore means “a minute opening”. Porosity or “the state of being porous”, it is one of the natural phenomena that is found in different aspects in nature and living creatures as in biology and in organic chemistry porosity is defined as: “the characteristic of living body to have a large number of small openings that permit matter to pass through”. It is also ca be found in the geological transformation that occurs in ground and rocks due to the atmospheric effects. In porosity, the forms, the sizes and the distribution of pores are usually random as shown in figure 10. Their functionality is related to circulation and filtration with respect to the external environment. The concept of porosity was transferred to architecture design either in form or facades solutions, to guide the creation of a porous morphology in architecture as a kind of reformulation of natural characteristics.

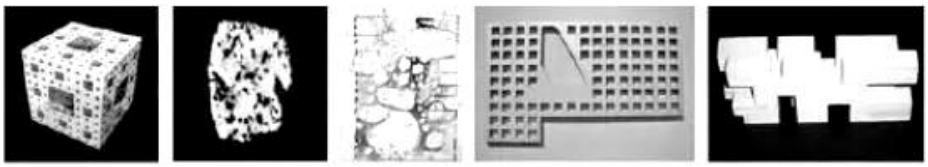


Figure 10. Organic and modular porosity, Early design schemes, Steven Holl Architects, New York, NY (Kotsopoulos. S., 2018)

Modular porosity in façades is a kind of surface fragmentation through pixilation technique, that can give an aesthetic preference within traditional architecture facades specially found in Islamic facades patterns. The porosity concept was part of a wider hypothesis, the “permeability hypothesis” that also found in Islamic Architecture (Wooden Treatments) as shown in figure 11, in which a porous morphology would have positive effects at building facade scale: better air circulation and light penetration, better accessibility and visibility at an urban scale, and better communication between interior and exterior at a building scale with a great achievement of privacy aspects for the internal building spaces. (Kotsopoulos. S., 2018)

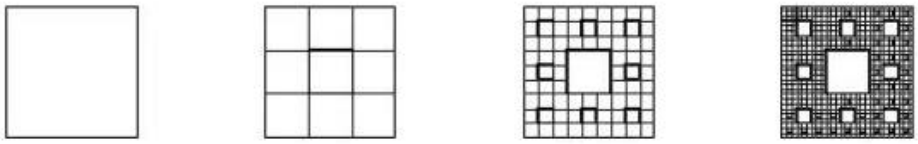


Figure 11. Levels of modular porosity (Kotsopoulos. S., 2018)

3.4. LOFTING (RIPLLES)

The term lofting originates from early shipbuilding. The ship large wooden framework called a loft, which was built to hold the external ship surface while it was assembled. The process of lifting the ribs (cross-sections) of the external surface into the loft became known as lofting. In Architecture, Lofting is one of the significant techniques for 3D object creation. Shape objects are created to serve as a path with any number of varied cross-sectional shapes either varied in shape or in height and area. (www.designstrategies.org). as shown in figure 12 which shows different shapes for lofting sectioning between regular and irregular.

Figure 12. On the left United National Movement building in Tbilisi, on the right Tampere art museum' in Finland by 3GATTI (www.designboom.com)

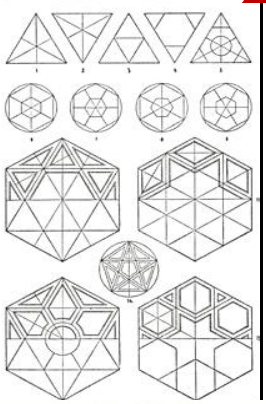
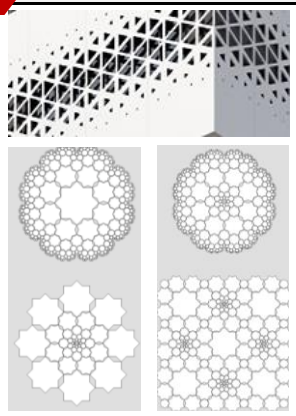
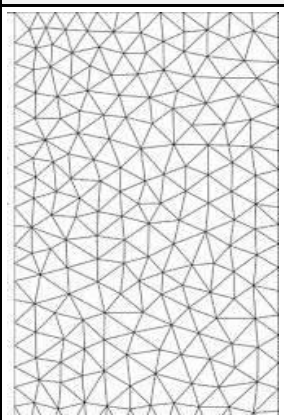
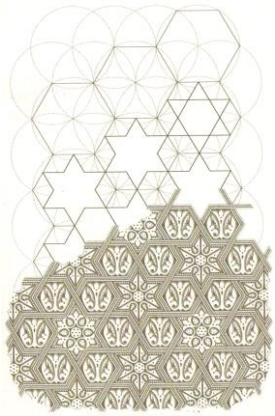
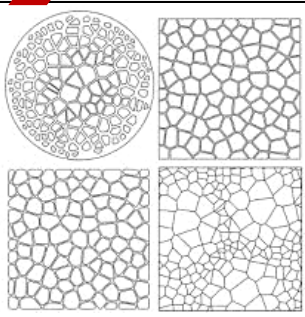
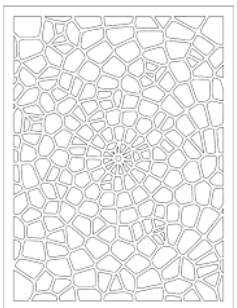
This technique can reformulate the repetitive cross section of Islamic Arches, as shown in figure 13. Accordingly, first create two or more spline objects. One of these splines will be the rail, which is referred to as the path. The rest of the splines are the cross-sections of your object, which are called shapes. As you arrange your shapes along the path, 3ds Max generates a surface between the shapes.

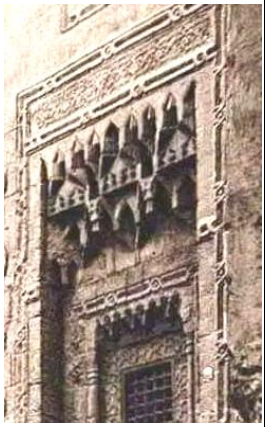
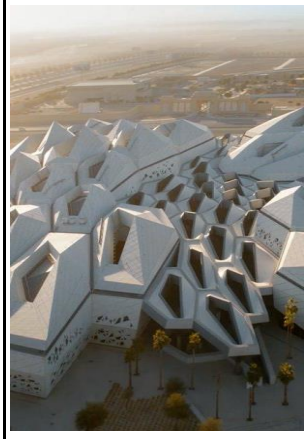
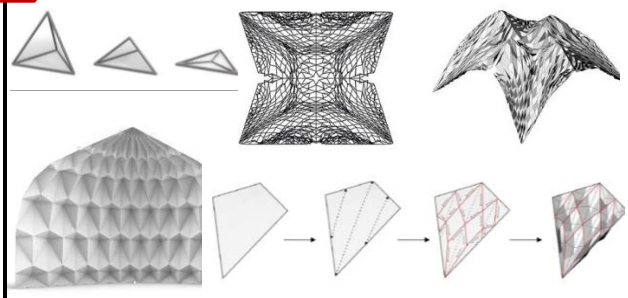
Figure 13. The Chamber Church aims to create a spatial container that both respects the past and looks towards the future (architizer.com)

4. A Comparative Study Between Islamic Facades Vocabulary and Digital Methods and Techniques

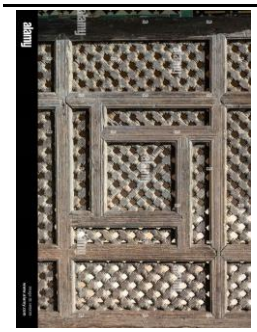
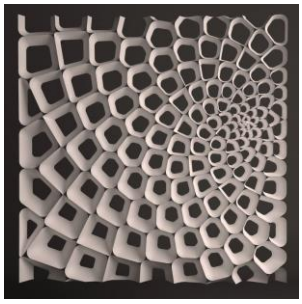
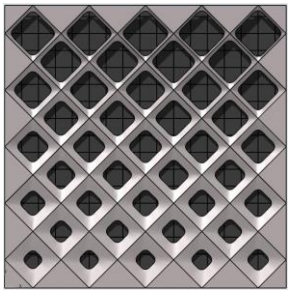
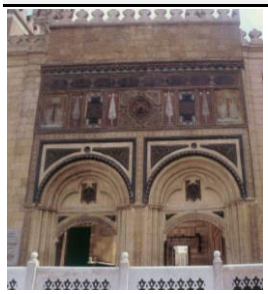
Through the following analytical table, the research will analyze how Islamic architectural facade elements and vocabulary can be reformulated through digital methods:

TABLE 2. Digital reformulating Islamic geometric compositions. (by the researcher)

Islamic Geometric Compositions	**Digital Reformulating**	
Geometric Ornaments	Fractal Self Similarity	Fractal Delaunay
		
	First photo self-similarity using triangles, second photo self-similarty using ismalic star only. (P. Webster, 2013)	Abstract geometric pattern using fractal texture of delaunay triangulating, (www.shutterstock.com)
	Fractal Voronoi	
		
Interlocking of the Islamic basic shapes forming infinite no of ismalic geometric patterns.	• Round gradient Voronoi 2d pattern • Voronoi 2D pattern. • Voronoi 2D pattern with rounded corners. • Voronoi diagram with 3 attractor points • Round gradient Voronoi 2d pattern with round corners and offest. (www.craftsmanspace.com).	

Al-Muqarnas	**Fractal Self Semilarity**	**Fractal Voronoi**
		
Concept of Muqarnas in Islamic architecture depend on small 3d pieces or cells which are simple in shape combined in successive layers together produce this complex surface. These cells are the structural blocks on which can be reformulated and developed through digital vocabulary by different methods and theories.	Al- Muqarnas effect by using self-similarity square pattern with different depth points in soft stone project – Iran (architizer.com).	Organic Voronoi fractal scheme expansions that allowed to grow multiply like fractal cells of Muqarnas in petroleum research center by Zaha Hadid (Elgohary, A.-2019).
	Geometric Folding	
		
	Examples from 2D pattern towards 3D formation; digital through geometric folding modelling forming al-muqarnas. (Alaçam, S., 2017).	

Islamic Wooden Treatments	**Porosity**

	 
Porosity is one of the main characterstics that distinguish islamic wooden treatments.	Porous can be achieved by many shapes in digital theories as the following, permeable, honeycomb screen, net riddle, sponge pore opening, hole aperture, and many others, it addition it can be a step more after achieving fractals pattern by its different theories, as shown in the photos. (Kotsopoulos. S., 2018)
Islamic Arches	**Lofting (Ripples)**
	 
Arches used as openings or in determining the main entrances of islamic building which in many cases depend on the repetitive concept.	Lofting adopts the structural form of a series of arches in islamic architecture, with different heights, which can make a formal language and spatial structure of Islamic facades. At the same time, it also responds to the traditional idology of Islamic architecture from a structural point of view. (www.archdaily.com).
Conclusion	From this analytical study we can conclude that Digital vocabulary featured with many characteristics as complexity, rhythm, geometric, changing and growth compositions, which shows a great ability in dealing with Islamic visions in forming vocabulary and compositions, which can be exploit to develop the modern facades within the Islamic context in the tradition Islamic regions.

5. Case Study: Applying digital Vocabulary in Islamic Geometric compositions

Through the following practical study, the research will apply digital vocabulary that has been studied in the previous theoretical and analytical study on a proposed façade of three-story building. Through practical study, the research can assure that digital vocabulary and theories are able to compromise with Islamic architecture facades designs. Consequently, it can be achieved and applied on modern buildings which located in Islamic heritage regions to reach a new contemporary style that can homogenate with Islamic architectural vocabulary and compositions but with a new digital style.

5.1. PRACTICAL STUDY SAMPLE

Choosing and designing the sample depended on two main aspects. The first aspect; analyzing Islamic façade and standing on their main elements. The second aspect; designing a basic model of a modern three-story facade, which contains the main elements of the façade that we concluded from the first aspect, in addition to, its simulation to the modern facades that are located within heritage Islamic regions, shown in figure 14.

Figure 14. Proposed modern façade model of three story with simple and basic elements

5.2. THE PRACTICAL STUDY TOOLS

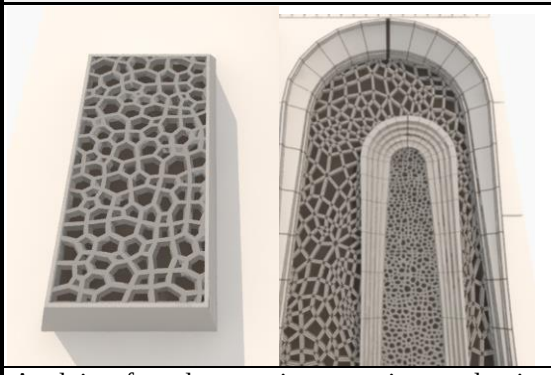
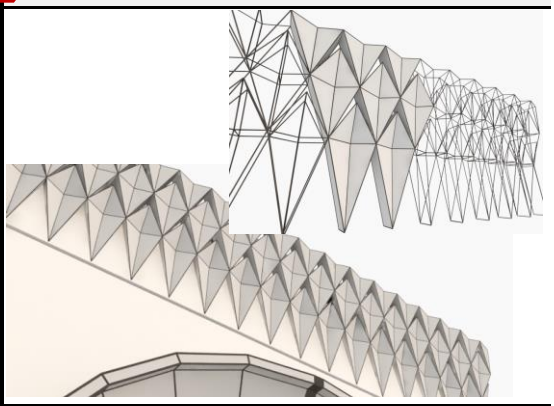
The practical study chose 3ds Max program as study tool to apply digital techniques, according to the its general features as a computer graphics program for creating 3D models, animations, and rendering photorealistic images. In addition to its modelling techniques such as, Polygon modeling includes multi sub-object levels, navigating and a rich modifier stack and creating commands like; loft, mesh topology, edit poly, inset, morph,

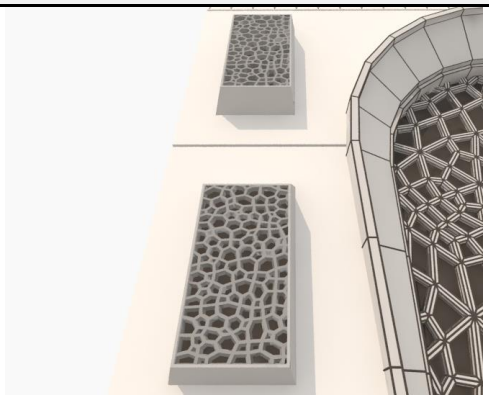
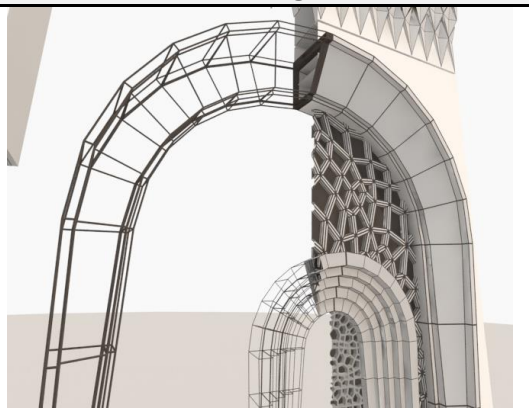
Boolean, NURBS and modifier list, like; twist, bend, FFD, sweep, etc. and also its accuracy with complex forms.

5.3. PRACTICAL STUDY DIGITAL VOCABULARY APPLICATION

The practical study chose some of the digital vocabulary that have been studied previously to be applied on the proposed façade.

TABLE 3. Practical Study Digital vocabulary application. (by the researcher)

Practical Study Digital vocabulary application	
Geometric Ornaments	**Fractal Voronoi**
The Islamic ornaments applied through Voronoi diagram with multiple attractor points in entrance and Voronoi 2D pattern with rounded corners in openings	
Commands used: Applying (Edit Poly) on a multi-face plane, then apply (Mesh topology) to create the Voronoi pattern, after that applying (Inset) to create struts.	Applying fractal voronoi on openings, also in the entrance area as ornaments to determine the entrace area..
Al-Muqarnas	**Geometric Folding**
Applying Islamic muqarnas through geometric folding from 2D hierarchized triangulating pattern that transformed to 3D formation by moving specific lines and points	
Commands used: Creating 2d Sp-line triangulated pattern. Moving vertices and giving it extrude, then apply 3d array with different scales.	Applying geometric folding as a Muqarnas on the top of the building façade.
Practical Study Digital vocabulary application	

Wooden treatments	**Porosity**
Porous techniques applied on Voronoi patterns to simulate porosity treatment of Mashrabeya and Islamic wooden treatments.	
Commands used: Applying (delete mesh) on Voronoi editable poly, then applying (bevel) to create the opening thickness.	Applying porosity on the Voronoi pattern of the openings to ensure the Mashrabeya concept and the entrance arched pattern.
Isalmic Arches	**Lofting**
Applying Lofting by using three sections with different scales and shapes, to simulate the tradition arched entrances with its upper ornament, but in an abstracted and modern way.	
Commands used: Applying (loft) using three cross-sections as a loft shape, and apply it on an arched path.	Applying lofting on two scales in the entrance area to determine the entrance as in Islamic architecture and to ensure the concept of repetition of arches in Islamic designing.

5.4. THE PROPOSED DIGITAL FACADE:

By applying the previous techniques, the research proposed an integrated modern façade which homogenate with Islamic tradition façades, which proved the research hypothesis that digital techniques and vocabulary can be used to develop the modern facades in Islamic region.

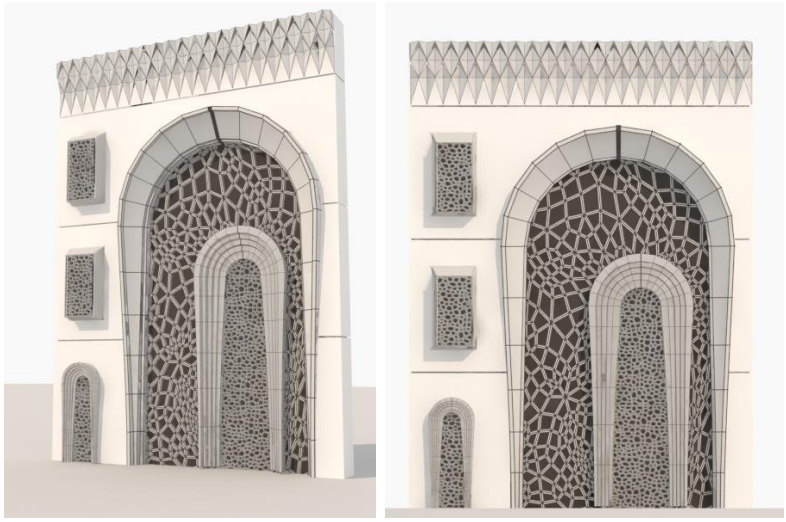


Figure 15. The integrated proposed Islamic façade model and elevation after applying digital vocabulary.

6. Conclusion

The research can be considered as a step to achieve a systemization of digital design strategies to facilitate the generation of Islamic-inspired façade, to develop the modern architectural output which located within the Islamic heritage regions -particularly in the façades design - through digital methods and techniques. Consequently, the research proved the great impacts of digital theories and its new architectural vocabulary in creating a new Islamic architecture that can be applied on modern buildings facades to transform it homogeneously with its Islamic heritage surrounding. In this context the research proposed sequenced steps of the facades development as the following:

- firstly, stood on the main elements that formed the surrounding Islamic facades.
- Secondly, analysing the modern facades (that will be developed).
- Then selecting from digital theories the suitable vocabularies that can help in achieving the features and compositions that resemble Islamic architecture formations.
- applying the elected vocabularies to get new integrated façade alternatives
- finally evaluating the new façade designs to stand on the most suitable proposal which homogenates with the surrounding facades.

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DEVELOPING A DESIGN FRAMEWORK FOR THE MASS CUSTOMISATION OF HOUSING IN SAUDI ARABIA: A CRITICAL REVIEW

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Abstract. *This paper explores the suitability of mass customisation (MC) technologies and techniques in order to provide affordable housing solutions for Saudi Arabia. In particular, the paper analyses ten articles filtered through 1.165 publications searched by using the keywords 'mass customisation housing or off-site construction' in the databases Scopus, CumlnCAD, ScienceDirect, and Engineer village and categorised them based on their suitability for the Saudi Arabian context. Our findings include a comparative analysis chart evaluating workflows, tools and technologies on their suitability for the MC design and an MC workflow proposal for including parametric design and digital fabrication tools and techniques.*

Keywords: *Mass customisation; housing; off-site manufacturing; client involvement*

الملخص .تستكشف هذه الورقة مدى ملاءمة تقنيات التخصيص الشامل من أجل توفير حلول إسكان ميسورة التكلفة للمملكة العربية السعودية .على وجه الخصوص، تحلل الورقة عشرة مقالات تمت تصفيتها من خلال ١١٦٥منشورا تم البحث عنها باستخدام الكلمات الرئيسية "الإسكان، التخصيص الشامل ، والبناء خارج الموقع"في قواعد بيانات سكوبس وكيومنكاد وساينس دايركت وانجنير فيليج، وتم تصنيفها بناءً على مدى ملاءمتها لسياق ا لمملكة العربية السعودية. و تتضمن النتائج التي توصلنا إليها مخطط تحليل مقارن يقيّم تدفقات العمل والأدوات

والتقنيات المتعلقة بمدى ملاءمتها لتصميم التخصيص الشامل بالإضافة إلى اقتراح سير عمل التخصيص الشامل .لتضمين أدوات وتقنيات التصميم المعياري والتصنيع الرقمي.

الكلمات المفتاحية: الإسكان، التخصيص الشامل، البناء خارج الموقع، مشاركة العميل.

1. Introduction

Mass customisation (MC) is a design and manufacturing approach that focuses on providing customised goods at a low cost (Ganji et al., 2018). Seeking to exploit mass customisation concepts such as modular standardisation, configuration, and flexible manufacturing requires the use of several tools to assemble and generate customised items for commercialisation under comparable conditions as serially produced standard products. MC can be applied in various industries, such as product design, vehicle design and architecture. It progresses through principle design, planning, manufacturing, and assembly stages. However, the architectural project's fabrication stage takes place largely on-site rather than in the manufacturer's location (Winch, 2003). MC provides more durability, improved quality, shorter time, and decreased cost. In contrast, mass production commonly results in identical, monotonous homes that no longer satisfy market desires for individualised design (Noguchi and Friedman, 2019). On the other hand, personalised design is a vital characteristic in meeting the individual needs of homeowners, yet, customisation increases design costs (Smith, 1998). It creates mass-produced modular components yet can be constructed into a broad range of final products. That is one of the most thriving standards of MC, and it reduces costs while increasing personalisation (Noguchi and Friedman, 2019). MC integrates mass production through mass design to achieve qualities of customised design at an affordable price. Mass housing production consists of three primary notions. First, it is built utilising standardised design and factory building processes (Altan et al. 2016). Secondly, it is based on state leaders' belief in similar living circumstances as a societal ideal (Urban, 2012).

Finally, it is used to reduce costs in a short period. Consequently, this study explores the state-of-the-art of MC in housing construction, looking at three different aspects: 1) the amount of client engagement in MC, 2) the types of MC, and 3) the manner of MC implementation. It is found that there is considerable potential for MC in the housing construction sector. Despite the number of benefits promised by MC, its application in the home construction sector remains limited, and building solutions, space and choice navigation

tools are very deficient. As a reaction to the Fordian paradigm of mass production and standardisation, many researchers see the possibility of delivering diversity and personalisation with efficiency and economies of scale. Discussions on parametric design and fabrication are usually related to 'Mass customisation', as defined by Davis (1987). The latter term, as stated and described by Pine (1993), refers to 'the mass manufacturing of individually personalised goods and services, which combines the idea of personalisation with the economic cost involved with standardisation.

2. A Brief History of Housing in Saudi Arabia

Over time, dwellings in Saudi Arabia have been modified according to the changing needs of society, technological developments in construction and the available materials. Formerly, Saudi Arabia's traditional buildings were made of bricks comprised of mud mixed with dried hay and water baked under the sun's rays (Al-Hathloul, 2003). Even though there were differences in socioeconomic status, all houses were generally constructed using the same building materials and designs (Chapman et al., 1999). This construction method continued until the introduction of the reinforced concrete structural framework during the late 19th century. Since then, buildings and construction in Saudi Arabia have changed drastically. Foreign companies and construction workers introduced new materials, and new systems gave way to drastic architectural changes. Consequently, due to its durability, reinforced concrete has become the primary structural system solution, replacing load-bearing masonry walls, which allowed the construction of more homes to support the country's massive population growth (Chapman et al., 1999). Even though the idea of using reinforced concrete buildings came from western countries, the local community has used it differently due to its culture and specific religious and privacy regulations (Bahammam, 1987). The changes in the Saudi Arabian lifestyle have also had an impact on the typical dwelling floor plan (Bahammam, 1998). Overall, Saudi Arabian dwellings have been through three stages of building construction types throughout different periods: the traditional, transitional, and contemporary stages (Bahamam, 2018).

The early traditional buildings were constructed by Islamic rules and regulations and had certain advantages. For instance, building materials such as mud remain cool for long hours inside the wall (Tarrad, 2020). However, some issues emerged in traditional houses, such as maintaining the roof yearly due to rain conditions when clay on the rooftop absorbed the rainwater. Transitional buildings used mixed materials, including traditional materials such as wood, mud and cement blocks, which were more recent. This method

produced a better-quality home in terms of quality and less maintenance, especially on rainy existences. At the time, building regulations focused on specific rules such as setback building construction from land barriers and the height of the building.

Contemporary buildings have undergone three periods, early, late, and current. Due to social media and western influences, the Saudi Arabian public has had to change the traditional house styles in a bid to 'move with the times. More recently, building regulations have become more robust after adding new building codes such as fire, construction, and interior codes. By investigating all three stages, every generation has shown different needs in terms of accommodation design according to societal lifestyle changes, the impact of globalisation and technology. Furthermore, Western builders, contractors, and architects have influenced building techniques and ideas by incorporating and sharing their skills and knowledge in the Saudi Arabian context. When foreigners were hired to build large-scale projects rapidly, they erected prefabricated cubic, concrete buildings without aesthetic, contextual or environmental considerations. Governmental regulations in urban planning affected Saudi Arabian society; thus, the subsequent urban form conflict has augmented the gap between members of the public and their urban environment (Al-Naim, 1993).

Furthermore, there is a housing shortage in Saudi Arabia due to a rapidly growing population. Other causes of the housing shortage are construction delays and labour deficits (Alhajri and Alshibani, 2018). In addition, most of the market is still implementing conventional building techniques based on reinforced concrete structures, making housing construction highly inefficient and time-demanding. Still, none of the housing providers has applied client involvement.

Finally, the Saudi housing ministry has the ambition to establish an initiative to facilitate novel construction technologies and made agreements as part of its contribution to the national transformation plan 2030aiming to increase citizens' homeownership from 24% to 52% by 2030 (Overview, 2022).

To solve these issues, mass customisation could aim for affordable, sustainable, context-friendly and user-friendly housing solutions. Therefore, this paper investigates, classifies and compares MC case studies in constructions that could be applied in the Saudi Arabian context. In particular, we will look into the questions:

- Which methods, techniques and technologies are currently being applied globally for mass customisation of housing?

- How can we develop a design framework which can provide mass customised, affordable housing solutions for Saudi Arabia?

3. Methodology

To answer our questions, we will proceed with a systematic review of relevant literature and then analyse and categorise the related research according to the design and construction customisation methods and the tools and techniques used. In particular, our research method consists of four phases, as can be seen in Figure 1, including 1) searching papers through databases (Scopus, IEEE, Engineering Village, CumlnCAD, and ScienceDirect), 2) screening the selected papers, 3) comparatively analysing and categorising of the papers and 4) evaluating the research in charts and tables. In the first stage, our initial search concentrated on Scopus (Elsevier's abstract and citation database), Engineer Village, CumlnCAD (Cumulative Index about publications in Computer Aided Architectural Design), and ScienceDirect due to their reliability and comprehensiveness. Since the off-site building is a precondition for bringing industrialisation to the market (Gann, 1996), which is necessary for mass customising, the keywords utilised for the search include 'mass customisation' and 'off-site construction'.

The majority of the publications appeared in the database CumlnCAD, which is sponsored by the respective associations ACADIA, CAADRIA, eCAADe, SIGraDi, ASCAAD, and CAAD futures; nonetheless, Scopus and ScienceDirect provide journal articles and book parts connected to our research. Our search has screened 1.165 academic publications consisting of 1,067 conference papers in CumlnCAD, 88 articles and books in ScienceDirect, 20 papers and articles in Scopus, and 10 articles in Engineering village. The articles were screened in the second step by deleting duplicated papers, review publications, and low-relevance articles. The initial filtering was done with the databases' filtering tools, and 85 items were deleted. Reading the abstracts of the remaining 1,080 papers were used to review them.

The publications on the news, brief messages, and reviews were deleted in the second filtering. Likewise, items not dealing with mass customisation housing (for example, walls, shells, and interior fittings) were eliminated. An extra 1,070 items were deleted in total, resulting in the remaining 10 articles we present here. In the third step, the remaining ten papers were methodically classified and analysed into three parts: 1) levels of client involvement, 2) mass customisation categories, and 3) mass customisation method. The final article selection includes book chapters, journal articles, and conference papers. Lastly, in phase four, the categorised articles are analysed and compared in order to answer our research questions.

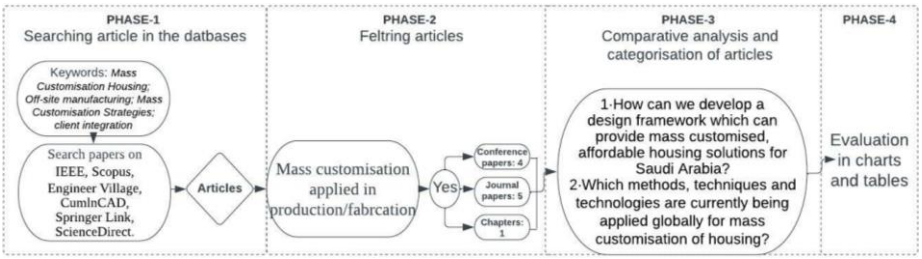

Figure 1. Flowchart of the systematic review process.

4. MASS CUSTOMISATION METHODS, TOOLS AND TECHNIQUES

This section will describe ten articles, summarising them in a comparative table [Table 1]. It includes several categories, such as MC design, MC type MC, MC applied tool, MC methods, materiality, software and level of client involvement. The MC design category was used to compare how each paper addressed the MC solution. The MC category type was used as a key component in determining the complexity or simplicity of clients' participation in their MC initiatives. The MC tool category was utilised to define the strategy research each project took, ranging from a single element to a complete complex. The MC methods category was used to define the various construction methods utilised in each study, ranging from pre-fabrication to mix customisation. This research looked into the material category to investigate the possible use of innovative materials. The software category was chosen with the goal of discovering new software that could be applied in our future research, as well as the possibility of using multiple software in order to speed up the design process. The level of client involvement category was used to determine the available options of client involvement throughout the design process as well as in each design phase.

Kolarevic and Duarte (2019) noted that one of the crucial points of MC is the neglected social aspect which highlights the lack of cultural characteristics considered in MC. Their MC method enables parametric design and digital fabrication of a table by using an interactive website which allows clients to determine their own desirable individual designs. They suggested the use of local materials to reduce construction costs. Depending on the MC processes employed, structure, enclosure, and partition components may be produced to varying degrees of automation utilising digital fabrication and robotic assembly.

Figure 2. Various m Table designs were created by customers using a mobile phone app.

Yuan et al. (2018) developed an adaptive strategy for prefabricated buildings using Building Information Modelling (BIM). The article explains in detail how to solve the problems of manufacturability and assembly of planned systems. Their methodology merges prefabricated dwellings with BIM-enabled parametric design. According to them, Design for Manufacture and Assembly (DFMA)-oriented parametric design needs to be improved regularly to be implemented. Through DFMA-oriented parametric design, the researchers concluded that incorporating domain experience from the manufacturing and assembly stages can increase the success rate of the design.

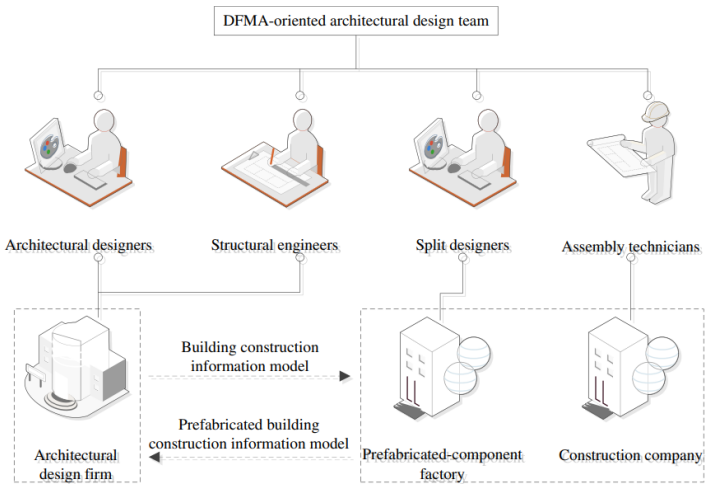

Figure 3. DFMA-oriented parametric design development for prefabricated buildings.

Gazel et al. (2018) designed a partial model using MC for large-scale housing, focusing on principles such as variability, flexibility, and prefabrication. Their methodology includes a modular, parametric system set up in a BIM modelling environment. It allows different spatial arrangements and simulates environmental comfort and construction costs (Figure 3). Their

proposed platform also allows client-designer interaction. The software used in their study is Rhinoceros/Grasshopper.

Figure 3. The adaptable layout of a parametric modular system.

Marchesi et al. (2017) suggested adopting a mass customisation method for prefabricated timber frame panel housing, focusing on robustness and flexibility. Their methodology employs developing a so-called Axiomatic Design tool (AD), a systematic approach to examining concepts and efficiently delivering customisable solutions (Figure 4). Axiomatic Design is a high-value design approach since it lowers the number of alternative beginning designs to one while using limited resources (Benavides, 2012). The sublayers of walls, windows, floors, and roofs are made of standardised modular panels built into spatial modules based on standard board sizes. These panels can generate a variety of spatial arrangements and can be simply dismantled and replaced without affecting nearby components. The software used in their study is AD.

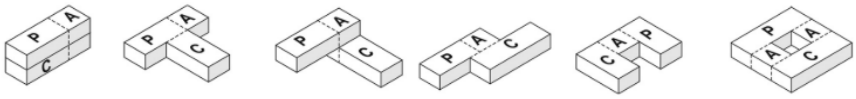

Figure 4. Variation of configuration space moulding by using Axiomatic Design.

Ma and Ameijde (2022) described the criteria for an adaptive modular building system and a multi-objective optimisation process for high-rise constructions. They encourage combining spatial and structural systems; otherwise, workflow conflicts may occur. Their research suggests full customisation. They utilised the Rhino/Grasshopper plugin ‘Wallacei’ to develop different apartment configurations based on diverse lifestyle preferences. Showkatbakhsh (n.d) used ‘Wallacei’ to run simulations using

highly detailed rational tools as well as various complete selection methods, including algorithmic clustering, to help users better understand their evolutionary simulations and make more informed decisions throughout the process. It comprises specifying the design challenge, executing the evolutionary algorithm, analysing the results, and picking the required solutions for the outcome. Once a simulation has been finished, users can choose, rebuild, and output any phenotype from the population. Figure 5 presents assemblies of their 'kit-of-parts' system that is used for all buildings, which can be altered and customised to meet the needs of various occupants. Prefabricated components are assembled onto in-situ concrete cast core elements, which serve as the primary load-bearing structure.

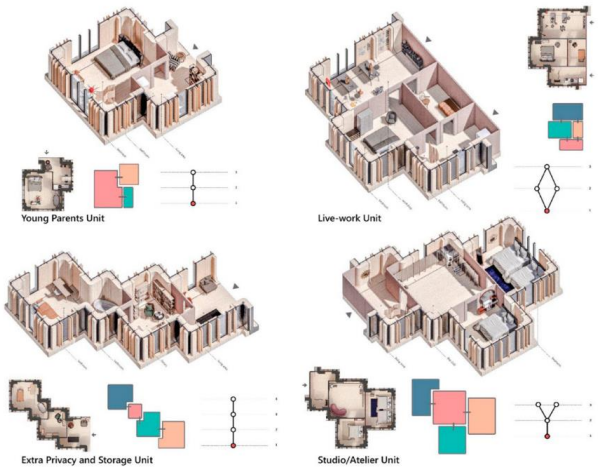

Figure 5. Varied spatial modular shows the flexibility in arranging the sizes

Formoso et al. (2022) attempted to standardise a product that provides affordable accommodation for developing nations (Figure 6). Their methodology is based on an assemblable modular system. Their research focused on small businesses and the MC approach they applied. They found out that the interchangeability of parts of an assembly can lead to various end products implementing MC in affordable house-building projects. Moreover, additional customisation choices were offered in the earlier design stage for consumer involvement in the design. Consequently, the construction firm defined customer order decoupling points in accordance with design phases and client engagement.

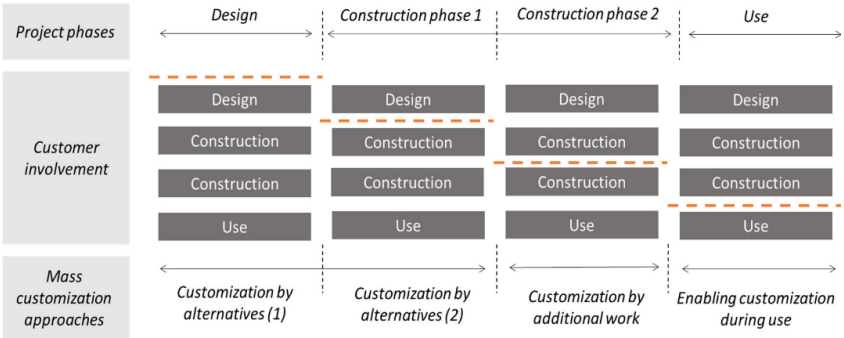

Figure 6. A mixed MC strategy to support customisation

Anane et al. (2022) suggested a modular building framework for design and production. They offered discrete design (DD) as a strategy for MC. They showed how a BIM-driven discrete design method might be used in conjunction with computational design to create modular structures. Their methodology is based on off-site fabrication construction supported by BIM (Figure 7). They suggested a modular system which includes plumbing. Furthermore, off-site manufacturing will use robotic arm cells that can perform cutting and assembly tasks.

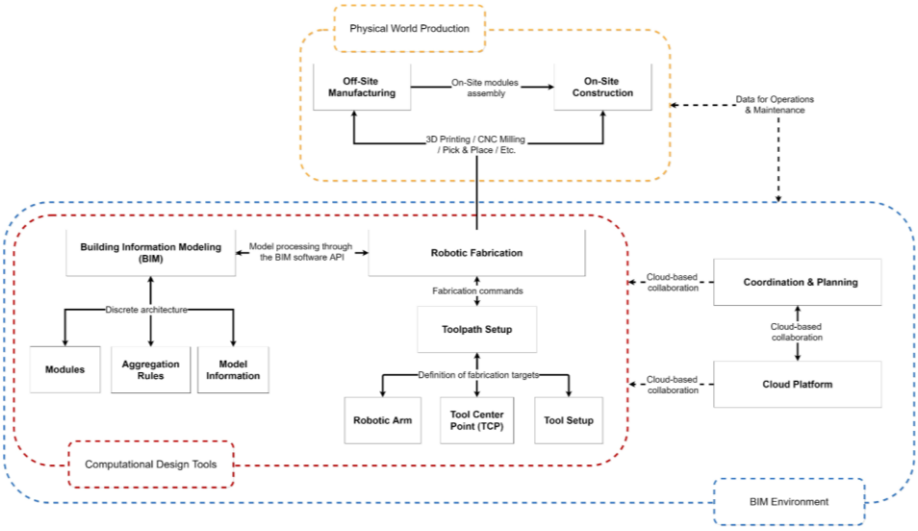

Figure 7. A framework of the DD for modular construction driven by BIM design

Alwisy et al. (2018) presented a systematic methodology for automating the design and fabrication of modular, wood-framed residential buildings based on the platform framing construction method. Building information modelling (BIM) was implemented to facilitate design

automation and drafts for manufacturing. They developed the tool Modular Construction Manufacturing Pro (MCMPro), which generates sets of shop drawings and material take-off lists needed for framing module walls, floors and ceilings ready to be used for the production line (Figure 8).

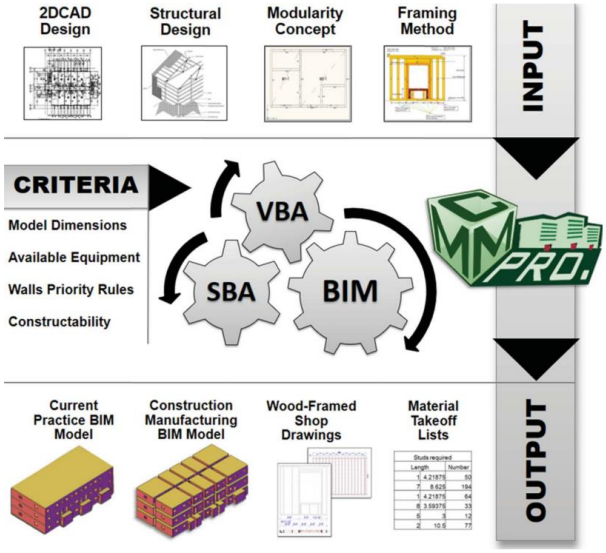

Figure 8. A methodology of the design process

Bakhshi et al. (2022) developed a BIM-related algorithm that allows assembly and customisation in high quality (Figure 9) as well as the participation of the client in the building configuration process based on assembly limitations. They claim that compared to the current strategies offered to implement prefabricated construction, their 'Prefabricated Information Model' provides marketing experts with a product and building-oriented understanding.

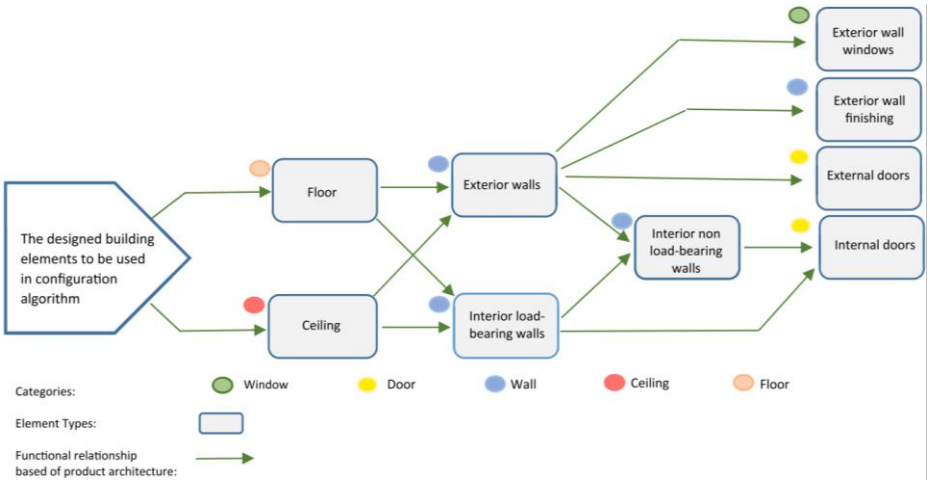

Figure 9. The notion of housing configuration algorithm and choice limitations

Wang et al. (2022) proposed a 'skeletal' parametric scheme for generating building layout variations to optimise a performance-based design (Figure 10). Their skeletal parametric scheme tool was used to generate building layout configurations. It can create plan/construction variations utilising a collection of skeletal lines based on numerous architectural features aligned with parameters like sidewalks, space, and setback regulations. They claim that using parametric models will optimise the design and increase the overall construction quality providing designers with various design possibilities. The software used in their study is Rhinoceros/Grasshopper.

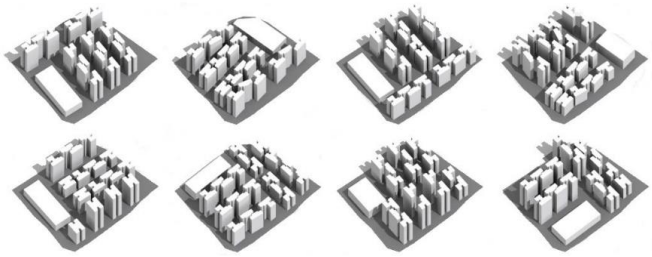

Figure 10. Variety building layout 'skeletal' parametric scheme

5. Findings

Our findings are collectively illustrated in Table 1. Consequently, we can observe that MC interactive products should not be fully customised, and the level of customisation could be between customised standardisation and tailored customisation (Kolarevic and Duarte, 2019, Rocha et al., 2016). The

three primary deciding factors—time, cost, and building quality—are also considered advantages of modular construction. The modular building technique is a crucial breakthrough that promises to provide the construction industry with contemporary ways to build dwellings quickly and effectively to satisfy demand. Due to the higher initial costs needed during the planning and design phases, which were out of the reach of conventional builders, the cost was frequently perceived as a barrier to off-site activity (Young et al., 2020). Similarly, the majority of recent studies have shown that parametric tools may help the MC process by reducing the design process time and data storage (Kolarevic, 2015). (Kolarevic and Duarte, 2019, Rocha et al., 2016, Gazel et al., 2018) noticed that the simplicity of design for MC is essential. Visualisation and simulation appear to be of great importance in the majority of studies because it increases clients' satisfaction. MC helps to reduce construction time due to efficient workflows and doesn't rely on weather conditions (Kolarevic and Duarte, 2019, Rocha, 2016). OSM housing approach mainly facilitates the construction process to occur concurrently, reducing the time necessary for the construction, cost and quality (Seidu et al., 2021).

In general, we have identified two types of MC: full customisation and part customisation (Figure 11). Full customisation allows the client to be involved in the entire design process, while part customisation tolerates the client to be involved in the segment design process customisation is limited. Based on client preferences, manufacturers can provide a degree of flexibility for users in the design, from simple to complex. Client involvement can take place in different ways and starts from pure standardisation, segment standardisation, customised standardisation, tailored customisation and pure customisation, as shown in Figure 12.

TABLE 1. The ten articles are analysed on the side of MC design and optimisation.

Mass Customisation design	Type of MC	MC tools	MC method	Material	Software	Level of client involvement	Type of article	Reference
Building a modular model in mass housing scale with principles in terms of variability, flexibility, and prefabrication	Part Customisation	Parametric Modelling	Prefabrication Modular Model	Steel Frame	Grasshopper	Choice Options	Conference	Gazel et al. (2018)
Adopting the mass customisation of prefabricated panels housing	Full Customisation	Systematic Approach.	Prefabricated Housing	Timber	Axiomatic Design (AD)	Full Involvement	Journal	Marchesi et al. (2017)
Parametric provides a viable method to produce building layout configurations.	Part Customisation	Parametric Modelling	Analysis of Two Cases Design Optimisation	N/A	Grasshopper	Layout Variations	Conference	Wang et al. (2022)

An off-site robotic prefabrication proposal for a modular home using discrete architectural ideas	Full Customisation	Discrete Design.	Discrete Aggregation Tools	Composed of Wooden Parts Interlocked	BIM	Full Involvement	Conference	Anane et al. (2022)
Using interchangeable elements of a fully prefabricated system of modular building	Full Customisation	Kit-of-part' Systems Genetic Algorithm	Panel Systems	Composition of in-situ cast concrete and precast elements	Wallacei Plugin	Full Involvement	Journal	Ma and Ameijde (2022)
Practical integrated methodologies for implementation in the OSC industry, combined with a design framework	Part Customisation	Parametric Modelling	Prefabrication	N/A	BIM	Choice Options	Journal	Bakhshi et al. (2022)
Design for Manufacture and Assembly (DFMA) into the design of prefabricated buildings	Full Customisation	DFMA-Oriented Parametric Design	Prefabrication and Assembly Method	Composition of off-site cast concrete and precast elements	BIM	N/A	Journal	Yuan et al. (2018)
Standardise a product of affordable accommodation projects in developing nations has been challenged	Part Customisation	Analysis of customer demand for customisati on	Mixed Customisatio n Levels	Traditional Building Technologies	N/A	Custom Choice	Journal	Formoso et al. (2022)
Design parametric goods with increased functional performance and customer satisfaction	Part Customisation	Parametric Design	Prefabricated Housing	N/A	N/A	Dialogue Options	Book	Kolarevic and Duarte (2019)
BIM-based automation of design and drafting for manufacturing panels for modular buildings	Full Customisation	Modularity Approach	Panel systems	Wood Panel	BIM	N/A	Journal	Alwisy et al. (2018)

The tailored customisation could provide design selection, layout choices, finishing, materials selection, and catalogues. Tailored customisation could be applied conventionally by a face-to-face meeting with the client or online by giving options to the client, such as an open design involving, design selection, layout choices, dialogue, finishing, materials selection, and catalogues.

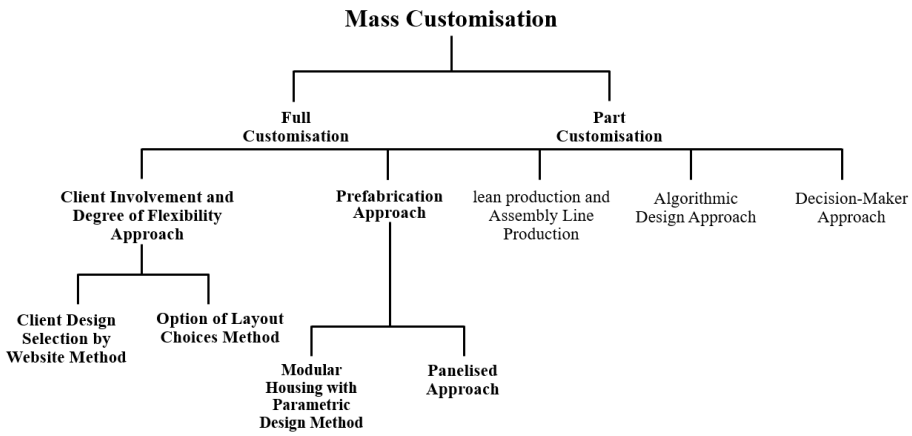

Figure 11. Categories of Mass Customisation made by the author.

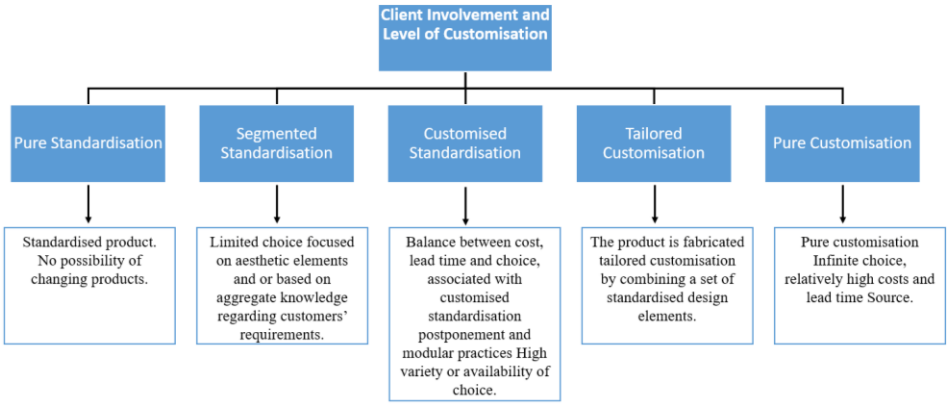

Figure 12. Client's integration level of mass customisation made by the author.

Consequently, we propose a novel, parametric MC method, as shown in Figure 13. It allows the involvement of both designer and client via an interactive interface linked to floor plans, room sizes, elevations and courtyards. All data will become available to the designer via a data cloud; thus, he can start the design process. The interaction will continue in all design and construction phases. The proposal has made an easy platform to be accessible for architects and non-architects to be used without complexity. For instance, in the first stage, an interface will be provided on a website which would be easy for anyone to use. The page interface will provide basic information about the plot's dimensions. The clients can determine the number of stories, rooms and the courtyard. In the second phase, all data will be used for processing and creating plans supported by an algorithm. The date

will be made available to the designer via a could database. The last phase will include alterations and finetuning of the drawings up to completion.

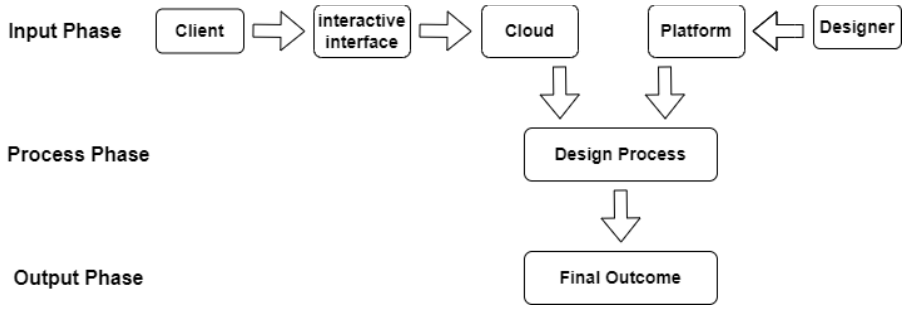

Figure 13. Arthur proposed a methodology for MC.

6. Conclusion

This paper contributes to the Saudi vision by using such technology with building structure elements. It focuses on using technology software with offsite structure elements that will help the high demand of housing in the country. Looking at our findings, one can see that MC was difficult to achieve up to recent years. It was implemented by conventional methods, which are inefficient due to the required time for data processing and labour. However, emerging tools and techniques such as data clouds, smartphones, parametric design and digital fabrication have enabled new possibilities. Client involvement may occur even in preliminary design stages via internet browsers or phone applications.

Furthermore, there is a plethora of websites and design communities where designers exchange their knowledge, designs, and scripts. In this regard, Hippel (2005) argues that clients who design can develop precisely what they desire instead of depending on producers to function as their (sometimes very inadequate) agents.

Additionally, parametric tools are among the most effective ways of achieving MC. Kolarevic (2015) suggests that a customisable mass house should be parametrically specified, interactively planned (through a website or an app), and digitally built, employing file-to-factory procedures in order to achieve ‘real’ personalisation.

Combining the structural system with the spatial design system of a house through parametrisation is an efficient way to obtain and optimise MC

production. There were numerous implementations of MC in the last decade, which did not engage with layout and structural systems but only allowed client involvement on exterior applications and finishing materials. As a consequence of our analysis, we identified the need for a novel file-to-fabrication framework utilising parametric tools and responding to the stakeholders' needs and allowing their involvement to participate creatively in the design process.

In our future work, will focus on developing a tool which will allow the involvement of the client in the design process alongside the designer, aiming for a faster and more efficient designer-client collaboration.

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CONSTRUCTION BASED ON MAN-MACHINE COLLABORATION

A case study of a bamboo pavilion

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Abstract. With the development of advanced digital design approaches and mechanical facilities, architectural intelligence liberates conventional construction from conventional paradigms. Computational design and digital fabrication have achieved progress in space innovation, construction efficiency, and material effectiveness. However, those high-tech manufacturing techniques are not widely available in developing countries, where the locals used to carry construction experience from age to age in a nonacademic way. This study explored a collaborative workflow of complex structural design and machine-aided construction in Chinese rural areas. First, we designed a bamboo pavilion parametrically in an irregular site on a hill. Second, its primary structure was optimized based on determining critical load and earthquake resistance to meet local building codes. Then, before material processing, every bamboo component was numbered by algorithm, with its location and morphological data of length and radian calculated accurately on the construction drawings. In the transitional process from the conventional paradigm by experience towards man-machine collaboration, local workers' manual techniques helped minimize construction errors and improve details, which were not adequately predicted and considered beforehand. This study case suggested that respective advantages of both traditional and digital modes should be integrated and balanced based on collaboration between local construction workers and professional researchers, especially as a social role for future vernacular architecture practice.

Keywords: *Parametric design; Machine-aided; Bamboo material; Collaborative construction.*

ملخص. مع التطور المستمر فى مناهج التصميم الرقمي المتقدمة والمرافق الميكانيكية، أصبح الذكاء المعماري محررا للبناء التقليدي من النماذج التقليدية. وقد حقق التصميم الحوسبي والتصنيع الرقمي تقدمًا في الابتكار الفراغى وكفاءة البناء وفعالية المواد. ومع ذلك، فإن تقنيات التصنيع عالية التقنية تلك ليست متاحة على نطاق واسع في البلدان النامية، حيث اعتاد السكان المحليون على نقل خبرة البناء من عصر إلى آخر بطريقة غير أكاديمية. تعمل هذه الدراسة على استكشاف سير العمل التعاوني للتصميم الإنشائي المعقد والبناء بمساعدة الآلة في المناطق الريفية الصينية. وقد قمنا أولا بتصميم جناح من الخيزران بشكل بارامترى في موقع غير منتظم على تل. ثم تم تحسين هيكلها الإنشائى الأساسي بناءً على تحديد الحمل الحرج ومقاومة الزلازل لتلبية قوانين البناء المحلية. بعد ذلك وقبل معالجة المواد، تم ترقيم كل مكون من الخيزران بواسطة خوارزمية، مع حساب موقعه وبياناته الشكلية للطول والراديان بدقة على رسومات البناء. وأثناء العملية الانتقالية من النموذج التقليدي من خلال التجربة إلى التعاون بين الإنسان والآلة، ساعدت التقنيات اليدوية للعمال المحليين في تقليل أخطاء البناء وتحسين التفاصيل، والتي لم يتم التنبؤ بها بشكل كافٍ ومراعاتها مسبقًا. اقترحت حالة الدراسة أن المزايا الخاصة بكل من الأنماط التقليدية والرقمية يجب أن تكون متكاملة ومتوازنة بناءً على التعاون بين عمال البناء المحليين والباحثين المحترفين، لا سيما كدور اجتماعي لممارسة العمارة المحلية في المستقبل.

الكلمات المفتاحية: *التصميم البارامترى، التصميم بمساعدة الآلة، مادة الخيزران، الإنشاء التعاونى .*

1. Introduction

In an age of the intelligent building industry (Ghaffarianhoseini, Berardi, AlWaer, et al., 2016), architects are increasingly focused on improving design and construction patterns to shape new living styles and relieve environmental burdens. However, compared with the development of advanced building industries and construction technologies applied in modern mage-cities, villages in rural areas in China face a decline in conventional construction (Vellinga, 2006). On the one hand, modern buildings widely use industrial materials like concrete, glass, and steel, which dominate the overwhelming majority of the local construction market. On the other hand, local craftsmen full of conventional techniques in wood, bamboo, and soil gradually lose their competition in terms of construction efficiency, durability, and ornamental. Those vernacular architecture styles are relatively less fashionable and delicate than modern approaches like digital design and robotic fabrication, which have been proved practically in advanced architecture laboratories worldwide.

This study discussed an exploratory practice of balancing conventional construction and machine-aided fabrication. Professional architects led the design and construction process with local workers' participation. The performance of such a collaboration mode was observed and evaluated through a hands-on project on a bamboo pavilion (Figure 1), whose design process first started in 2019 and is currently under regular use. The reasons why selecting bamboo as the primary material for the pavilion lie in three aspects: 1) as a natural and organic material, using bamboo aims to respond

to rising worldwide topics of sustainability and environmental protection, significantly contributing to the goal of carbon neutrality (Xu, Xu, Zhu, et al., 2022); 2) A raw bamboo rod has excellent bending performance (Chen, 2016), whose deformation happens in proper pressure and shape reinstatement is automatic after removing the external forces. So it is considered suitable and competent in innovative structure design to achieve material potential; 3) there has been a long history of bamboo utilization in China, particularly in some rural areas where bamboo once supported the local economy and society in ancient times.

Figure 1. Bamboo Pavilion (Anji, China, 2021).

2. Methodology

Typically, local bamboo craftsmen inherit manual techniques and specific prototypes of raw bamboo construction from the older generations without any modern professional training in academic institutions. They are full of practical experience in building small-scale and simple structures through living practices and activities for several decades. However, such non-standard practices have gradually failed to compete with modern machine-aided construction based on bamboo composites (Sun, He, and Li, 2020), produced and commercialized in construction factories. Compared with conventional construction, the latter shows superior and stable performance in design complexity, fabrication automation, and even architectural intelligence. The differences between the two approaches are listed in Table 1, according to the actual conditions of this project.

TABLE 1. Comparison between two ways of design-construction workflow.

	Conventional Construction	**Machine-aided Construction**
Practitioner	·Local people	·Professional staff
Material	·Raw bamboo	·Bamboo composite
Cost	·Low	·High
Design Process	·specific prototypes ·Simple shape ·Small scale	·Computer-aided parametric design ·Complex shape ·Large scale
Construction process	·Situated construction ·Manual techniques	·Pre-frabrication ·Mechanical assembly
Advantages	·Experienced ·Real-time adjustment and compensation	·Automatical calculation, record, and adjustment ·Accuracy control through visual sensors
Disadvantages	·Lack of scientific summary and data ·High error rate	·Lack of sufficient experience ·Machine availability

We took the challenge of making a joint effort with the engagement of bamboo craftsmen. Though there were unpredictable barriers throughout the design and construction process when both sides had no similar collaboration experience, it was reasonable to take advantage and optimize the entire workflow in the notion of nonlinear thinking (Knyazeva, 1999) to deal with the uncertain and dynamic factors. It did not mean to invite local people to help build a bamboo pavilion under our commands but to invite them to devote their previous experience to semi-automatic construction using raw bamboo.

3. Project Implementation

3.1. STUDY AREA

This program was in Anji County, Zhejiang Province, China (Figure 2). Anji has a manual tradition of bamboo production and tectonic, which supports the backbone industry and primary source of social finance income. Due to limited plasticity, raw bamboo is seldom favored in the local construction market compared with industrialized materials. We were entrusted with supervising the whole design and construction program on a small hill full of bamboo and tea trees, where a pavilion was planned to provide visitors with an outdoor space for entertaining activities like tea breaks.

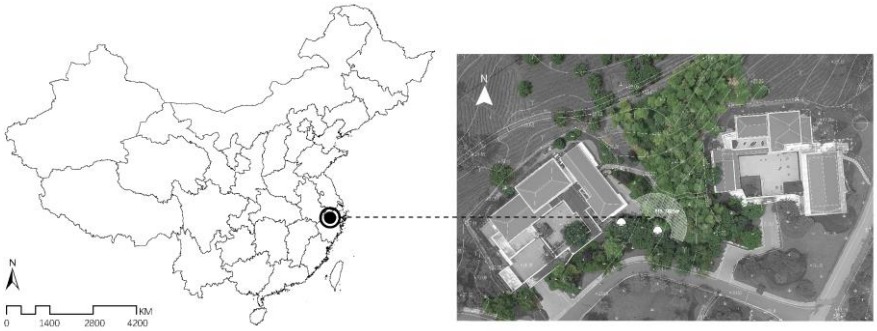

Figure 2. Location of Anji, China, and site conditions.

3.2. PARAMETRIC DESIGN

The design was intended to create a flowing curve shape in response to the natural and free-form surroundings (Figure 3). The vertical facade was open without envelopes to show an affinity with nature. Besides, the space for activity was sheltered by a gently slanted crescent-shaped roof, complying with the site's sloping terrain. In addition, we tested the structural unit of bending bamboo to explore the flexural capacity of raw bamboo with its loading action. As a result, almost each component form was various in radian and length, increasing difficulties for later fabrication.

Initially, unmanned aerial vehicles collected geographic information beforehand with image data converted into virtual landforms. The primary design ideas were virtually expressed in a digital model through architectural software Rhinoceros, and physical force was roughly simulated in the Grasshopper plug-in. Through a digital model, the geometric pattern of every bamboo component was supposed to be calculated and diagrammed precisely in an ideal case. However, the raw bamboo material behavior could not be simulated and evaluated accurately either in the existing software applications or tested as a scale-down physical prototype in real time. Such a dilemma was explained in several aspects (Crolla and Goepel, 2020): 1) the flexural capacity depended on a series of raw bamboo properties of specie, age, height, diameter, and internode length et al., while both single effect and composite quality of those bamboo properties on the flexural capacity had not experimented sufficiently beforehand in the laboratory; 2) bamboo behaviors were further influenced by the bending machining of processing equipment, environment (air temperature, humidity) and techniques (drying temperature, applied bending-force et al.), whose potential performance under bending moment were sometimes uncontrollable; 3) there were realistic limitation of the construction period and budget so that a cost-efficient approach was preferred. Thus, increasing uncertainty might have

stopped the project midway if decision-makers had kept thinking about strictly automatic machine-aided construction. Finally, we decided to give up the attempt of complex bamboo material testing work in the laboratory and then searched for help from the local bamboo craftsmen on site.

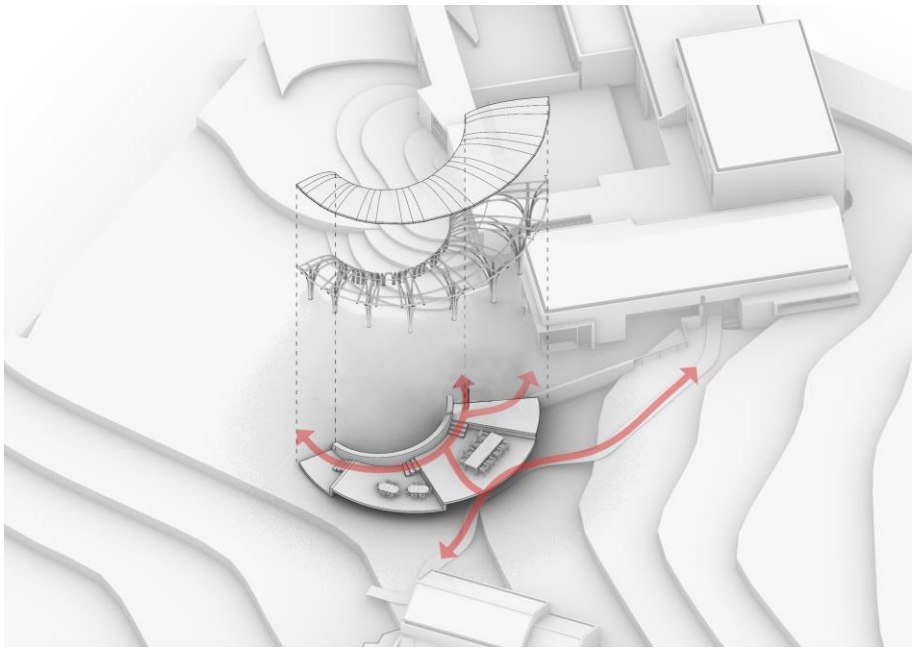

Figure 3. Open space organization of the bamboo pavilion on a hill.

In the design generation stage, several alternatives were generated by controlling spatial parameters (Grobman, 2010.), which realized continuous and delicate adjustment according to the functional, aesthetic, and visual criteria. The craftsmen's role in the design process was their evaluation after completing the primary generative design stage. They screened the embryonic form of every bamboo component on the drawing for potential material suggestions on structural stability. Their verbal instructions were indirectly coded as empirical parameters to assist design evaluation and virtual simulation. The critical point was to control bending bamboo components' curvature to ensure their material behaviors. In case a bamboo rod was bent beyond its capacity, unpredictable cracks began to appear in the weak part of the rod where the external force was concentrated (Askarinejad, Kotowski, Youssefian and Rahbar, 2016). It was suggested that once the weakness of cracks happened in the bending process, the bamboo rod should be deserted; otherwise, it would lose its resistance to bending, and the crack might grow broader and larger under loads of roof, snow, and other environmental factors. This optimization advice drove the

designers to adjust the previous scheme to ensure structural stability before fabrication.

3.3. FABRICATION AND ASSEMBLY

As for the selection of bamboo material specification, local bamboo on the left side of Figure 4 was around 6 cm in diameter, with 8 cm on the right side. As is shown in Figure 4, the natural form of bamboo varies with internode, thickness, and diameter, which determines the high probability of machining error. Though bamboo of 8 cm in diameter has been more commonly used in the local area of Anji, we finally chose the thinner bamboo of 6 centimeters under the guidance of the craftsmen after the pre-production attempt. The reasons were considered in the following aspects: First, bamboo is commonly wide at the base and tapered at the top, so it cannot be standardized like error-free building components fabricated in the factory. The morphological character of 6 cm in diameter is relatively more consistent than the 8 cm in diameter bamboo, which has its own advantages of accuracy control. Secondly, the thinner bamboo is, the more flexibly it performs under pressure. As a result, bamboo of 6 cm was tested to not only meet the requirements of C-shaped bending but also preserve a strong bearing capacity than thicker bamboo. This experience of selecting the appropriate bamboo type was well gained by the craftsmen and applied before on-site fabrication.

Figure 4. Raw bamboo on site after pre-treatment.

Human-machine collaboration (Liang, Wang, Kamat and Menassa, 2021) improves productivity, efficiency, precision, and safety in construction factories. Thus, we decided to pre-fabricate bamboo components in the factory by thermal bending facilities and then transported them to the construction site. The factory provided a stable environment for bamboo processing, replacing conventional in-situated fabrication. We found that such a primary machine-aided processing mode had grown maturely in the local industry, but there was still a significant gap from pre-programming to adaptive manipulation. Especially in the assembly stage, manual assembly played an irreplaceable role in dealing with complex deformation problems.

In Figure 5, a number rule was created in the cross-section of the bamboo pavilion. The entire structure consisted of 8 units of different sizes, each composed of 36 bamboo rods. Except for those total of 8*36 (288) main bamboo rods, there were sub-rods functioning as the connection between the two units. The petitionary work of numbering and locating hundreds of bamboo rods was executed through computer actuation, releasing the burden of workers to visually identify a particular bamboo rod.

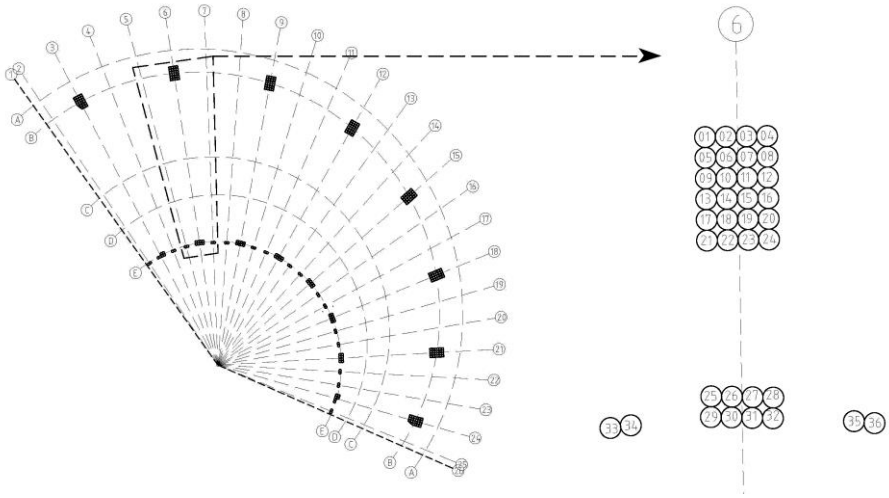

Figure 5. Number rule of a structural unit.

Since bamboo building construction is characterized by a structural frame approach similar to traditional Chinese timber frame design and construction (Sanjeev, Amit and Aninash, 2017), the structure system organized different components from pillars, main beams, secondary beams, skew beams, and purlines as a whole (Figure 6). Among them, pillars and main beams were assembled as the first level of the pavilion skeleton, then strengthened by the secondary and skew beams to bear the roof load partially. In addition, purlines linked the first and secondary level structure together, with tiny

bamboo branches covered at the top. The flexural property of bamboo led to potential shifts in location during each level assembly, whose second deformation was monitored by laser scanners in real-time. Since there were quantities of bamboo rods, it was impractical to sense (Vasey, Maxwell and Pigram, 2014) the location and dynamic form of every component once it had been fixed, which might have requested more time and data calculation. Therefore, an error-tolerant but flexible solution was proposed to examine the construction precision by sensing every structure unit of 36 bamboo rods as a cluster. The errors of clusters were compensated by the later part correspondingly.

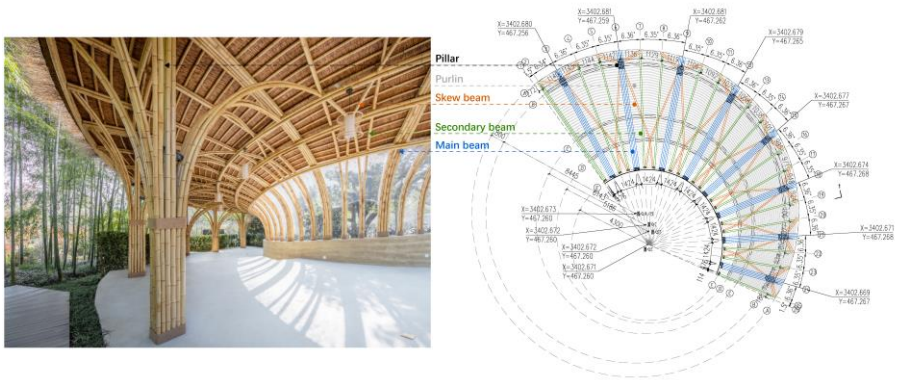

Figure 6. Bamboo structure system.

Overall, the optimized workflow and division of hybrid labor of workers and architects were illustrated through seven steps in Figure 7. Craftsmen's evaluation and manual assembly were preserved as the base of workflow, but multiple devices of sensing and computer algorithms were equipped to help standardize the assembly work more precisely and efficiently. Smart devices played a role in specific conditions to assist visual inspection and calculation during in-situ assembly. For example, the location information of the two ends of a bamboo rod was generated in three dimensions in the digital model so that workers could assemble the rod by merely finding two destinations. In addition, since one end of a bamboo rod was fixed on the ground as a structural foundation, potential shifts of the other end were considered the primary source of errors. Therefore, the compensation process was simplified to adjust the structure by comparing finite details with their presupposed location.

However, it was tough to conduct the entire process of balancing the virtual model with the actual construction situation, similarly to autonomy and digital twins in the manufacturing industry (Rosen, Von Wichert, Lo and Bettenhausen, 2015). The main difficulty lies in the ability of system

adaption. First, bamboo behaviors during construction had to be supervised to ensure their practical capabilities and precise location. Though the computer vision system helped a lot, we still found that manual fabrication was more adaptive to bamboo's natural and original properties. Workers were good at predicting material performance through their experience and hand feelings, while few current artificial neural networks have been trained to gain such an ability to simulate bamboo behaviors. Second, conventional construction of low technology has a relatively high tolerance to structure distortion, which acts as resilience to dynamic changes. Such a significant departure from standard was hard to process in the computer and generate instructions automatically. As a result, the construction data recorded and saved in a unique project may not be applied in the other models fittingly.

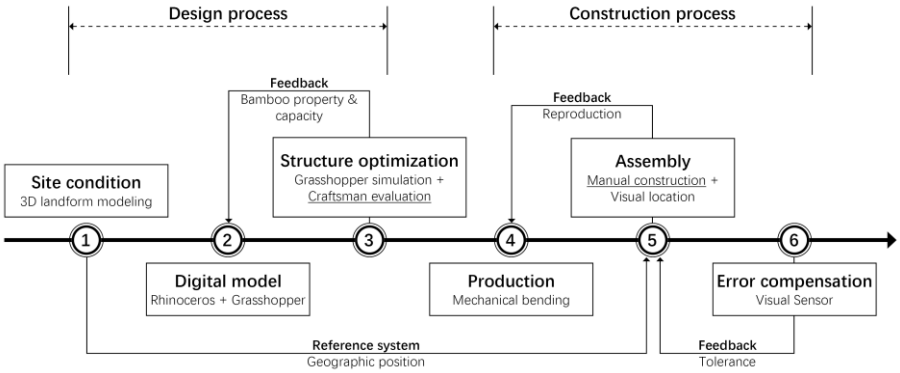

Figure 7. Man-machine collaboration workflow in the bamboo pavilion project.

4. Discussion and conclusion

This case study pointed out that advanced machine and robotic intelligence improved the engagement of both architects and locals in the design and construction process, where we could generate design alternatives and manage the entire process through the executive control system. During the project, making an optimal decision meant thinking from multiple perspectives, including material performance, precision management, and budget control under time and financial restrictions. These factors put different weight on the rural areas where real-world conditions were usually worse than expected. Therefore, construction precision was not the final goal in intelligent fabrication, while there should also leaving space for workers to reach their potential.

We appreciated the efforts multiple groups have made in such a transition in the construction process. Involving the participatory and collaborative aspects of the workflow seems like a compromise to conventional

construction, which is considered time-consuming and coarse. In the digital augmented design and construction trend, traditional craftsmen still have much wisdom that should not be neglected and replaced. Imitating their tectonic behavior (Brugnaro and Hanna, 2018) and learning their thinking model of evaluation, prediction and decision-making seem challenging but reasonable for more intelligent adaptive robotic fabrication and construction. Different from industrial manufacturing, it is proven that conventional wisdom should not be ignored in intelligent construction.

Acknowledgments

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MOISTURE-HARVESTING LIZARD SKINS AS AN INSPIRATON FOR PERFORMATIVE BUILDING ENVELOPES IN ARID CLIMATES

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Abstract. Research on shape-shifting adaptive architectural skins has recently focused on bio-inspired programmable materials. Only a few studies however examine the microstructure of living organisms, especially in terms of morphological adaptation in harsh climatic conditions. This paper explores the microstructure of moisture-harvesting lizard skins, specifically the Trapelus species of the Agamidae family in North East Africa, as an inspiration for programmable materials in adaptive building skins in the arid climate of Egypt. The paper investigates the ability to improve the durability and morphological capabilities of programmable materials based on surface formation, utilizing digital fabrication techniques. A series of physical experiments were conducted on different samples of 3D printed wood filament under several humidity conditions, as a single layer, with textured patterns, and with the addition of potassium chloride as a moisture-harvesting chemical composite. The paper concluded that materials composed of textured patterns and moisture-harvesting chemical composites exhibited the highest moisture retention, therefore leading to advantages in its use in adaptive building skins in arid climates, through a wide variety of design possibilities for performative building envelopes.

Keywords: *Programmable materials, adaptive building skins, hygroscopy, moisture harvesting lizard skins.*

ملخص. ركزت الأبحاث التى تتمحور حول أغلفة المبانى المتكيفة المتغيرة الشكل مؤخرًا على المواد القابلة للبرمجة المستوحاة من الطبيعة والكائنات الحية. ومع ذلك، فإن القليل من الدراسات فقط يعمل على دراسة البنية الدقيقة للكائنات الحية، خاصة من حيث التكيف

المورفولوجي في الظروف المناخية القاسية. تستكشف هذه الورقة البنية الدقيقة لجلود السحالي التي تحصد الرطوبة ، وتحديداً أنواع "الترابيلوس" من عائلة "أجاميدا" في شمال شرق إفريقيا، كمصدر إلهام للمواد القابلة للبرمجة في جلود البناء التكيفية في المناخ الجاف المميز لبلد مثل مصر. تبحث الدراسة في القدرة على تحسين المتانة والقدرات المورفولوجية للمواد القابلة للبرمجة بناءً على تكوين السطح باستخدام تقنيات التصنيع الرقمي. تم إجراء سلسلة من التجارب الفيزيائية على عينات مختلفة من خيوط الخشب المطبوعة عن طريق تقنية الطباعة ثلاثية الأبعاد في ظروف رطوبة عديدة، متمثلة فى: الطبقة الواحدة، والأنماط المنسوجة، وتلك التى تنتج عن إضافة كلوريد البوتاسيوم كمركب كيميائي لحصاد الرطوبة. وخلصت الورقة البحثية إلى أن المواد المكونة من أنماط منسوجة ومركبات كيميائية لحصاد الرطوبة أظهرت أعلى احتباس للرطوبة، مما أدى إلى مزايا في استخدامها في جلود المباني المتكيفة في المناخات القاحلة، من خلال مجموعة متنوعة من إمكانيات التصميم لأغلفة البناء عالية الأداء.

الكلمات المفتاحية: *المواد القابلة للبرمجة، أغلفة البناء المتكيفة، الاسترطاب، جلود السحالى الحاصدة للرطوبة.*

1. Introduction

The latest software and hardware developments in the use of programmable materials in advanced manufacturing processes and workflows have demonstrated several new possibilities for the design and morphology of architectural shape-shifting systems. The ability of certain materials to change shape based on external climatic stimuli such as hygromorphic materials that react to humidity, and thermo-bimetals that react to temperature, has allowed for naturally actuated shape-shifting and self-assembling systems. In our previous research on generating different morphological transformations using the hygroscopic properties of wood (El-Dabaa and Abdelmohsen, 2020; Ibrahim et al., 2020a; Ibrahim et al., 2020b; Aly et al., 2021; El-Dabaa and Abdelmohsen, 2022; Ibrahim et al., 2022), we develop systems that use motion grammars to computationally simulate such transformations that are induced by the deformation of wood as a natural material.

Similar studies have attempted to develop bio-inspired programmable materials and architectural shape-shifting systems (Vazquez et al., 2019). However, very few studies examine the microstructure of living organisms, specifically in relation to their morphological adaptation in harsh climatic conditions. This paper explores the microstructure of moisture-harvesting lizards (Comanns, 2011), specifically the Trapelus Mutabilis and Trapelus Pallidus species of the Agamidae family in North East Africa (Vesely and Modry, 2002), as an inspiration for programmable materials in adaptive building skins in the arid climate of Egypt.

The paper first explores the geometrical and structural configuration of the Trapelus species, and the different morphological patterns, densities, and

protective skin abilities afforded by the size, shape, and relative position of microstructures on its integument (Yenmiş, 2021). A wide range of design possibilities for adaptive building skins are deduced accordingly, with focus on the variety of identified actuation mechanisms such as twisting, twirling, and bending.

Second, the paper explores the adaptation of the lizard species' skin structure to different climatic conditions and its ability to harvest moisture in order to determine the impact on water transfer and wettability. An investigation of the lizard's skin microstructure is conducted (Comanns et al., 2014), including a biomimetic analysis of its semi-tubular longitudinal and latitudinal channels, and the uptake of moisture through its harvesting behavior process. By means of a comparative analysis between planar surface formations and the lizard species' skin formations that consist of a variety of surface extrusions and protrusions (Yenmiş, 2021), the paper concludes different hygroscopically informed morphological characteristics related to retaining water for long durations.

The paper then develops a computational approach to emulate the adaptive and moisture-harvesting properties of the Trapelus species (Yenmis et al., 2016) for adaptive architectural skins. A test case in Cairo, Egypt is used to explore specific parameters and rules for the design and form generation of an adaptive architectural skin in a hot arid environment using Rhino and Grasshopper. By mimicking the lizard species' skin moisture harvesting techniques, a series of design iterations are developed that achieve a variety of morphological transformations and responses under varied environmental stimuli. The results are simulated using performative plugins on Grasshopper to test the environmental performance of the generated iterations and achieve optimal levels of adaptation and durability.

2. Mimicking Lizard Skin

2.1. LIZARD SKINS AND THEIR MORPHOLOGICAL SYSTEMS

The remarkable ability of moisture-harvesting lizards to live in arid environments is demonstrated by different lizards. Lizards exhibit a unique physical property and ability to absorb water by capillarity and carry it for ingestion due to specific skin characteristics. These characteristics include a micro-structured skin featuring capillary tubes between irregular overlapping patterns that facilitate passive and occasionally directed transfer of the collected water. The ecological function of this system is the absorption of water from various sources (Comanns et al., 2016).

The increased wettability of the lizard integument is known as hydrophilicity, which is brought on by chemical characteristics and frequently occurs in conjunction with specific microstructures, as shown in Table 1. Several species of desert lizards belonging to the Phrynosoma,

Phrynocephalus, Trapelus, Moloch, Pogona, Cordylus, and Uromastix genres have been shown to passively absorb water from their surroundings.

TABLE 1. Classification of different wetting behaviour based on different angles and microstructures of lizards (Comanns P. 2016)

classification	wetting behavior	required topography
$0° \leq \theta < 10°$	superhydrophilic	only on rough or structured surfaces
$10° \leq \theta < 90°$	hydrophilic	also on smooth surfaces
$90° \leq \theta < 120°$	hydrophobic	also on smooth surfaces
$120° \leq \theta < 150°$	hydrophobic	only on rough or structured surfaces
$150° \leq \theta < 180°$	superhydrophobic	only on rough or structured surfaces

Different types of the Trapelus Pallidus lizard species display the behaviour of rain-harvesting (Vesely & Modry, 2002), as shown in Figure 1. The species under study are the Trapelus Mutabilis and Trapelus Pallidus species which are from the Agamidae family that is located in arid regions in Egypt (Yenmiş, 2021).

Figure 1. Rain-harvesting posture of the female Trapelus Pallidus (Vesely & Modry, 2002)

The geometrical and structural dimension of such lizard species is accompanied by specific morphological capabilities and potentials, as lizard bodies and skins are covered wholly with different densities and pattern variations. These patterns have different sizes, shapes, and relative positions that vary to facilitate the desired motion of the lizard as well as providing a protective skin. Several biomimetic techniques have been developed to mimic this actuation system utilizing different parameters regarding densities, position, and geometrical shape (Yenmiş, 2021), and to demonstrate the adaptation of lizard skin structures to technical applications (Comanns et al., 2014), as the skin's ability to harvest moisture impacts wettability and water transfer.

2.2. MICROSCOPIC VIEWS

The microstructure of lizard skins is generally known to contain semi-tubular channels in both longitudinal and latitudinal directions. This geometrical configuration enhances the skin to uptake more moisture through the harvesting behaviour process (Yenmiş, 2021). The inner surfaces of the semi-tubular, hinge-joint system's expanded cavity through which the water enters are in contact with fragmented surfaces. Water fills the hinge-joint channels as capillary action draws it down the scale hinge holes, where the greater surface area of the enlarged and convoluted hinge-joint enhances the attracting interactions between the surfaces and water, as shown in Figure 2 (Sherbrooke et al., 2007).

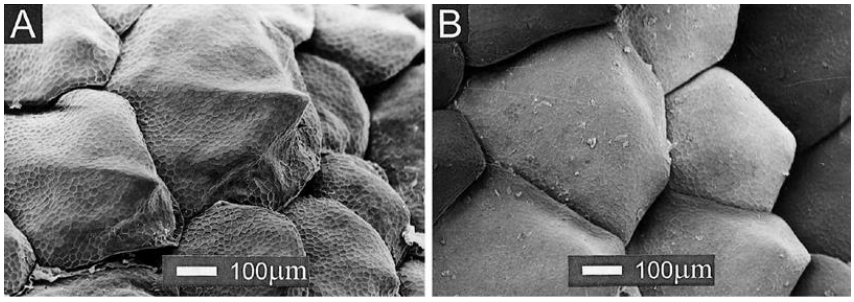


Figure 2. Electron photomicrograph scan of the surface of (A) Trapelus pallidus and (B) Trapelus ruderatus (Vesely & Modry, 2002)

The dispersion of water through several channels across the complete branching network of semi-tubular hinge-joint channels may increase the speed at which water is transported. Water may travel from the lizard body contact surfaces to the head via capillary forces in resistance to the force of gravity (Sherbrooke et al., 2007). In terms of wetting, depending on surface structure and roughness, each liquid-material interaction leads to a different wetting phenomenon, as shown in Figure 3 (Comanns, 2016).

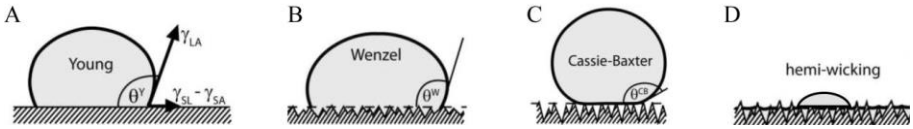


Figure 3. Wetting phenomenon model mentioned by A) Young model, B) Wenzel, C) Cassie-Baxter, and D) hemi-wicking (Comanns, 2016)

2.3. MOISTURE-HARVESTING PROCESS IN MATERIAL COMPOSITES

In arid areas, the extraction of water from air is a promising method of supplying water. Desiccant materials, which have the ability to attract and retain moisture, can help achieve this process, guided by moisture-harvesting

activities and processes in lizard species as an inspiration (Kallenberger & Fröba, 2018). In order to improve the material moisture absorption capability and process of humidity retention, chemical composites and components are applied to catalyze these processes. One of the chemical composites that are significantly known to retain moisture for long duration is Potassium Chloride (*KCl*). The hygroscopic growth factors of potassium chloride against water activity are mapped in Figure 4 (Jing et al., 2017). In the next section, the paper investigates the incorporation of potassium chloride as an additive to 3D printed samples to test the hygroscopic properties of the composite, based on lessons learned from the microstructure and moisture-harvesting properties of lizard skins.

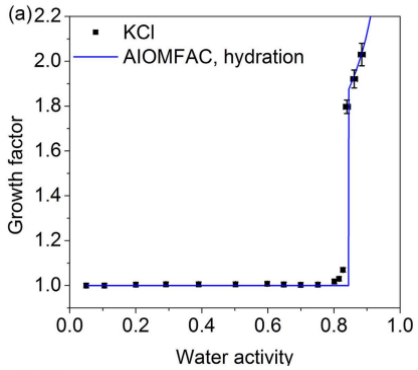


Figure 4. Graph of hygroscopic growth of potassium chloride against water activity (Jing et al., 2017)

3. Computational Implementation

3.1. PHYSICAL EXPERIMENTS

Based on studying the microscopic structure of moisture-harvesting lizard skins, the paper explores the testing of composite materials that mimic this moisture-harvesting behavior. The first phase of this testing implemented physical testing or experimentation of different materials under different humidity conditions. This was conducted using a transparent humidity chamber utilizing specific equipment, including a humidifier, dehumidifier, glue, and a hygrometer.

The samples under study included primarily 3D printed wood due to its hygroscopic properties related to shrinking and swelling based on varying humidity conditions. Wood filaments (40% wood, 60% PLA) were 3D printed for the purpose of this experiment, using a 0.8mm thick nozzle. Three samples with dimensions 5cm x 10cm were tested. These included: (1) a single plain unit, (2) a single unit with extrusion patterns, and (3) a single

unit with extruded pattern and filled with potassium chloride. The three samples were tested in a humidity chamber with dimensions 50cm x 50cm x 80cm, which consisted of a humidifier and de-humidifier to apply and vary specific humidity conditions throughout the experiment.

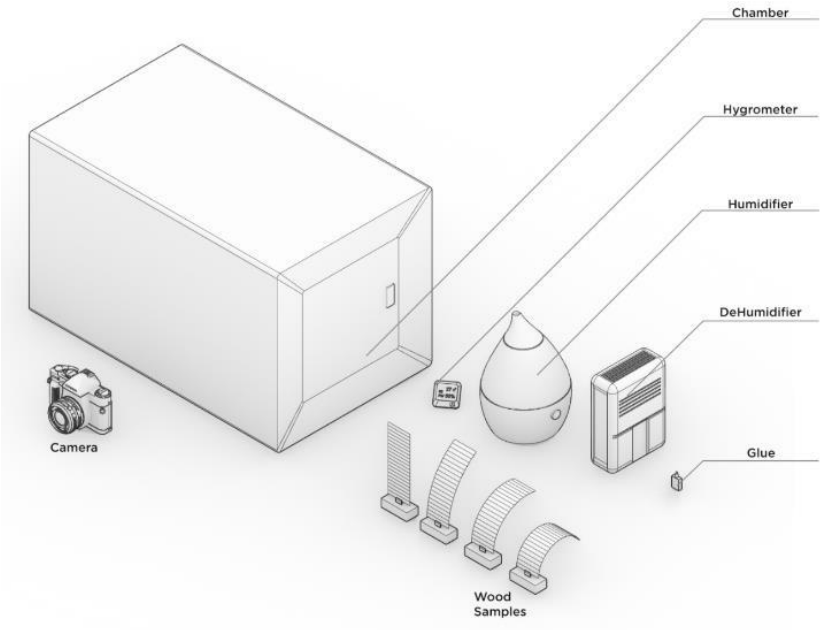
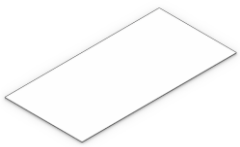
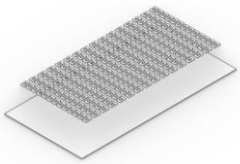
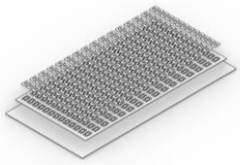


Figure 5. Setup of the physical experiment under different humidity conditions for multiple wood filament 3D printed samples

The experiment started off by designing the samples using 3D modeling tools (including Rhinoceros & Grasshopper 3D). Multiple designs with multiple considerations were developed based on patterns that were seen to mimic the morphological configuration and process inspired by the lizard skin, specifically the Trapelus species. The three types of material compositions were then compared. Based on the results, the input parameters were concluded to identify the suitable parameters to reach a specific design consideration. The three samples under study are shown in Table 2.

TABLE 2. Details of the three tested samples

3D Printed - Single Layer	3D Printed - Pattern Layer	3D Printed – Potassium Chloride Layer
		

Layer 1: 3D printed wood filament	Layer 1: 3D printed wood filament Layer 2: Extruded immersed pattern	Layer 1: 3D printed wood filament Layer 2 & 3: Extruded pattern immersed filled with potassium chloride

The selected designs were then imported into the *Cura* open source slicing application for 3D printers to prepare the samples for 3D printing. Several parameters were adjusted, including layer height, number of layers, direction of printing, and temperature. Upon fabrication of the three designs, the samples were tested together under the same humidity conditions. Figure 6 shows the outcome of the 3D printing for the three wood filament samples.

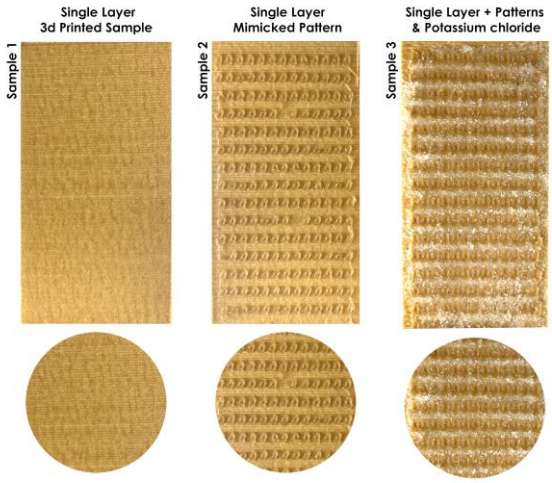


Figure 6. Fabricated samples prepared for the experiment

The response behavior of three samples was then tracked and analyzed, following the validated physical experimental study for shape-shifting materials by Grönquist et al. (2018) and Menges et al. (2014), and the validated *Kinovea* image analysis software for measuring angles of curvature by Puig-Diví et al. (2017). Based on both methods, the effect of each design parameter on the angle of curvature was measured for each sample when exposed to variation in humidity (El-Dabaa and Abdelmohsen, 2020). Figure 7 shows an example of the material motion during the experiment.

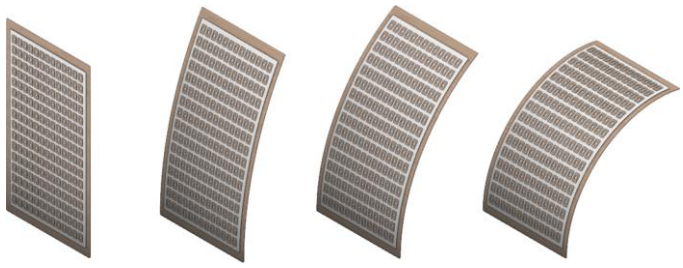


Figure 7. Material motion during the experiment

After each stage of the experiment, the motion for each of the samples was documented through multiple photographic images, and the angle of deflection was measured using the Kinovea software. In the first stage of the experiment, the samples reacted gradually to room humidity (54%) by an angle of deflection of 3˚ only. After one hour, while increasing the humidity to 83%, the angles of deflection gradually increased for each of the samples. The angle of deflection for sample 1 (single layer) was recorded at 8˚. Sample 2 (with extruded immersed) pattern was shown to retain more humidity due to the surface pattern, where the angle of deflection was recorded at 11˚. Sample 3 (with extruded immersed pattern and potassium chloride) exhibited an angle of deflection of 7˚ due to absorption. After finalizing the experiment and observing the samples for a total of 5 hours, Sample 1 and Sample 2 were shown to return gradually to their initial shape, while Sample 3 was shown to react to the humidity absorbed by the composite and exhibit the largest angle of deflection (39˚). Figure 8 shows the different motion responses and angles of deflection for each of the three samples upon the start of the experiment, after 1 hour, and after concluding the experiment after 5 hours respectively.

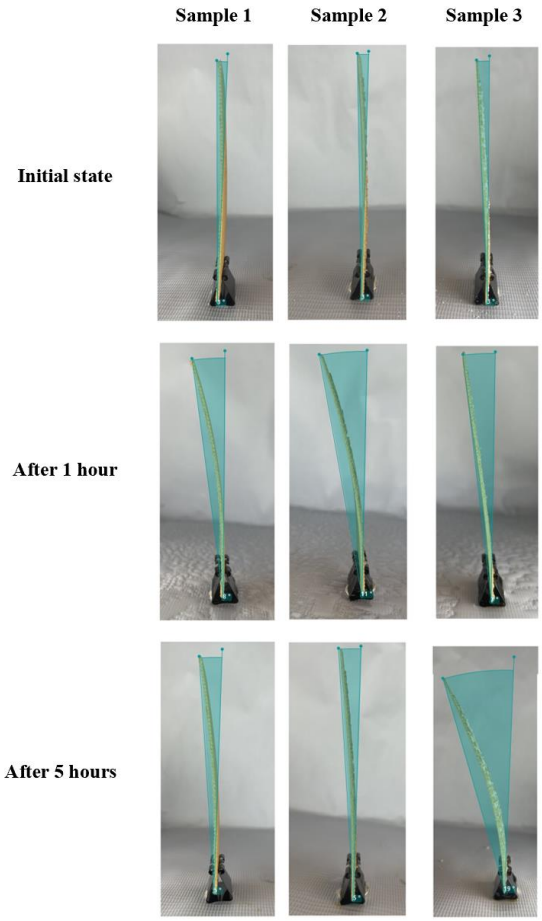


Figure 8. Motion responses and angles of deflection recorded for the three samples using physical experiments and Kinovea image analysis software

3.2. SIMULATION

Based on the previous experimentations, it was observed that the mimicked geometrical sample with surface extrusion and capillary protrusions with chemical composite embedded retainer, which was inspired by moisture-harvesting lizard skins, could absorb percentages of moisture from external stimuli. An annual humidity analysis for the Sinai desert region in Egypt, specifically the city of Ras Sedr, shows an increasing level of humidity at night more than day hours, as shown in Figure 9. This indicates that the material can retain humidity at night times to influence its morphological ability and programmed transformation stability during the hot day time.

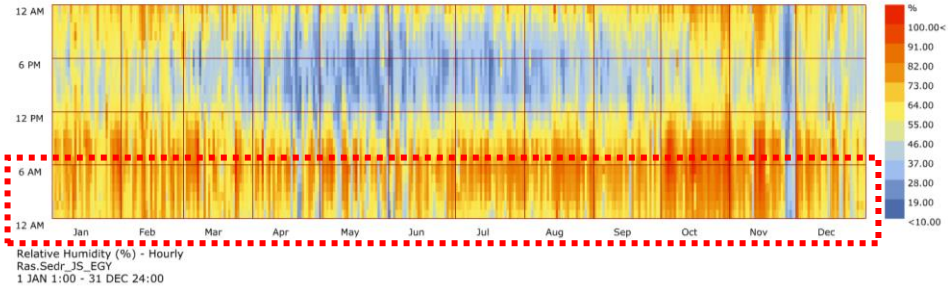


Figure 9. Humidity levels using Grasshopper and Ladybug plugin for the city of Ras Sedr (desert region of Sinai, Egypt)

3.3. DESIGN CONSIDERATIONS FOR BUILDING ENVELOPES

The previous studies and experiments demonstrate the manipulation of design decisions toward improving building performance. Façade skins can be programmed based on multiple parameters. One of the parameters studied is the surface design element that affects the time and type of motion response to external stimuli and weather conditions. It was also shown that the amount and type of embedded chemical composites (such as KCl) are considered to control the amount of absorbed moisture and the duration of moisture retention that directly impacts the time of morphological transformation of the material of the building skin. Each panel of the skin can be programmed with a specific morphology based on the amount of optimized temperature and illumination. Figure 10 shows a sunlight hour analysis and radiation analysis for a sample designed building skin throughout the year.

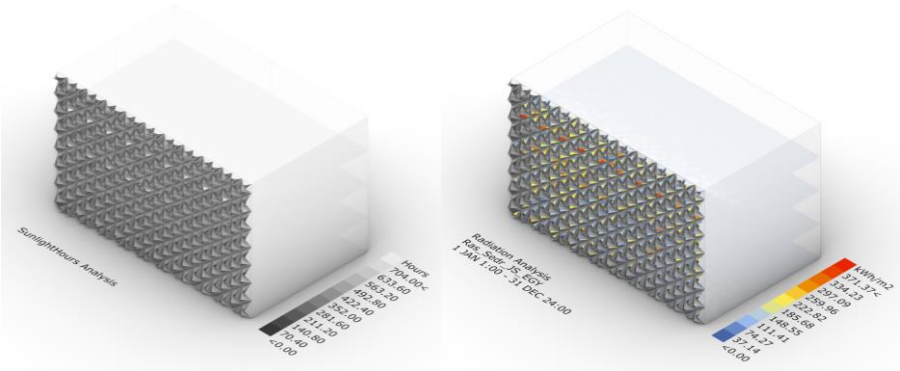


Figure 10. Sunlight hour analysis and radiation analysis for a sample designed building envelope during the year

4. Discussion

From the previous experiment, it was observed that the 3D printed samples using wood filament retained their initial state after decreasing humidity. The single layer plain sample was exposed to external stimuli, and its surface was directly influenced by humidity. This sample reacted gradually based on the layer thickness and direction of printing. This planar texture surface allowed the material to dry faster. The material absorption varied from one geometry to another due to the surface formation.
The sample with the extrusion patterns reacted to humidity faster due to having a larger number of channels, leading to higher humidity retention. The potassium chloride composite was shown to exhibit a higher ability to retain humidity due to the chemical capability of the composite to retain moisture for a long time. In this case, a significantly larger deflection was recorded, owing to both extrusion patterns and texturing on the one hand, and the high humidity retention property of the chemical composite on the other. This moisture-harvesting inspired process opens up new possibilities for design and for tailored morphological compositions and configurations in adaptive building skins.

Conclusions

This paper investigated the ability to improve the durability and morphological capabilities of programmable materials based on surface formation, utilizing digital fabrication techniques. The study aimed to translate the biological formation of skins of lizard species residing in arid regions into geometry and material composition. The process of mimicking morphological complexity and humidity retention in lizard skins was used to inform a digital workflow from inspiration to fabrication stage. 3D printing techniques were shown to produce more design variations and possibilities, allowing for simulating and programming material motion for building envelopes.
The research concluded that the materials of single layer plain surfaces react directly to humidity with minimal ability to retain moisture. Materials composed of textured and patterned surfaces containing extrusions and channels were shown to retain more moisture, therefore impacting the morphological capabilities of the material. It was also shown that utilizing chemical composites on top of these textured layers was highly significant in the process of moisture retention. The sample building envelope design that used potassium chloride acts better due to the ability of the composite to absorb moisture while exposed to humidity and releasing it gradually, giving it an edge in terms of moisture retention in adaptive building envelopes in arid climates.

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DAY 2 - PARALLEL SESSION 3

TOPIC 4 - VIRTUAL ENVIRONMENTS AND EMERGING REALITIES

TOPIC 6 - HYBRID CITIES

GAMIFICATION IN URBAN PLANNING: EXPERIENCING THE FUTURE CITY

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Abstract. Virtual Reality (VR) systems have been commonly used in the game and entertainment industries and are also increasingly explored in architecture and urban planning. They assist designers to communicate design ideas to a wider public and can engage them in the design processes. In this paper, we explore gaming environments to allow users to learn about smart city applications, such as innovative mobility approaches, urban farming, drone delivery, etc. The project is part of a real-world project for a future city for 50,000 inhabitants in the European side of Istanbul, Turkey. VR technologies can offer a testing ground for testing ideas, simulating performance, crowdsourcing ideas, before building the actual city physically. Gaming incentivizes citizens to participate in the design process, and the data collected provides a significant feedback loop to shape the city of the future. Citizens can immerse themselves in the VR environment, and experience the design via four circulation modes, e.g., walking, biking, driving, and flying. They allow users to explore novel circulatory approaches within new and innovative city arteries. Indeed, the design of the city accommodates a portfolio of mobility options, and the gamification allows testing pioneering designs, e.g., parallel streets for pedestrians, vehicles, etc. Furthermore, the game allows users to collect points when engaging in smart city topics, such as urban farming, solar energy usage, carbon neutrality, etc. Feedback loop that helps to iterate on the design. The project consists of three phases, a. an immersive VR version of the city experienced on head-mounted-displays, b. edutainment and the gamification of the city, and c. the integration of the digital version of the city into Meta's

multi-user space. In the paper, we present early findings of the project, the methods/tools explored, and discuss the utility of VR technologies in the design processes of architecture and urban planning.

Keywords: *Gamification, smart city, mobility, VR, carbon neutralization.*

ملخص. تم استخدام أنظمة الواقع الافتراضي بشكل شائع في صناعات الألعاب والترفيه، كما يتم استكشافها بشكل متزايد في مجال العمارة والتخطيط الحضري. فهذه الأنظمة تساعد المصممين على إيصال أفكار التصميم إلى جمهور أوسع وإشراكهم في عمليات التصميم. نستكشف في هذه الورقة البحثية بيئات الألعاب للسماح للمستخدمين بالتعرف على تطبيقات المدن الذكية مثل أساليب التنقل المبتكرة والزراعة الحضرية والتسليم عن طريق طائرات بدون طيار، وما إلى ذلك. هذا المشروع هو جزء من مشروع واقعى لمدينة مستقبلية تسع ٥٠٠٠٠ نسمة في الجانب الأوروبي من اسطنبول بتركيا. ويمكن لتقنيات الواقع الافتراضي أن تقدم فرصة لاختبار الأفكار ومحاكاة الأداء وأفكار التعهيد الجماعي قبل بناء المدينة فعليًا. فالألعاب تعمل على تحفيز المواطنين على المشاركة في عملية التصميم، وتوفر البيانات التي يتم جمعها حلقة ملاحظات وتغذية مرتجعة هامة لتشكيل مدينة المستقبل. يمكن للمواطنين الانغماس في بيئة الواقع الافتراضي وتجربة التصميم من خلال أربعة أشكال للحركة، مثل المشي وركوب الدراجات والقيادة والطيران. فهى تتيح للمستخدمين استكشاف طرق جديدة للحركة داخل شرايين المدينة الجديدة والمبتكرة. وفي الواقع، فإن تصميم المدينة يستوعب مجموعة من خيارات التنقل ويسمح نظام الألعاب باختبار التصميمات الرائدة، على سبيل المثال، الشوارع الموازية للمشاة والمركبات وما إلى ذلك. علاوة على ذلك، تتيح اللعبة للمستخدمين جمع النقاط عند الانخراط في مواضيع المدينة الذكية، مثل الزراعة الحضرية واستخدام الطاقة الشمسية وتحييد الكربون، وما إلى ذلك. يتكون المشروع من ثلاث مراحل: ١. نسخة واقع افتراضى غامرة للمدينة تختبر بواسطة شاشات عرض مثبتة على الرأس، ٢. التعليم الترفيهي و"تلعيب" المدينة، و٣. دمج النسخة الرقمية للمدينة في مساحة Meta متعددة المستخدمين. يقدم البحث النتائج المبدئية للمشروع والطرق والأدوات التي تم استكشافها ومناقشة فائدة تقنيات الواقع الافتراضي في عمليات تصميم العمارة والتخطيط الحضري.

الكلمات المفتاحية: *التلعيب، المدن الذكية، التنقل، الواقع الافتراضى، تحييد الكربون .*

1. Introduction

Smart Cities and Virtual Reality (VR) are two important research topics that have come to the fore in recent years. There are many start-ups in this field apart from academic studies working on the subject matter (Rebelo, 2021).
Especially in the last decade, studies on user participation and teaching urban design through gamification have intensified. The studies, which focus on VR with the collaboration of architecture students and engineers of computer sciences, support the importance of VR and city experience, and the 'participation' as a topic seen in previous studies, supported by experiments and results of the studies (Redondo, et al. 2020a, 2020b).

Nowadays, the current sources, the predictions, and scenarios of the books, and especially reviews articles, written on the subject show that the topic of 'VR and Smart Cities' will contribute to a wide range of fields and scales, from city life to design process. The results encourage researchers to think and to aim production about this subject because even the sub-titles in the content of the topic are open to very important developments and the potential of this subject is very high, not only in the academic environment but also in commercial game companies.

Behaviors and movements of users in the VR game environment can be a serious research and analysis input. The use of real-world data creates a virtual experience and urban mobility simulation in the game environment, in this way, it can enable the development of data-based systems, which will be close to the reality models (Johannessena, et al. 2016).

Especially, while working on mobility with IoT data, the simulation environment can be created with gamification and the data that close to the real transportation data can be observed (Poslad, et al. 2015). As case study topics; mobility within the city, commuting, and home-school mobility can be important components of the mobility studies (Kazhamiakin, et al. 2021).

Additionally, The VR Smart City research will be beneficial for governments, other industries, and the sustainability of finance and ecology. The VR Smart City games will simulate future cities with real geo-data, population, transportation, and energy data. The results of the simulations-VR will provide high quality in urban areas and protection to ecologic values (Rebelo and Soares, 2020; Nijholt, 2020).

In this paper, we examine gaming environments to allow users to learn about smart city applications, such as innovative mobility approaches, urban farming, drone delivery, etc. Knock et al., analysed 691 case studies, and used 40 of them to redefine the gaps and needs in gamification in terms of psychological and social behaviours of mostly public transportation-focused studies (Klock, et al. 2021). Our study focuses on the idea of game development to educate users and increase the awareness on smart city applications. Choreographing users through the city is an important part of our study in terms of game development. In this study, the issue of 'gamification' is very important in terms of energy consumption and environmental sustainability of the city.

2. Background

A smart city is an urban development vision to integrate information and communication technology (ICT) and Internet of things (IoT) in a secure fashion to manage the city's assets. Nevertheless, a smart city needs to be built to meet the needs and requirements of its citizens. A smart city is,

beyond technology, populated by people and can be raised by its citizens' contribution and gamification is the means to motivate them (Tandon, 2022).

Gamification is a term introduced in 2002 by Nick Pelling but became popular only in 2010. Gamification can be defined as a set of activities and processes to solve problems by using or applying characteristics of game elements (Tandon, 2022). Gamification techniques are intended to leverage people's natural desires for socializing, learning, mastery, competition, achievement, or closure, or simply their response to the framing of a situation as a game or play. Action, motivation, and reward are the basic principles in the gamification of smart cities for better engagement with the city. Gamification commonly employs game design elements to improve engagement, organizational productivity, flow, learning, crowdsourcing, employee recruitment and evaluation, ease of use, the usefulness of systems, physical exercise, traffic violations, voter apathy, and more (Zica, et al. 2018).

Gamification has been applied to almost every aspect of life. Examples in the business context include the U.S. Army, which uses a military simulator America's Army as a recruitment tool (Kumar, et al. 2020). In the UK and Australia gamified programs were implemented in order to encourage citizens to walk and cycle. In Australia, the result was that 35% of the car trips to schools were replaced with healthy transportation means. Another program for public transportation was introduced in Singapore. The goal was to motivate citizens to use public transportation in other intervals than rush hours. They were included in a raffle and received rewards. After 6 months of testing in 2012, the result of the program was an estimated 8% shift from rush hour to normal hours (Desouza, et al. 2020).

Gamification can be a real solution for involving citizens in building a smart city and also in its customization so that it responds to everyone's needs. Smart city applications are often top-to-down developments introduced by the tech industry. Therefore, using gamification may help the development of IT abilities for all citizens, bottom-up. Creating an application that gives the citizen an opportunity to create their own customized city, would represent real feedback for the authorities on what they can do for the city and its community.

A few examples of urban gamification in its broadest sense of fostering engagement are as follows: Second Life, an online environment created by Linden Lab, a company based in San Francisco. Second Life is an online world in which users -called residents- create virtual representations of themselves, called avatars, and interact with other avatars, places, or objects. In Second Life, residents can go to social gatherings, live concerts, press conferences, and even college classes. They can do a lot of things people can do in real life: buy land, shop for clothes and gadgets. They can also do things that are impossible in the real world, avatars can fly or teleport to almost any location (Lindenlab, 2022). Another example is SimCity, an

urban-planning game that is now being used for education in the form of SimCity Edu (Simcityedu, 2022). The game can teach anything from economics, urban planning, and even environmental studies. The goal of SimCity Edu is to make the game a common part of the classroom experience; students can learn a wide variety of subjects while working together, and teachers can create detailed curricula that adhere to learning standards (Electronic Arts, 2022). With these gamification applications, it can be seen that people have considerable trust in this method.

There are also other studies that claim that it is possible to use augmented reality and virtual reality in urban design, and that digital transformation can be used as a decision-making mechanism. The game called "Virtual Smart City Hero" is remarkable with its theoretical background, approach to the problem, method, and data and a very good example to understand the importance of the research subject, as well as the importance of VR experience of smart cities in the future (West, et. al. 2019).

3. Method and Tools

The game is basically designed to be mobility-centered, and convey crucial information around the smart city topic to the users. A roadmap can be drawn by defining the hardware, software, data, method, and users one by one and clearly identifying their relationships. Hence, for this project, the Unreal Engine game environment, and VR headset hardware are identified as hardware and software components of this Smart City VR Game Project.

The Unreal Engine has the 3D model of the city, i.e., the landscape and architectural model, thus the game offers a unique experience with highly detailed architectural models. We produced a rough 3D model of the future city site (Figure 1.).

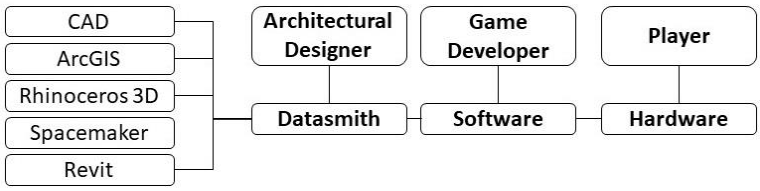

Figure 1. Datasmith and Data Workflow to VR Headset Hardware.

The components within the scope of the game designed in the study consist of 3 different groups, these are the architectural design group, the game development group, and the users. The game development group, deals with the maintenance of the game, updates all requests derived from the architectural design group and produces the game for use to the players (Figure 1.).

VR can provide valuable information and future predictions, because the system we are working on consists of real-world geodata, population,

vehicle, and energy data. The game is a simulation of a smart city design. Our main aim is to educate VR users about the smart city concept. The environment and scenario of the project is the digital twin of the real landscape data of the NAR Future City project in Esenler, Istanbul. (Figure 2., 3., 4.).

Figure 2. NAR Project City Masterplan produced via Spacemaker.

Figure 3. NAR Project City Model with low level of detail.

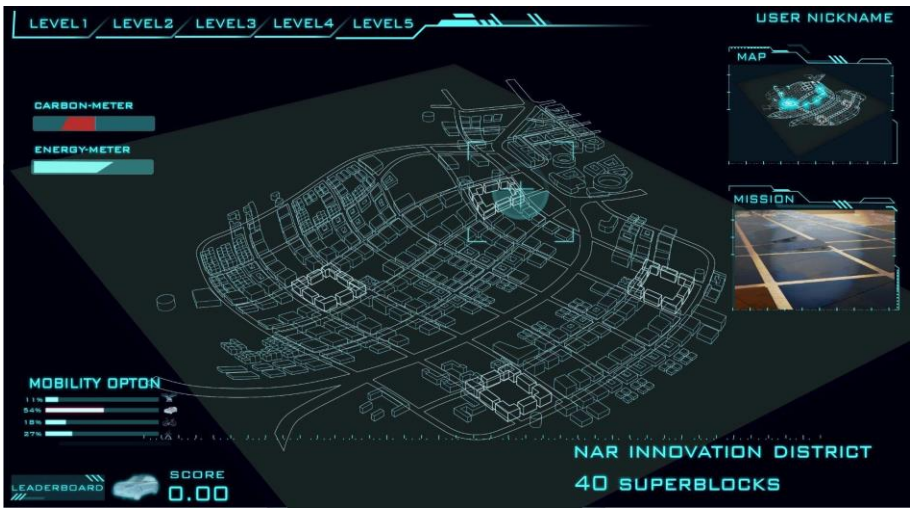

Figure 4. NAR Project area representation in the game environment.

User experience and behaviours in the game environment and social interaction with other users is stored in the unique Data Base Management System (DBMS) of the game. All mission detail, every success, and failure will be saved in DBMS and provides unique data points for understanding user activities, and patterns. The metadata makes it possible to produce future predictions, and offer quantitative analysis. (Figure 5.)

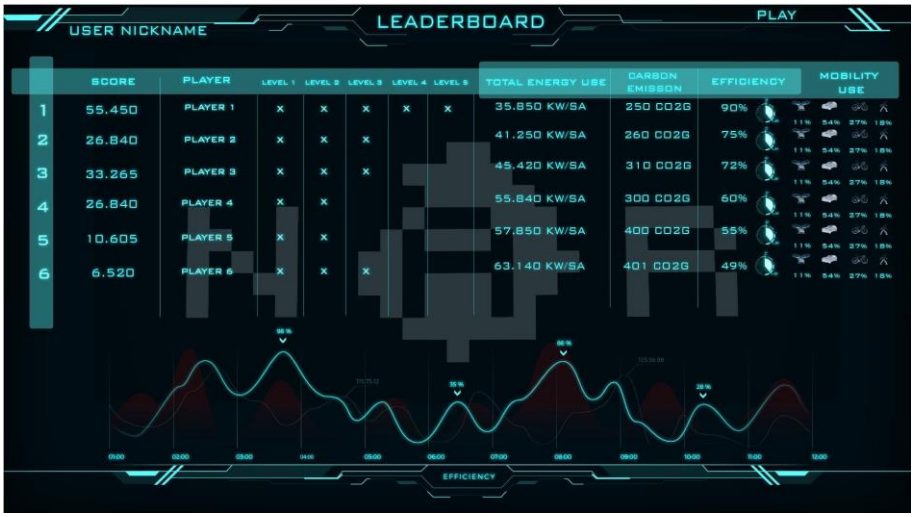

Figure 5. Leaderboard as a part of DBMS.

4. Case Study: Future City NAR Project

The design of the city accommodates a portfolio of mobility options, and the gamification allows testing pioneering designs, e.g., parallel streets for pedestrians, vehicles, etc.
The NAR Innovation District (NAR) is designed in Istanbul, Esenler. It integrates new technologies and sustainable principles such as smart city applications, flexible spatial organization, smart grid infrastructure, smart waste management system, environment-friendly public transportation modes, participatory governance, and smart emergency and disaster prevention systems.
The NAR district is made out of 40 superblocks. All superblocks in the project, namely 40 superblocks and 4 squares, are modelled and plugged-in to the VR game. The proposed mobility portfolio, such as bicycle, scooter, and autonomous vehicles constitute the main methods of circulation within the city. The landscape model is produced with photogrammetric techniques with high spatial resolution in addition to the Region of Interest (ROI) area as the project area, neighbouring buildings of the city are also integrated into the 3D model.
Users learn these smart city principles and at the same time experience the design of the NAR Future City in first person. The main goals of the Game are to increase awareness of smart city principles, democratize participation and governance structures, generate interest in smart city technologies, and inform citizens on matters of sustainability.

4.1 Scenario

As opposed to traditional games, the main scenario has been shaped around mobility approaches, e.g., visiting the squares, exploring the streetscapes, and city squares, which are designed via pedestrian and autonomous vehicles. The educational system of the game is defined under 10 ‘Suggested smart city applications’:

1. Crowdsourcing
2. Smart Mobility
3. Smart Buildings
4. Smart Economy
5. Smart Environment
6. Smart Government
7. Smart Energy
8. Smart Health
9. Smart Security
10. Smart Disaster Management (Figure 6.).

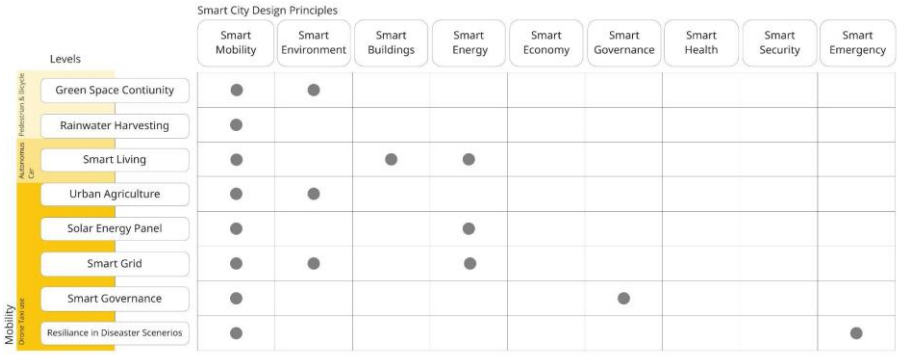

Figure 6. Smart city design principles relations with mobility scenarios.

Users pass the levels by learning seminal topics with the help of lightboxes that provide information about smart city applications at each stage. Mobility options become available after users completed certain tasks and have collected various points, i.e., as the user progresses through the levels and learns the fundamentals of the smart city, s/he can get access to say the autonomous drone taxi and experience the city from a birds-eye.

In the first version of the game, eight levels are defined that have unique missions to promote the city in terms of at least one of the mentioned smart city applications. The eight levels are named with the following titles: maintaining green space continuity, rainwater use, optimization of the energy use, urban agriculture, renewable solar energy, smart grid, smart governance, and plan for a post-disaster resilient city.

All dynamic and static components of the game have an ID and an attribute table. Statistics data is displayed as pie and bar charts throughout the game and usage data is collected in the IDs of the users. In this way, users' carbon emission values, user behaviors, and in-game development are displayed. Carbon emission values will be displayed as actual values from vehicle engines in the NAR area. The comparison will be made with the actual data of the fossil fuel consuming vehicle engine of the same power. In addition, since each building has a separate ID number, attribute table, building information is shared with the users in a certain level of detail.

The titles that are hosted in the game interface are defined, and the necessary game scenario and fiction, such as the editing, interface, and endgame reports, are created to evaluate the experience of the game from start to finish (Figure 7.) In addition to smart city applications, smart home applications are also being introduced in the designed VR game.

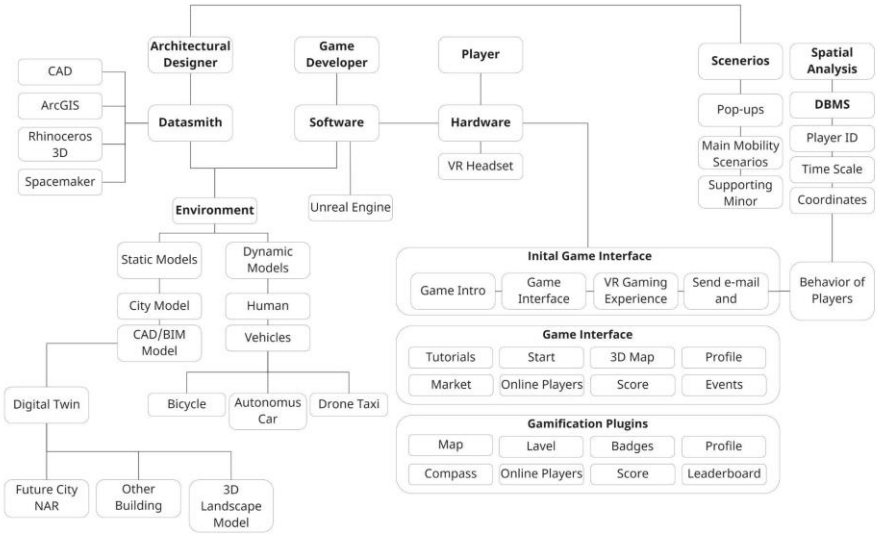

Figure 7. Workflow of the VR Smart City Game.

4.2. Game Structure

The mobility-centric gamification focused on carbon neutrality. The background, in reality, and gamification, the main of the system focus on the basics of sustainable and renewable energy in the NAR project and this study. The player controls unexpected circumstances that result in carbon emissions and resolve problems that raise energy consumption throughout the game. Successfully accomplishing the eight tasks results in the City's future being preserved and its being carbon neutral. The general structure of the game is based on the smart mobility systems that consist of pedestrian walking, bicycles, autonomous cars, and a flying drone car (Figure 8., 9., 10., 11.).

Figure 8. Pedestrian mode

Figure 9. Mobility by bike

Figure 10. Autonomous car as mobility option

Figure 11. Air navigation process of The CEZERI Air Taxi

1st Level: Maintaining Green Space Continuity. Currently, the amount of green space per person in the Esenler district is 1 m2/person. This rate has been increased to 22 m2/person in the NAR Innovation District. The purpose of this task is to preserve the continuity of green areas inside and outside of the NAR and also to learn about the features of plants in the district. The user encounters problems that damage the continuity of the green line and collects points by solving these problems. These tasks are watering a drying tree, repairing the broken irrigation system, extinguishing the fire caused by the climate crisis in the green area, and learning information about the climate crisis. At the same time, while rescuing the plants, the user gains

points by learning about the features of plants. After successfully completing this task, the player won points and was entitled to use an autonomous vehicle (Figure 12).

Figure 12. Maintaining Green Space Continuity.

2nd Level: Rainwater harvesting Players plant a vegetable in the cultivating area of the NAR Smart District. This cultivating area is irrigated by the rainwater harvesting system. Players learn the green system of rain harvesting and collecting water. After successfully completing this task, the player goes to the next task in an autonomous vehicle (Figure 13.).

Figure 13. Rainwater harvesting system

3rd Level: Smart Living is a daily housework simulation. The player does daily housework using water and electricity while using these sources minimum. The aim of the player is to optimize the water and energy in housework routines, and explore the waste management system (Figure 14.).

Figure 14. Smart Waste Management System.

4th Level: Urban Farming Zone is located on the roof of the building. The user goes to the roof, sees an agricultural area on the roof, plants vegetables or fruit on the ground, and waters it. After successfully completing this task, the player passes to another roof (Figure 15.).

Figure 15. Urban farming

5th Level: Solar Energy Panel raises awareness about the use of renewable energy. The player gets points by cleaning the solar energy panel with special cleaning techniques. In addition, annual energy saving of solar panels and their effect on carbon neutrality is shown (Figure 16.).

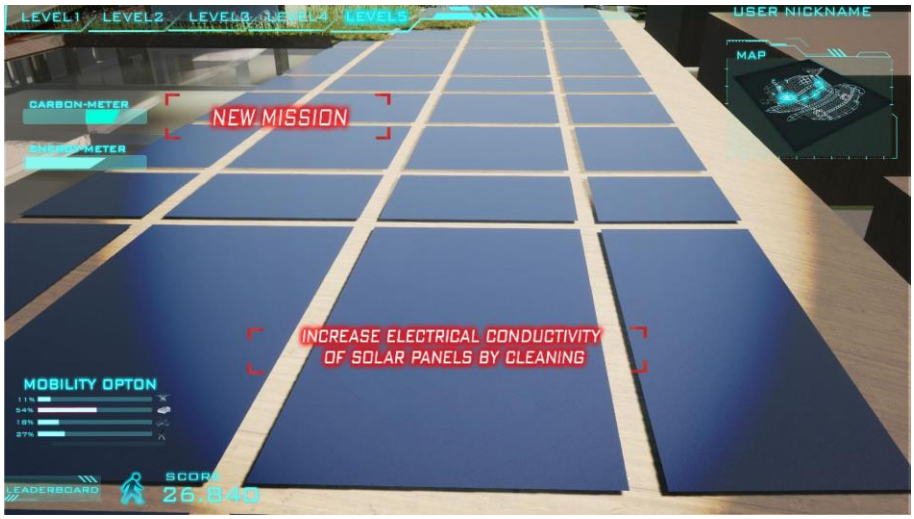

Figure 16. Learning about the solar panels

When the player reaches the necessary point by successfully completing the 5th task, is granted access to the air taxi Cezeri and can explore the Nar Area by visiting superblocks, innovation districts and cultural centers (Figure 17.).

Figure 17. Landing process of the autonomous air taxi Cezeri

6th Level: Comprehension of the Smart Grid is the task that will give information about the modern grid-centric urban design of the city.

7th Level: Smart Governance will give the user an opportunity to vote about current city problems, e.g., hours of the events, etc. The users will decide about city issues in a fast, democratic, and cooperative way.

8th Level: Resilience in disaster scenarios provides information to users about the disaster management approach and plans of the city. For instance, the new pandemic policy and application plan of the city will be described to users. As another example, the city's water policy, such as the city's infrastructure, rainwater collection tanks, and gray-black water treatment, will be introduced regarding the expected future water crisis in the region of Istanbul, etc.

The main purpose of the game is to ensure the carbon neutrality of the NAR Smart District. Every task contributes to this purpose. Players try to decrease the carbon emissions of the city by completing tasks, but this is not a finite process. Players keep trying to ensure carbon neutrality and energy efficiency. Every player has a scoreboard that shows carbon emissions, energy consumption, and the point score. The Player tries to use minimum energy and tries to reduce its carbon footprint. Energymeter and carbon meter hands are tried to be kept at a minimum level. Tasks and learning about the city provide the player points. Players can buy some items like solar energy panels, agriculture areas, or energy-saving devices. Thus, players can save more energy and even generate it. Therefore, players can share these produced energy or agricultural products with other players. In this way, a player would get more points.

5. Conclusion

The study describes the effort and process of developing a smart city game in the VR environment with all semantic and ontological approaches and details. This study initially redefines a study in which the NAR Future City project is transferred to an immersive VR environment and designs a game which is engaged with smart city applications. Game scenarios and data relations were created via the literature review process, and data preparation of the study was delineated. The main effort of the study is to create relationships among city data, VR game scenarios, and other components of the game such as users, hardware, software, and all other entities of the game. The system was created as a mobility-centric VR game for exploring the smart city and its' smart city applications. The study allows to experience future smart city applications and future examples like electric consuming mobility alternatives, e.g., the use of air taxis as well as indoor of buildings, streets, squares, roofs, and urban infrastructure as a utopic underground city

VR experience. Furthermore, the game motivates citizens to understand sustainability and offers citizens a competitive environment in the context of ecological awareness and energy saving.Therefore, future publishing of the VR Smart City Game will be a shining example for citizens and all other enthusiasts of smart cities around the globe. At last with the consumption of the game users will gain a. VR smart city experience, b. entertainment and education about smart city components, e.g. drone delivery, air taxi, smart city infrastructure, smart building, smart mobility, eco-friendly city, c. the integration of real-time, multi-user digital city experience, d. VR gamification acts as a significant simulation of the NAR Future City with its' digital twin spatial data and real-time mobility data as well as will provide spatial analysis, future predictions, and to identify problems. The missions and interfaces in the game are designed in a way that can be improved over time. The designed VR environment technically has the possibility to combine and work together with other smart city projects to be designed in the future. In the future smart cities that are separate cells can be merged in the future in a VR environment. It is clear that this VR application will attract attention to the topics of virtual reality, smart city gamification, and Metaverse.

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AN EVALUATION OF AUGMENTED REALITY-BASED USER INTERFACES IN THE DESIGN PROCESS

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Abstract. The aim of this study is to evaluate the user interfaces that reflect different interaction layers in the context of Augmented Reality technology. Depending on the physical characteristics of human interaction with the computer, these layers were examined under four sections: Graphical User Interface (GUI), Tangible User Interface (TUI), Natural User Interface (NUI) and Spatial User Interface (SUI). In this context, a proposed Augmented Reality application interface has been developed to bridge the physical and digital environment. The use of AR-based applications in the design process provided a basis for evaluating the user interface in these interaction layers. In future studies, the interface and experience offered by this application have the potential to be supported by more comprehensive functions and a collaborative working environment.

Keywords: *Human-computer interaction, Augmented reality, User interfaces, User experience, Design process.*

ملخص. الهدف من هذه الدراسة هو تقييم واجهات المستخدم التي تعكس طبقات التفاعل المختلفة في سياق تقنية الواقع المعزز. تم فحص هذه الطبقات اعتمادًا على الخصائص الفيزيائية للتفاعل البشري مع الكمبيوتر، ضمن أربعة أقسام: واجهة المستخدم الرسومية (GUI) وواجهة المستخدم الملموسة (TUI) وواجهة المستخدم الطبيعية (NUI) وواجهة المستخدم المكانية (SUI) . وفي هذا السياق، تم تطوير واجهة تطبيق مقترحة للواقع المعزز لربط البيئة المادية والرقمية. وقد قدم استخدام التطبيقات القائمة على AR في عملية التصميم أساسًا لتقييم واجهة المستخدم في طبقات التفاعل تلك. وفي الدراسات المستقبلية، يمكن للواجهة والخبرة التي يقدمها هذا التطبيق أن تدعمها وظائف أكثر شمولاً وبيئة عمل تعاونية.

الكلمات المفتاحية: *تفاعل الإنسان والحاسوب، الواقع المعزز، واجهات المستخدم، تجربة المستخدم، عملية التصميم.*

1. Introduction

In the design process, images and abstract ideas in the designer's mind, formal and environmental consciousness, spatial qualities, functional and aesthetic priorities are collected and represented by relevant media and tools. The reconsideration of the relationships between analog, digital, real and virtual allows the creation of new design environments to create a more integrated process (Asanowicz, 2002). The gap between the architectural data prepared in the physical environment and the digital environment (Koleva et al, 2003; Chen and Schnabel, 2011) can create a dilemma in the design process and it may be possible to bridge them with the technologies developed for human-computer interaction (Hsiao and Johnson, 2011).

The transfer of architectural knowledge in terms of the designer's intention and the design can gain a new perspective with not only the cycle of sketch, 2D CAD drawing and 3D models but also human-computer interaction in the direction of new technological innovations. Interfaces developed to examine the interrelation between designer and design, idea and representation, physical and digital media in the frame of physical representation and digital information (Ullmer and Ishii, 2001), provide a reinterpretation of the interaction through concepts such as immersion, interactivity, haptics, augmentation and simulation. In the design process, the perception and interaction between the designer and the digital model can vary according to the characteristics of the user interface developed (Kim and Maher, 2006). The interfaces used in the design process can support designers in creativity and communication and can be an assistant to work with maximum efficiency. Multi-layered information and representation forms such as Virtual Reality, Augmented Reality and Mixed Reality is being developed as a part of Graphical User Interface, Concrete User Interface, Natural User Interface and Spatial User Interface studies.

One of the methods that can be developed with the awareness of the potential and limits of the digital media and physical environment is Augmented Reality technology (Belcher and Johnson, 2008). Although it is used as a visualization tool for most studies, the areas where Augmented Reality (AR) can be used in the design process have much more potential (Seichter, 2007). AR can be classified into two main functions increasing the perception of reality and creating an artificial environment. These functions make a positive contribution to the decision-making process by increasing the understanding and perception of environmental and spatial information (Kipper and Rampolla, 2012). This method provides a successful framework for evaluating alternative ideas during the design process.

This study aims to evaluate GUI, TUI, NUI and SUI environments reflecting different interaction layers in the context of Augmented Reality technology. In this context, a proposed AR application interface has been

developed to bridge the physical and digital environment. The use of AR-based applications in the design process has provided a basis for evaluating the user interface in these interaction layers. The creation, modification, animation and information functions in the content of the developed application, together with the connection with the physical environment, allow the designer to experience the interface. In addition to its GUI and TUI features, the system allows the user to interact physically with design thinking and offers an area where natural gestures and the real environment support the design in the digital environment.

2. Augmented Reality as a Design Medium Bridging Between Physical Model and Digital Design Tools

AR, where designers can use a real and virtual environment to create solutions to a common problem, creates an environment suitable for creative thinking and collaborative working activity for designers. Multilateral transferring of design alternatives between designers and making the designs that sometimes can have complicated connections more comprehensible can be possible by using AR technology (Chen and Schnabel, 2011).

Sketchand+ is one of the first applications to use AR in the field of architecture (Seichter, 2003). It has set out from a very basic need and aimed to be able to collaborate in the design of individual sketches and diagrams in the early design phase. The application was developed as a research study to keep the creative design process in the virtual environment at the beginning of the 2000s by using the technological equipment of the period. As another application, ARTHUR has been developed nearly the same period as Sketchand+. The study aims to create a program in urban planning to expand the areas of use in the architectural design process and added the existing CAD system to the AR environment (Broll et al, 2004). MultiTouch (Chen and Schnabel, 2011) and Arch4models (Costa et al, 2017), have more advanced features in terms of interface and technical content. Both applications have developed AR functions by placing the interaction with the physical model based on the study. The MultiTouch application uses predefined hand gestures for recognition and aims to enable users to communicate more naturally. On the other hand, the most recently developed Arch4models application uses a tablet interface.

3. User Interfaces in the Context of Augmented Reality

The term interface provides reciprocal communication as a feature of the assets. Interfaces facilitate human-computer interaction (HCI) by enabling computers to communicate with the physical environment through

controllers and displays. In the process of communication established with the environment, commands of input through the controllers and output through the displays are processed in the interface. (Bongers, 2004).

Figure 1. Two-way interaction in the interface as input and output (modified from Bongers, 2004).

3.1. GRAPHICAL USER INTERFACE (GUI)

Graphical user interfaces are widely used form the 1980s to nowadays. Although there has been considerable progress in the development of computer devices and technological innovations, after GUI there has not been an accelerated change in the interface context used in the devices (Salih, 2015). GUI directs the user to enter a command using visual elements and generates information by answering this command. Icons, buttons, menu items, panels, or tabs organize the layout of the interface content and create an order that the user will follow and provide visual output such as labels, images, or text boxes (Lafkas, 2013). In the process of interacting with the user, GUI has a sharp separation between the input and output tools as control and display (Ghalwash and Nabil, 2013). The language developed to provide the interaction between the user and the computer involves moving and clicking the mouse in the horizontal plane. Terms such as one-click, double-click, drag-and-drop, scrolling and right-click are often applied to communicate computer via mouse (Lafkas, 2013). The most commonly used elements of a graphical interface are the icons of functions and applications, the windows where the icons are displayed, the menus and a marking tool used for selection.

Figure 2. Two-way interaction of GUI as input and output.

Although significant advances have been made in terms of program functions and ease of use of the graphical interface, the design options for design programs are limited to tools such as screens, keyboards and mouse. In an AR environment, the GUI may be on the screen of the tool used, or it

can be seen from the position determined as a virtual button in the physical space (Ortman and Swedlund, 2012).

3.2. TANGIBLE USER INTERFACE (TUI)

Tangible user interfaces (TUI) provide digital information to a physical object used for control and display and establish a computable relationship between digital representations and physical objects (Ullmer and Ishii, 2001). TUI takes advantage of the available usability experience and tactile interaction skills that users can have with objects in the physical environment (Ghalwash and Nabil, 2013). Tangible interfaces develop as a conceptual search at the point of removing the sharp distinction between input and output in graphical interfaces. They base on the complementarity of physical and digital representations. (Ullmer and Ishii, 2001). As the process between the controller and the display in the current GUI system can be interrupted and can have a complex appearance (Hsiao and Johnson, 2011), TUI also includes physical objects to improve the process.

The AR environment has advanced viewing possibilities and it is a convenient interface for viewing virtual objects while TUI can perform intuitive manipulation of virtual data very well, but it is insufficient for imaging (Billinghurst et al, 2002; Billinghurst et al, 2008). In this sense, AR and TUI interfaces can be used together, as a new method to eliminate the distinction between real and virtual worlds (Billinghurst et al, 2002), that can be named Tangible Augmented Reality (TAR). In the AR environment, the physical environment is superimposed with information in a virtual environment, but in TAR, digital data corresponds to a physical object. One of the studies using the TAR environment is MagicPaddle (Kawashima et al, 2001) a physical object is defined as a marker for AR. Virtual objects can be added, removed, or moved to the virtual scene and displayed by HMD, using the physical paddle. The interaction between the user and the object is provided with the keyboard and mouse in a CAD program, but in the TAR environment, it is established in the physical environment with the help of a touchable object and supported by virtual images (Koleva et al, 2003).

3.3. NATURAL USER INTERFACE (NUI)

In the NUI concept of interacting naturally with technology, interaction forms, such as speech and view, comes to the forefront instead of mouse and keyboard (Ballmer, 2010). While with the GUI, a command that is received entirely through a device is processed into the digital environment, physical objects were also included partially in the process with TUI. However, the Natural User Interface (NUI) sets out to interact directly with physical and digital objects. This interface system combines the detection area and the

field of action by recognizing the movement of people or the condition of a physical object in a horizontal working area with visual, auditory, or other sensors (Rauterber et al, 1997). Based on the natural communication between people, the natural interaction between the user and the application is examined under this type of interface.

NUI represents a more comprehensive interface concept and TUI can be considered a subset of NUI (Ghalwash and Nabil, 2013; Lafkas, 2013). NUI, as one of the new generation UI, aims to improve the user experience by using the attributes such as speech, touch, face and hand gestures as data (Salih, 2015). According to Lafkas, particularly the ability to understand speech is an important step for NUI, because the words or phrases can be defined in the interface and appropriate responses can be created. Environmental sensitization beyond user demands also means that contextual awareness is possible in NUI. Exemplary, depending on the ambient light, it is possible to adjust the display brightness of the device used, or to turn the display off and on according to the user's viewing direction (Lafkas, 2013). In the process of interacting with the user, the graphical interfaces on a device should have information about the contents of the menus or buttons created, while the NUIs begin with the subjective movements of the users. NUI provides intuitive, flexible ease of use, interface training is rarely needed and users can change the interface according to their demands (Aliprantis et al, 2019). In the interaction process with the GUI, tools such as keyboard and mouse are evolved from the visual or auditory human source data or the position of a moving object (Kaushik and Jain, 2014). It means that the original data such as voice, walking or handwriting is now digitally can be detected with NUI.

In the DreamHouse example, the study aims to integrate NUI features with a realistic AR environment (Park et al, 2016), users can change the size, position and rotation of virtual objects displayed in HMD using only their hands. Users can simulate the decoration of their homes with virtual furniture in this study. It enables the user movement in the physical environment to be simultaneously transferred to the computer and then interacts directly with the virtual environment. In an AR environment that places digital information contained in the user's field of view, human interaction with virtual objects is possible with NUI to perform gestures used in everyday life (Aliprantis et al, 2019). The use of NUIs in an AR environment that aims to provide an uninterrupted user experience has the potential to alter majorly the boundaries of user interaction.

3.4. SPATIAL USER INTERFACE (SUI)

Spatial User Interface (SUI) is one of the recently developed user-oriented interface types and based on the user's freedom of movement. Within the scope of the user's spatial perception and awareness, the movement within an area can be defined spatially by using SUI. A spatial interface is for data that is likely to change continuously within an interactive volume. It can be considered as the whole of speech, hand and face gestures, bodily movements and orientations, physical and digital interactions and position changes within the space (Bongers, 2004). The UI development process started with GUIs in HCI and continued with the virtual identification of physical objects in TUIs. In SUIs, no natural intervention is required, the natural environment itself is generated and direct manipulation can occur due to the consistency between the environment and the object in interaction (Marner et al, 2014).

The usage areas of SUIs are mostly in the game industry. In a virtual immersive reality environment, players can play with their natural movements and although they are in a completely virtual environment, they do not feel independent of the real environment. In addition, the objective of using spatial interfaces is to enrich the working areas. The ability to edit the data in a virtual environment in a way that the user wants in a physical environment creates a more user-focused, intuitive experience than switching between tabs on a single digital screen (Ens and Irani, 2017). Spatial Augmented Reality (SAR) is a method of identifying physical objects with the help of projectors and manipulating them without HMD and mobile devices for viewing. The environment is only possible to interact with when projected onto a physical object with the projector (Ens and Irani, 2017).

4. Evaluating User Interface Concepts Through an AR-based Application Proposal

Within the scope of this study, an application interface proposal was developed that bridges the design information in the digital environment with the physical model through AR. In the study, starting from the interface concepts, the GUI interface on the tablet and the 3D model in the real world were supported by the interaction of the designer with the model spatially.

The proposed design environment is based on the development and control process of design information around a physical model to work individually or in groups. One of the most important features that make the application different is the use of a 3D object's scanning data as the marker recognition method required for AR. In addition, due to the widespread use

of mobile devices in recent years, a tablet is preferred rather than HMD as a display device to reach more users and provide mobility. The digital components based on the platform of the application used in this study are Unity and Vuforia. As the software language supported by Unity, C# was used to create the contents of the interface and functions. To create an AR environment, 2D or 3D objects in the physical environment must be recognized on a digital platform. In this study, these objects, recognized and stored as databases in Vuforia Target Manager, are assigned as targets to the AR camera created in Unity. In this way, when the camera of the device on the AR application is installed can recognize the defined objects as a marker in the physical environment and the displaying screen of the device can represent the data in the digital environment. The fact that haptic communication with objects in the physical environment is easier to perceive than the use of visual data only on the screen (Gillet et al, 2005; Schkolne et al, 2001) is also an important factor in representing design ideas. In this study, the aim of developing the AR environment centered on the physical model is to enable the users to design with virtual elements without breaking away from the physical environment with the model that they can perceive by touch. Despite the innovations in digital design media and tools, the use of the physical model in the design process is due to the demand of the designers to touch, measuring and manipulate physically. For this reason, the proposed interface takes the physical model into the center.

4.1. THE INTERFACE COMPONENTS

In the application interface, the main menu panel is displayed when the physical model defined as the database is scanned in real-time on the AR camera. There are four menus under the main menu panel, Generate, Modify, Inform and Animate and each menu has its sub-menus. Each sub-menu opens as a new panel so that there are not too many panels or buttons on the tablet screen. In this way, it is aimed to simplify usage by displaying as few buttons as possible on the screen. Within the scope of the menu contents in the application, basic arrangements such as creating basic geometries such as cubes, spheres and cylinders, adding digital models ready for the scene and deleting unwanted geometries can be made. In addition, color, size and position changes can be made on these models.

Figure 3. 3D modelling by using basic geometric forms on AR environment, on the right. Pre-installed digital models on the physical model, on the left.

Functions have been added to the objects in Unity for operations such as moving, resizing and rotating 3D objects added to the screen by taking advantage of the possibilities of the AR environment. In order for the application to work properly, the scanned physical model must be viewed uninterruptedly by the tablet camera. As long as rotating the physical model or walking around the model with the tablet does not reduce the imaging quality of the AR camera, it provides the user with the opportunity to design from different angles.

4.2. DESIGN ACTIVITY IN AR ENVIRONMENT

To evaluate the use of the application in the early design stages, data were obtained in line with the positive and negative feedback on the current state of the application with a Test study. These data have formed a framework for how the application used in the design process in the AR environment can be developed. In order to test the application by users, a group of 5 students continuing their graduate education in architecture was determined. The case study carried out is based on the experiences of 5 students who created an alternative to the given mass settlement program using the developed AR application and the physical model. In this context, the mass settlement program requested by the students consists of a 4-unit dormitory, a 2-unit cultural center, a dining hall and a sports area. In addition, they also showed the pedestrian and traffic flow to show the general circulation and entrances and exits in the area where they designed their projects. While students P3, P4 and P5, who designed the placement of these units in the project area within 10 minutes in the AR environment, had AR experience before, students P1 and P2 had not experienced the AR environment before.

In the design process, the interaction with the physical model was observed in two ways. One is the participant changes their own position

around the table by moving. The other way is for the participant to change the position of the model by touching the physical model. During the test study, participants P1, P2 and P3 preferred standing. Users P4 and P5 completed the process by sitting down. The interaction of the participants in terms of positioning with the physical model is shown in Figure 5. During the design process, the participants exhibited behaviors such as bending around the table, examining their designs by holding the tablet in line with the model in the horizontal plane, or changing the position of the tablet according to the physical model.

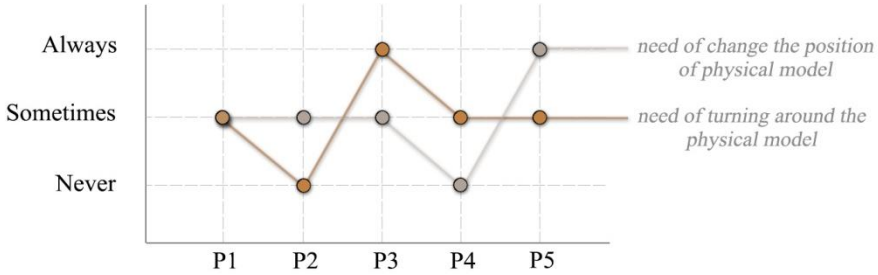

Figure 4. In the interaction of the participants with the physical model, the frequency of changing their own positions and the position of the model.

Participant P1 requested the feature of being able to zoom in on the image in the application, since the 3D scanning process of the tablet with the AR camera of the tablet is interrupted in the positions where it gets too close to the physical model or too far from the model. P2 stated that designing with an AR application is more difficult than they thought. P3 stated that the desired view was obtained only from certain angles. P4 also stated that her designs are positioned as she wishes only when viewed from certain perspectives. The participant who interacted the most by touching the physical model was P5. He had difficulty holding and modeling on the tablet, as he constantly needed to turn the physical model with one hand. For this reason, he requested that the tablet be placed on a tool such as a tripod.

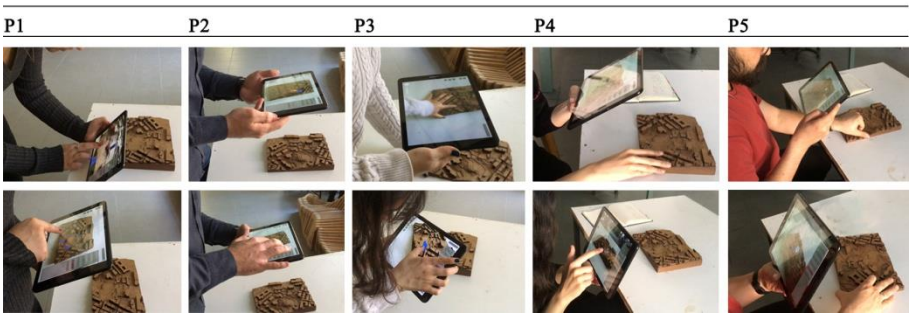

Figure 5. The changing positions of the participants according to their interaction with the physical model.

Each participant differed in the focus points they paid attention to in practice and their approach to design tasks. For this reason, the order of use of the commands and the resulting images in the design alternatives they created using the same design tools also varied. Even though the functions in the application may cause some bugs in the process they are used, the existing problems do not prevent the physical model from being informed. To create different layers of information on the physical model, the functions included in the application were examined in terms of usability and interaction with the physical model. The term usability refers to here how positively the functions they used could have responded according to the design ideas that the participants wanted to apply. Both the usage of the functions in the application and the interaction of the application with the physical model are evaluated as shown in Figure 6.

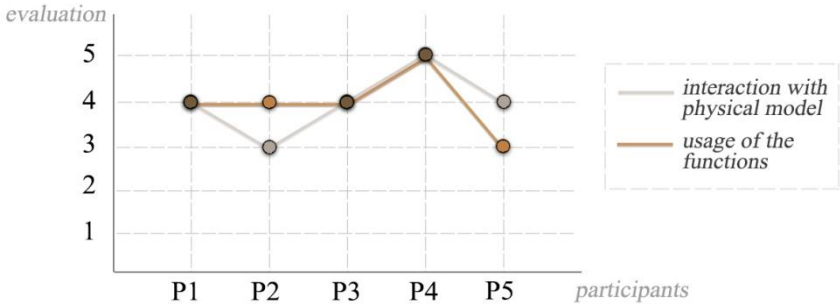

Figure 6. Evaluation of the application functions and interaction with physical model.

5. Discussion and Conclusion

Users interact with objects in the digital environment through interfaces. With the developments in software and hardware, interfaces based on graphical representations have become possible to allow different approaches within HCI. As a result of the widespread use of technologies such as AR/VR, a more natural communication can be established with interfaces.

Within the scope of this study, AR-based user interfaces were evaluated and an AR-based interface proposal was prepared to be used in the early stages of design. The advantages and limitations of an integrated interaction model, where designers interact more naturally with graphical and tangible user interfaces, are explored. The usability of the application in the design

process was experienced with the case study conducted during the development of the application. The application, is basically a study aimed at enriching the physical models frequently used in the architectural field with different layers of information. In this sense, the AR interface was prepared using a 3D model scan and provided an advantage in terms of connecting the layout designs made with the real scale.

The AR-based GUI, developed within the scope of the study, is also supported by the real physical model, offering an area where the user can interact physically. This bridge that the GUI builds with the physical model creates a powerful TAR example for users. The fact that the GUI on the tablet has different scanning and usage scenarios depending on the physical model makes it necessary for users to interact with the model in different bodily positions. This paves the way for a more natural digital design process that extends to the designer's interaction with the physical model during the conventional early design process.

As a result of the evaluation data obtained by testing the application by the users, it is thought that the use of the AR environment in the design process will contribute positively to the design in terms of interacting with the physical and digital environment. Especially, enriching the physical models with an AR application and turning them into a tool that supports the digital design environment, is important in terms of both designing with mobile tools and using them as a different representation tool than the existing representation methods. In the next stages of the study, it is aimed to expand the case study on the use of the application in the design process and the evaluation of the developed functions. It is planned to expand the model and material libraries in the application content in order to provide users with more options for creating design alternatives. Making improvements in the interface and functions in line with the data to be collected through a test study with more participants are factors that can increase the usability of the application and its contribution to the design process.

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THE VIRTUALITY OF INTELLIGENT CITIES

The Road to Hybridizing our New Cities

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Abstract. The incorporation IoT into our social systems and the digitization of our everyday life has become the new norm for societies worldwide. This study posits that digitization should apply to our cities as well. The digital aspect of technology is not always tangible – even in the figurative sense of grasping a concept – and its allure lies in this virtual aspect. That is the starting point of discussion in this paper – the virtuality of intelligent cities, the intangible forces that make these new cities smart, and how said forces can be incorporated to create new smart hybrid cities that also aim to be intelligent, connected, and efficient. This research paper was designed to first set a strong theoretical base, which includes how the Circular City Actions CCA assessment framework works. This framework is applied to the three virtual methods, Sharing Economy, Smart Parking, and Virtual Power Plants VPP, as well as an international case study, the VPP in South Australia. The CCA framework was then applied to the data gathered for the local case study, the New Administrative Capital NAC in Egypt, which was chosen because it is the largest smart city being constructed currently in Egypt right now. Since it is still not fully operational, the data collected was based on governmental plans, proposals, and published papers about the city released within the last 5 years. After theoretically incorporating the proposed virtual methods into the NAC's plans and reapplying the assessment framework, the results were greatly improved in different aspects. This study made it clear that the NAC has a strong hypothetical foundation to become an intelligent connected city, but there were some missed opportunities of incorporating virtual intelligent solutions to be implemented at different levels as the three proposed in this paper to reach its goal.

Keywords: *Smart virtual cities, intelligent hybrid cities, IoT, digital twins, circular city actions framework.*

ملخص. أصبح دمج إنترنت الأشياء في أنظمتنا الاجتماعية ورقمنة حياتنا اليومية هو المعيار الجديد للمجتمعات في جميع أنحاء العالم. تفترض هذه الدراسة أن الرقمنة يجب أن تنطبق على مدننا أيضًا. لا يكون الجانب الرقمي للتكنولوجيا ملموسًا دائمًا - حتى بالمعنى المجازي لفهم تلك الفكرة - وتكمن جاذبيته في هذا الجانب الافتراضي. هذه هي نقطة البداية للمناقشة في هذه الورقة البحثية - افتراضية المدن الذكية، والقوى غير الملموسة التي تجعل هذه المدن الجديدة ذكية، وكيف يمكن دمج القوى المذكورة لإنشاء مدن ذكية مختلطة جديدة تهدف أيضًا إلى أن تكون ذكية ومتصلة وفعالة. تم تصميم هذه الورقة البحثية لوضع قاعدة نظرية قوية أولاً، والتي تتضمن فهم كنه إطار العمل للتقييم الدائري لإجراءات المدينة أو ما يسمى CCA. يتم تطبيق هذا الإطار على الطرق الافتراضية الثلاث، اقتصاد المشاركة، المواقف الذكية للسيارات، ومحطات الطاقة الافتراضية، بالإضافة إلى دراسة حالة دولية وهى محطة الطاقة الافتراضية في جنوب أستراليا. تم بعد ذلك تطبيق إطار عمل CCA على البيانات التي تم جمعها لدراسة الحالة المحلية، المتمثلة فى العاصمة الإدارية الجديدة NAC في مصر، والتي تم اختيارها لأنها أكبر مدينة ذكية يتم إنشاؤها حاليًا في مصر. ونظرًا لأنها لا تزال لا تعمل بشكل كامل، فقد استندت البيانات التي تم جمعها إلى المخططات الحكومية والمقترحات والأوراق البحثية المنشورة حول المدينة والتي تم إصدارها خلال السنوات الخمس الماضية. بعد دمج الأساليب الافتراضية المقترحة نظريًا في خطط NAC وإعادة تطبيق إطار التقييم، تم تحسين النتائج بشكل كبير في جوانب مختلفة. أوضحت هذه الدراسة أن NAC لديها أساس افتراضي قوي لتصبح مدينة متصلة ذكية، ولكن كانت هناك بعض الفرص الضائعة لدمج حلول ذكية افتراضية ليتم تنفيذها على مستويات مختلفة مثل الثلاثة حلول المقترحة في هذه الورقة للوصول إلى هدفها.

الكلمات المفتاحية: *المدن الذكية الافتراضية، المدن الذكية المختلطة، انترنت الأشياء، التوائم الرقمية، إطار العمل للتقييم الدائري لإجراءات المدينة.*

1. Introduction

The spike in popularity of the metaverse notion, as well as terms such as ‘virtual reality’, ‘smart’ or ‘intelligent cities,’ all begs the question of what the fuss is all about. Despite these terms’ ubiquity, many use them without quite understanding what they actually entail, due to the fast-paced visual world we are living in; to quote Taylor and Saarinen “our postmodern world can be considered radically decentred and thoroughly disseminated” (Taylor and Saarinen, 1996), especially through IoT, information technology and the rise of the increasingly intelligent cities and communities we inhabit.

This research paper aims to investigate the virtual nature of intelligent cities and to do so, some of these ubiquitous terms need to be defined, such as the virtual city, the digital city, and the intelligent city, as well as concepts and methods that pinpoint the virtuality of these intelligent cities, from the smart reusable nature of the sharing economy concept to the large-scale cloud-based intelligent approach of virtual power plants, to the time-saving fast-paced smart parking systems. These are the chosen virtual-intelligent

approaches that were discussed further and incorporated into the local case study's blueprints.

Through this study, this research paper delved deeper into what types of virtual technologies could be implemented on a large scale in the city to create a more intelligent sustainable city while using the CCA framework to assess both the international case studies discussed as well as the proposed plans for the local case study, the NAC of Egypt. Since it is still a work in progress, this research paper reviewed the NAC's proposed plans and policies considered 'intelligent,' and provided recommendations that include and maximize the IoT- and ICT-based virtual technologies in such strategies to provide a more enhanced virtually embedded intelligent city framework to build upon.

2. Methodology

The research methodology sequence for this paper is divided into segments; (1) the literature review in which the study's theoretical background will be set, including the definition of main concepts such as the virtual and intelligent city, as well as the virtual aspects of intelligent cities the study focuses on; (2) the assessment framework that was used to analyse certain aspects in the international case studies and which aided in defining a proposal for the local case study; (3) the analysis of the local case study, the NAC, through the collection of a plethora of data regarding governmental plans related to it, either from governmental documents or publicly issued presentations, as well as published peer-reviewed journal papers focused on smart policies or sustainability plans.

As mentioned, the data collected in this study is based on governmental articles, proposed plans, and published papers written about the NAC in the past 5 years. The NAC is an upcoming urban project to be built in Egypt, also considered the largest in recent history. Given that authorities claim it is to be designed as an intelligent city, as well as the fact that it is still in the making, make it the most convenient city to study and analyze. To classify the relevant data, this study looked at different scales of the proposed virtual intelligent implementations with a "micro to macro" approach, to provide various implementations of different natures, from governmental, economic, as well as transportation- to infrastructure-based.

Then, the previously mentioned framework was applied to this gathered data, upon which the lessons learned from the international case studies were extracted and tailored to the local case study's plans. In the discussion section, certain recommendations from the takeaways of previous cases are provided, meant to be added to the NAC's plans to capitalize on, expedite, and maximize the efficiency of the virtuality of the NAC, and from there act as a base for other intelligent cities to learn from. This impact could later be studied further with the simulation within a Digital Twin of the NAC.

3. Limitations

Due to the nature of this study, the primary limitation was the qualitative nature of the data provided since the NAC is still not fully functioning and could be considered a work in progress. Thus this research paper's arguments are based on the information gathered from proposed ideas, plans and policies. Another issue with this approach is that most of the gatherings are considered secondary data, simply because of the lack of primary data available. This highlights another limitation, and that is the limited amount of official governmental documents describing in detail the proposed plans to achieve the smart aspect of the city, which is understandable because of the nature and scale of building an entirely new capital. However, when the city starts functioning fully, explorations of a similar nature would be much easier to conduct, as there would be tangible data to collect and policies set in place, allowing for a reassessment of the level of intelligence and sustainability of the NAC. Further limitations could be considered in the international case studies as well, as they could also be considered infantile given the concepts discussed are relatively new technologies on the city scale. Some of these projects either exist on a small scale or are too premature to define their level of success.

4. Literature Review

4.1. UNDERSTANDING THE VIRTUAL CITY

Hearing the term *virtual city* could cause one to link it to alternate, non-realistic spaces, where the laws and rules of our current realm don't apply to this new space, leading one to believe that the option to push boundaries is more intriguing than in a physical city. However, that may not really be the case, despite the amount of misleading connotations in literature describing the virtual city as, for example, "fundamentally and profoundly unspatial" (Mitchell, 2010). In actuality, the *virtual city* can be considered a mirror that shows the hidden and intangible transactions, communications, services, and information flow that make up the 'reality' of the physical city we inhabit (Firmino, 2003). It might even be considered an alter ego to our existing cities, showcasing hidden layers, as well as the various conjunctions and overlaps of various flows, but according to Firmino, these parallel layers make it a parallel city (Firmino, 2003). However, the virtual city is not just considered a parallel urban city, as it bears just as much complexity – with variously interwoven layers – as its physical counterpart, and as such, it has actually become embedded within the tangible city. Thus, it should be considered yet another face of the city, which links and connects different flows of information. This then begs the question, how can the virtual sources and drivers of city intelligence – which assure a higher efficiency in

addressing the dilemmas of contemporary urban agglomerations – be understood? First, one needs to understand how the virtual city works. It is built with building blocks, as is the case with the physical city, although in this case it is data and information that make up this intangible city. These bits and bytes of information are constantly building new intangible urbanism, and since knowledge is always in flux, so is the infrastructure of a virtual city (Mitchell, 2010), which makes it easy to build, reshape, connect, and respond to any problem. It also makes it quite resilient, unless the cloud falls.

4.2. VIRTUALITY OF INTELLIGENT CITIES

An intelligent city is one that capitalizes on ICT and IoT to connect the different aspects of the city together, allowing for the most efficient services and readiness to solve any problems that my arise. It aims to improve transportation, accessibility, and social services, promote sustainability, and give its citizens a voice. The main goals of a smart city are to improve policy efficiency, reduce waste and inconvenience, improve social and economic quality, and maximize social inclusion. There are two major driving forces that sustained the paradigm shift towards intelligent cities – the rapid rise of the knowledge and innovation creative economies – which sustain contemporary economic development worldwide. Now, with the even faster spread of the Internet and sprawl of cyberspace that intertwines the physicality of our world, they became major players in the rise of intelligent societies, thanks to the fourth industrial era (Konmēnos, 2012).

An *intelligent city* depends on both the physical (existing) city and its ICT-based virtual counterpart. Increasingly more scholars, as well as city governance workers have started to implement and utilize the virtual counterpart of their cities to migrate, mitigate and evolve their cities into more intelligent hybrids (Konmēnos, 2012). So, what makes an intelligent city intelligent? Basically, it learns from the past by sustaining the knowledge economy in developed countries, which it applies to future scenarios by facilitating rapid urbanization in developing countries (URENIO, 2020). Achieving intelligence requires certain types of intellect, and that is where URENIO's *spatial intelligence* of cities idea comes in. This refers to the urban cognitive processes of gathering, digesting, and building upon the streams of information from the urban context. Through the digestion part, the city can process in real-time, and alert, forecast, and learn from its inhabitants and its machines. This collective intelligence distributes problem-solving to different key players, and thus reaches solutions faster – one of the most prominent features of an intelligent city. The emphasis on the spatial dimension denotes that urban space and agglomeration are preconditions of this form of intelligence (URENIO, 2020).

4.3. ASSESSMENT FRAMEWORKS

Cities are extremely complex systems with all their interwoven layers and players, and since components that make up urban systems vary widely in form and nature – from resource flow to food distribution – intervening and creating change in any one of these components will most probably impact others, creating ripples in the entire system and thus creating systemic change (ICLEI, 2021). Taking the sustainable city as an example, it has to consider its social, economic, environmental, and cultural integrity. If it evolved into an integrated city – a virtual-intelligent-efficient hybrid city – theoretically it would be possible to achieve a high level of urban sustainability. But, how can this level of sustainability on the urban scale be assessed? This is where the frameworks come into play, and specifically in this case a merger of two frameworks to analyse the chosen case study cities. These two frameworks are *the Circular Economy Key Elements Framework* (*CEKE*), and the *ICLEI (International Council for Local Environmental Initiatives) Framework*. Where the CEKE Framework focuses on decoupling the economy from material flows, regenerating ecosystems, and focusing on the rate of resource reproduction, the ICLEI Framework works towards low emission, nature-based, equitable, resilient, and circular development designed to create systemic change (ICLEI, 2021). However, by combining both, a new framework was achieved – the *CCA* framework, which this study has adopted into its analysis.

4.4. CIRCULAR CITY ACTIONS FRAMEWORK

This is a framework that was developed by ICLEI (Local Governments for Sustainability) as well as the MAVA Foundation, Circle Economy, Metabolic, and the Ellen MacArthur Foundation, which together refined their assessment and guidelines to create the CCA framework. They also paired it up with a policy toolbox and a governmental monitoring framework, and divided it into five interconnected strategies that can be utilized to create more efficient circular city systems. These five strategies are:

1. Rethink

This is where the foundation for circular activities is laid, which enables that shift to become a circular economy through redesigning the system. This could be done by eliminating linear incentives, setting goals and incentives for circularity practices, and supporting *closed-loop systems* as well as *cross-sectoral synergies* on the urban governance and commercial level, and enabling a sustainable lifestyle on the resident level.

2. Regenerate
This core strategy relies heavily on harmonizing with nature by embracing infrastructure, production systems, as well as sourcing that allows natural ecosystems to thrive. This strategy is quite important as it aims to protect and restore our natural ecosystems by prioritizing renewable resources and promoting solutions inspired and supported by nature.

3. Reduce
This strategy is based on doing more with less, and that is envisioned to be done through designing infrastructure, processes, and products that would minimize material usage, water and energy consumption, and waste generation, from production to the end-user consumption phase. This would be applied by supporting local, low-impact circular economies, as well as circular and resource-efficient business innovations, plus designing infrastructure and a built environment that maximizes resource efficiency.

4. Reuse The fourth main strategy aims to use longer and more often by extending and intensifying the use of existing resources, products, spaces, and infrastructure. This could be achieved using several means, such as second-hand markets or sharing and exchange platforms, which could be considered a take on the Sharing Economy. It can also support the reuse, repair, remanufacturing and maintenance of existing resources, products, spaces and infrastructure, as well as the design and regulation of streamlined processes for extended use of property and resources.

5. Recover This is where they aim to make waste a matter of history, through maximizing the recovery of resources at the end of the use phase and reintroducing them once more into production processes. This could be executed through a three-phase process: (1) design and regulate for separation and recovery of the suitable waste; (2) the waste collection and sorting process itself which would help facilitate recovery; (3) and finally, processing waste and ensuring its re-entry into the industry at its highest value.

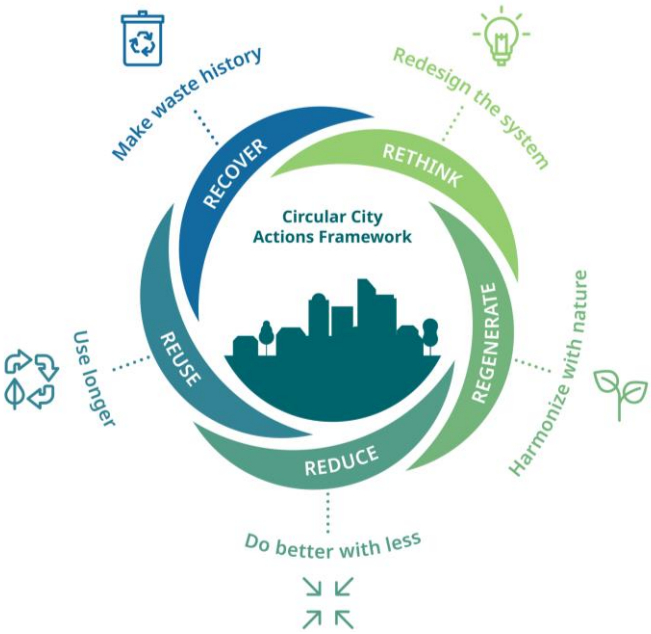

Figure 1. Circular City Actions Framework (ICLEI, 2021)

4.5. VIRTUAL METHODS THAT MAKE CITIES MORE INTELLIGENT

Now, how do these types of Intelligence modules help our cities? If they are applied in the virtual cloud-based counterpart of the city, it could be upgraded into a more efficient intelligent city. However, there are countless ways of utilizing technology and cloud-based intel to maximize cities' efficiency, among them being simple methods in various sectors and on different scales.

4.5.1. Micro Scale Concept Study: Sharing Economy

The sharing economy is an economic model defined as peer-to-peer-based, but what makes this type of economy quite vibrant and fast-paced is the fact that it is short-term and utilizes idle assets and services provided by or to facilitate collaboration (Investopedia, 2021). The sharing economy often involves some type of online platform that connects buyers and sellers. This again links to the virtuality of the city, where such an online platform that aids such transactions can be considered the virtual counterpart of a marketplace or mall. If somehow governed moderately, and even supported by the general urban governance and its citizens, such virtual spaces could be made safer spaces for the provision of urban services and thus would thrive even more, and thus feed into the urban economic ecosystem. The exceptionality of sharing economies lies in their allowance of individuals and groups to monetize on barely-used products and assets such as cars and

property, as well as the fact that they provide a vast array of assets to choose from (Investopedia, 2021).
Assessment: As a concept, it definitely implements the **reuse** strategy to almost its maximum potential, since it connects different people through a shared interest. Also, in a transaction, both parties **recover** by utilizing existing assets without having to supply new products, while an increasing number of users get access to this virtual marketplace and all parties benefit from it. If the issue of governance is resolved, this strategy may reach its utmost potential.

4.5.2. Semi-macro Scale Concept Study: Smart Parking System
This IoT digitally-based transportation system is loosely based on the previously discussed concept *sharing economy*, but is operated by deploying a convenient amount of sensors along the road networks which record, digest, process, and monitor data to create real-time traffic occupancy data for the area a user is heading to (Burbano, 2021). Implementing smart technology to facilitate this task will solve this problem, enhancing operational efficiency, simplifying the flow of urban traffic, and offering drivers a more enjoyable and time-saving experience. It also reduces the harmful effects of congestion as less cruising equates to fewer greenhouse gas emissions (Burbano, 2021).
Assessment: As with the previous concept, *smart parking systems* also capitalize on the notion of sharing economy, however, the strategy utilized here is to **reduce** – namely, time and energy consumption, as the user knows the exact location of a parking spot in advance.

4.5.3. Macro Scale Concept Study: Virtual Power Plants (VPP) and Case Study: VPP in South Australia
South Australia's VPP basically connects the source of energies and materials directly with consumers (i.e., citizens), and manages them remotely. Achieving the renewable energy integration target will require extensive consumer and private sector engagement in the investment and operation of renewable-based energy systems, and VPPs are an efficient way of accomplishing that (Behi, 2020). Optimization algorithms and resource flow management can be achieved through the cloud and satellite technologies to save time, energy, and land. In Adelaide, South Australia – the pioneering VPP-based city – batteries and VPPs are utilized to manage infrastructure and power flow needs.
Assessment: This complex infrastructure system incorporates **reduces**, **regenerates**, and primarily **rethinks** strategies into the traditional system**.**

5. Data Collection

The local case study is the NAC, which is the newest and largest city being built in Egypt currently is 45 km East from Cairo, with a total area spanning 170,000 feddans; 650 km of which are roads (MoHUUC, 2018). The NAC is divided into 3 phases; the first of which is 40,000 feddans, consisting of 20 residential districts, can house up to 6.5 million residents, as well as an international airport, the governmental district, commercial areas, public gardens, and large street networks for different modes of transportation (MoHUUC, 2018).

According to the Egyptian government's proposed plans, the NAC is meant to become a connected city that is reliable, high-speed, and efficient, as well as a *digital* city, that is both fully automated and revolves around customer-centric services, ensuring more efficient operability (ACUD, 2017). The proposed plan aims for a *connected* city built upon a unified information- and data-sharing base, where all aspects of the city communicate efficiently, from the stakeholders to the machines and buildings (ACUD, 2017).

5.1. MICRO SCALE: SMART CITY FURNITURE IN THE NAC

One of the interesting strategies considered both tangible and virtual is smart city furniture. Several ideas have been posited regarding intelligent connected urban furniture that documents user needs and actions, responds to the environment, and also coordinates with other urban components. This feature would correspond to and maintain the intelligent traffic system (ACUD, 2021); e.g., the proposed bus stations interworking with traffic lights, which alert users when a specific bus is approaching based on information received from traffic lights (ACUD, 2021). This type of urban furniture responds to a smart connected mobility scheme, but what about an environmental aspect? There also exist proposals and implementations such as solar-powered streetlamps, which also converse virtually with other city elements, as they would be connected to hi-tech sensors which monitor air quality and both vehicular and pedestrian traffic (Hassanein, 2017).

Assessment: Smart Furniture applies both the **reduce** and **reuse** strategies, as they have several functions and serves several purposes, as opposed to the traditional non-responsive ones. Their use of renewable energy means they are environmentally responsible, and the amount of power needed to operate them on a city scale is relatively low. These smart elements add a layer of connectivity on the street scale.

5.2. SEMI-MACRO SCALE: DIGITIZING NATIONWIDE PUBLIC SERVICES

There are several articles published through Egypt's State Information Service website that are in favor of creating digital systems for data

gathering and sharing, where they would transform many of their services into digital cloud-based systems that integrate and unify all types of information regarding management and operation in the city (SIS, 2018). Considered one of the major axes to tackle to achieve the UN's SDGs for 2030, ICT and IoT technologies would create smarter, more intelligent cities through a comprehensive virtual system that makes information readily available to the different sectors of the state (SIS, 2018). This system would entail digitizing all types of public services, from notarization to electricity, agriculture, and much more (SIS, 2020).

This, in a sense, could lead to the redundancy of physical public service for buildings, as the service will rely on the cloud and different sectors' integrated databases (SIS, 2020). The promised nationwide application of this system by 2030 would be truly world-changing.

Assessment: Applying the CCA framework shows this nationwide approach incorporates both a **rethinking** and a **reducing** strategy; the entire idea of public services was re-imagined and optimized through the creation of its virtual digital counterpart. This can be considered a cross-sectoral synergy that aids the governance of the city, as well as reduces the need for citizens' multiple commutes to different governmental buildings for simple procedures, thereby reducing emissions and energy consumption. In addition, the amount of labor, buildings, and infrastructure would be greatly decreased. Overall, this system would be less costly, allow for more efficiency in city management and operation, and from the user end, greatly reduce the time and effort usually required to obtain documents and services.

5.3. MACRO SCALE: SMART INFRASTRUCTURE IN THE NAC

Infrastructure in the NAC is proposed to be designed in a way that conserves water efficiently, as well as recycles organic waste more effectively. They also incorporated Honeywell City Suite technologies in their infrastructure, especially within "New Capital Egypt, City Operations Center" and "New Capital Egypt, Integrated Command & Control Cente" (ACUD, 2017) The proposal aims for an interconnected city powered by high-speed internet, open data, and GSM (4G+) technologies, all of which would be primarily powered by solar power given it is a desert city (Hassanein, 2017).

Assessment: This entire infrastructure system that aims to incorporate and handle smart techniques applies several strategies, specifically the **rethink**, **regenerate** and **reduce** strategies**.**

6. Discussion

It must be noted that these virtual intelligent methods will not alter the conceptual design of the NAC due to its virtual nature. Juxtaposing these virtual methods onto the NAC plans would result in the intelligent

interconnected city that the NAC aims to be, and incorporates the virtual intelligent solutions discussed earlier is shown and discussed further below.

TABLE 1. CCA Framework Application.

			Circular City Actions Framework				
	Scale	Approach	Rethink	Regenerate	Reduce	Reuse	Recover
Virtual Methods	Micro	*Sharing Economy*				X	X
	Semi-Macro	*Smart Parking System*			X		
	Macro	*Virtual Power Plants (VPP)*	X	X	X		
NAC Plans	Micro	*Smart City Furniture*			X	X	
	Semi-Macro	*Digitizing Nationwide Public Services*	X		X		
	Macro	*Smart Infrastructure*	X	X	X		
Applying Virtual Methods to the NAC Plans	Micro	*Smart City Furniture + Sharing Economy*			X	X	X
	Semi-Macro	*Digitizing Nationwide Public Services + Smart Parking System*	X		X		
	Macro	*Smart Infrastructure + VPP*	X	X	X	X	X

6.1. MICRO SCALE: SMART CITY FURNITURE IN THE NAC + SHARING ECONOMY

Since the Smart Furniture System regulates traffic and monitors the city's general mobility, and the major issue with sharing economy is lack of monitoring and governance, thus making it relatively unsafe for public use. Juxtaposing these virtual methods onto the NAC plans would result in the inherently intelligent interconnected city that the NAC aims to be, and identifies and proposes virtual intelligent solutions in its design to reach its goal, therefore together this issue is resolved. By adding a Sharing Economy space within the Smart City Furniture embedded throughout the city, where people could present their products in the public virtual space with a lot of constant traffic as they wait for their mode of transportation. This online marketplace of underutilized resources can be **reused** safely and create a new type of economy that is less money-based and more asset-based, and this would then **reduce** the need for new products and services since they will be **recovered** through this virtual marketplace and showcase.

6.2. SEMI-MACRO SCALE: INCORPORATING SMART PARKING SYSTEMS THROUGH THE DIGITIZED NATIONWIDE PUBLIC SERVICES

If this service is provided through the government portals where they can be monitored for street violations and would greatly save time and reduce energy and emissions wasted while finding a parking spot. Since, it will be connected to the NAC's Street sensors, which link to the governmentally

monitored and linked to a mobile app, this modification would be adding **rethink** to the **reduce** strategy.

6.3. MACRO SCALE: ADDING VPP TO THE SMART INFRASTRUCTURE IN THE NAC

Although the proposed infrastructure seems to have certain environmental goals, this could be taken a step further through the implementation of VPPs, eliminating the structural and power costs associated with building an entirely new physical power plant. Instead, the energy resource flow would be redirected from the source to the grid and operated remotely, making the process more efficient and transparent; the government would easily monitor and govern where the energy comes from, who uses it, when, and how much. Therefore, adhering to the **reuse** strategy. Set-up should also not be much of an issue, as the digital infrastructure it requires should already in place given the NAC is designed to be an interconnected city equipped with high-speed internet, open data, and GSM (4G+) technologies. Another important factor of this proposal is that citizens would be able to reuse any excess energy by storing it in batteries, which in a sense can also be considered a **recover** strategy. With the VPP added to the existing proposal of the infrastructure, this covers all five strategies of the CCA framework.

7. Conclusion

From what was gathered, analysed, and discussed, a conclusion can be reached – the NAC has a strong base for being an intelligent city, however, it needs to implement more IoT- and cloud-based virtual strategies to reach peak intelligence. All of these approaches if incorporated would add at least one more of the CCA framework strategies to the existing ones. The smart furniture case, for example, is more than halfway to the proposal suggested in this research paper, as these smart connected elements are installed all over the new city and some are even working at the moment. The addition of a connection to citizens' phones and the Smart Parking feature would allow the city to reach a whole new level of efficiency. Adding the Sharing Economy platform to the Digitizing Egypt movement would not just lead to reuse and recovery of idle resources taking up precious space, it would also generate income for both citizens selling these resources as well as the government, which would monitor and keep this entire digital-based interaction safe, rendering it a favourable situation for all stakeholders. Incorporation of VPPs into the proposed smart infrastructural system would mean that the five strategies would be in one way, or another achieved.
These three propositions are just the gateway to many more virtual strategies that could be weaved into this new city, with the addition of intelligent and smart city-based policies that truly cater to these new technologies and

would protect all stakeholders from any fraudulent activities that might arise from incorporating such new technologies onto the city scale, would definitely be a breakthrough.

Each new day sees the rise of new virtual and cloud-based technologies that could be incorporated into our cities, especially with the rise of real estate in the metaverse. If this research were to be conducted again in five years' time, it would contain more quantitative data, where the data collected would be gathered from the city itself, and these never-before-implemented strategies and policies could be analysed in the realized city.

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RESEARCH DATA MANAGEMENT AND A SYSTEM DESIGN TO SEMI-AUTOMATICALLY COMPLETE INTEGRATED DATA MANAGEMENT PLANS [POSITION PAPER]

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Abstract. Data is an integral part of modern scientific work. Good research data management (RDM) and the communication of the related information is extremely an important matter. It is not only crucial for the ongoing research and its claims but also for the future uses of data. In recent years some guiding principles, e.g. FAIR principles and initiatives at the national and international level, e.g. NFDI, NFDI4Ing have also been founded to improve RDM. The data and its metadata are often handled in file system like structures which are versioned and logged. The information relating to the data handling are documented in data management plan (DMP). DMPs are also usually managed in similar file structures. These are made available in editable document formats as well as online free-text editable forms to which users are required to keep updating manually. These are isolated documents which have neither direct relation to data for verification nor are common to understand with consistency. In this paper, research data management of large-scale interdisciplinary projects is presented. On one hand it introduces, contemporary practices of RDM and on the other hand it helps researchers to determine the features of RDM system in the situations when it comes to select or develop a system for the same purpose. It further introduces a system design for semi-automatic completion of DMP functions in collaborative environment a.k.a. virtual research environment (VRE). It is assumed that the proposed system will assist and enable users to update semi-automatically integrated DMP during all phases of data life cycle. Direct relation to the data for verification, common understanding and consistency will also be maintainable.

Keywords: *Research data management (RDM), dynamic Data management plan (dDMP), Virtual research environment (VRE), Research data management system, Open science.*

RESEARCH DATA MANAGEMENT AND A SYSTEM DESIGN TO SEMI-AUTOMATICALLY COMPLETE INTEGRATED DATA MANAGEMENT PLANS [POSITION PAPER]

ملخص. تعتبر البيانات جزءا لا يتجزأ من العمل العلمي الحديث. كما تعتبر الإدارة الجيدة لبيانات البحث وإيصال المعلومات ذات الصلة أمرًا بالغ الأهمية. وليس ذلك مهمًا فقط للبحث المستمر ولكن أيضًا للاستخدامات المستقبلية للبيانات. وقد ظهرت فى السنوات الأخيرة بعض المبادئ التوجيهية، على سبيل المثال مبادئ ومبادرات FAIR على المستويين الوطني والدولي، كما تم تأسيس NFDI و NFDI4Ing أيضًا لتحسين إدارة بيانات البحث. غالبًا ما يتم التعامل مع البيانات والبيانات الوصفية الخاصة بها في نظام الملفات مثل هياكل بيانات يتم إصدارها وتسجيلها. ويتم توثيق المعلومات المتعلقة بمعالجة البيانات في خطة إدارة البيانات (DMP). تتم أيضًا إدارة DMPs عادةً في هياكل ملفات مماثلة، ويتم توفيرها في تنسيقات المستندات القابلة للتحرير بالإضافة إلى نماذج النصوص المجانية القابلة للتحرير عبر الإنترنت والتي يُطلب من المستخدمين تحديثها يدويًا. هذه مستندات معزولة ليس لها علاقة مباشرة بالبيانات من أجل التحقق ولا من الشائع فهمها باتساق. في هذه الورقة البحثية، يتم تقديم إدارة بيانات البحث للمشاريع متعددة التخصصات واسعة النطاق. من ناحية، يقدم هذا الطرح ممارسات معاصرة لـ RDM ومن ناحية أخرى يساعد الباحثين على تحديد ميزات نظام RDM في المواقف عندما يتعلق الأمر باختيار أو تطوير نظام للغرض نفسه. يقدم أيضًا تصميم نظام للإكمال شبه التلقائي لوظائف DMP في بيئة تعاونية مثل بيئة البحث الافتراضية (VRE). من المفترض أن النظام المقترح سيساعد المستخدمين ويمكّنهم من تحديث برنامج إدارة البيانات المتكاملة شبه التلقائي خلال جميع مراحل دورة حياة البيانات. كما يمكن الحفاظ على العلاقة المباشرة ببيانات التحقق والفهم المشترك والاتساق.

الكلمات المفتاحية: إدارة بيانات البحث، خطة ديناميكية لإدارة البيانات، بيئة البحث الافتراضية، نظم إدارة بيانات البحث، العلم المفتوح.

1. Introduction

Scientific investigations are not only about theory and experiments but also include procedures and conducts (The Royal Society, 2012, Easterbrook, 2014, Leek and Peng, 2015). Communication of practices and results contributes together to reproduce and replicate the very same exercise again and again. Importance of reproducible findings have long been rooted in the modern investigation methodologies, i.e. science (The Royal Society, 2012). Whereas, digital instrumentation at large scale and dependence on data and computing machinery have reinforced the demand for the same in recent years (Baker, 2016, Stodden, 2010). As a result, notions emerge to align quantitative & qualitative matrices and the activities to define frameworks for investigation and scholarly communication (Hicks et al., 2015, DORA, 2012). These frameworks levy actual research activity with intensive disciplines, e.g. software engineering and also require knowledge and compliance with technical details of infrastructures as well as rules and regulations laid down by the concerned authorities, i.e. publication and funding agencies etc. (Wilson et al., 2014, Tenopir et al., 2011, Data Citation Synthesis Group, 2014, Stodden et al., 2013).

FAIR data principles and Open science are the two widely supported movements. FAIR principles set the goals for Findability, Accessibility,

Interoperability, and Reuse of data. Whereas Open science not only set goals to make scientific research, data and dissemination accessible to all levels of an inquiring society but also suggest principles of openness to the whole research cycle (Wilkinson et al., 2016, FOSTER). Thus, a classical research activity gets coupled with intensive tasks of information logistics (Klein, 1993).

However, it is assumed that RDM support services and systems could rescue from complications and relieve workloads of an investigation and its scholarly communication. These systems could achieve this by encapsulating the rules and workflows while offering collaboration, fostering adoptability and interoperability between diverse and multiple sources (Van Gorp and Mazanek, 2011, Candela et al., 2013, Gray et al., 2005).

RDM refers to the activities relating to the storage, organisation, documentation and dissemination of research data. These are continuous activities which are needed to be performed during the period of the research project (Borghi et al., 2018).

Different systems and services are being developed and proposed to accomplish challenging goals of RDM. In this context data types are defined based on its need and state, i.e. active and non-active research data. Data is considered active when it is part of an active phase of research, where data is considered non-active when it is not part of active phase of research. In this paper approaches and systems dealing with active research data are described from simple to complex in an incremental way.

In following sections, an overview of RDM policy and strategy, research data, a review of approaches together with types of RDM systems to manage research data and a system design for integrated dynamic DMPs are presented.

2. RDM policy and strategy

To ensure best practices during research, an RDM activity starts with the development of RDM policy and strategy as a binding document for all the participants. This document defines research data, its related information together with research outcomes, file formats to communicate research outcomes, naming and versioning conventions, initial metadata standards, platform and information infrastructure, categories of roles and responsibilities of the participants (Jones et al., 2013).

3. Research data

Different bodies define research data differently. However, for the sake of reference in this paper research data described by German Research Foundation (DFG) guidelines is considered as follows.
"Research data includes measurement data, laboratory values, audiovisual information, texts, survey or observation data, methodological test procedures and questionnaires. Compilations, software and simulations can equally represent a central result of scientific research and are therefore also included under the term research data. Research data in some subject areas is based on the analysis of objects (such as tissue, material, rock, water and soil samples, test specimens, installations, artefacts and art objects), so its handling must be just as careful and consideration must be given to a technically adequate option for subsequent reuse whenever meaningful and possible. Should subsequent reuse of the resulting research data be closely associated with objects, then please also elaborate on this by providing all relevant information. Please consider the existing standards in your discipline, any current subject-specific recommendations and any existing infrastructure services." (DFG, 2021).

4. Approaches to manage research data

This section first provides an overview of versioning concept. Then introduces versioning techniques and systems for RDM including strategies relating to the storage of data and then about organisation of the data. Lastly, documentation of the data.

4.1. DATA VERSIONING

During research, data evolves and goes through different stages and processes, e.g. from raw data to processed data and to data as product. So, it could have different versions. The stages of data are modelled as data lifecycle (Weber and Kranzlmüller, 2019).

For a modern research it is not only important to present the results but also provide a clear protocol to allow successful repetition and extension (Mesirov, 2010). Thus, maintaining different versions become important for repeatability and reproducibility of the same results. Each new version of data is maintained in a way that it has some important associated information, e.g. date and time of its creation, author, new contents, reference to the older version and description of changes.

4.2. RDM BY MEANS OF VERSIONING

There have been different strategies to maintain different versions of the data. A very basic and classic approach is that on every change a newer file of the data is created and saved with corresponding information. Creating versions in this way could cause creation of lots of files which could become difficult to manage. To deal with this issue software tools and solutions are being developed under the theme of Version Control System (VCS). These systems maintain changes and log associated information of a file or set of files in their internal databases. In this way they offer a simpler organisation of different versions as well as enable users to restore specific versions later (git-scm).

Those software tools are being categorised as Local VCS, Centralised VCS and Distributed VCS based on their design. The key difference among them is as follows. Local VCS maintains all the versions of data on local system. GNU RCS[1] is an example of such a system. Centralised VCS maintains all the versions of data on a central server and users can access specific version using client software. CVS[2] and Apache Subversion[3] are examples of such systems. Distributed VCS maintains data on a server with a difference that every client also has all the history of data versions. Therefore, they do not depend on the server as much as they do in case of Centralised VCS. Git[4] and Mercurial[5] are examples of such systems.

Simple version control systems have limitations. Therefore, to collaborate and reuse data, information managed in simple VCSs are not sufficient.

4.3. RDM USING SYSTEMS BUILT AROUND VERSIONING SYSTEMS

In case of collaborative research projects in which scientists are from different disciplines, stationed at distinct locations and generating heterogeneous data, the task of RDM requires a comprehensive solution. Because, requirements for the management of data in such cases get diversified, e.g. collaborative work requires comprehensive access management not only for already saved file like data but also for real-time collaborative authoring and viewing, internal communication, commenting and annotation, custom metadata etc. Therefore, applications and services

[1] https://www.gnu.org/software/rcs
[2] http://cvs.nongnu.org
[3] https://subversion.apache.org
[4] https://git-scm.com
[5] https://www.mercurial-scm.org

around VCS have also been developed to constitute new range of systems. These systems introduce further features and tools, e.g. unique IDs, wiki pages, project model, project pages, tasks and task boards, metadata creation and extraction, support for standard protocols and APIs (Amorim et al., 2017).

These systems can broadly be categorised in four main categories based on their function during RDM activity: -

- **Storage systems:** These are the range of systems which support to save data and manage access to it. Some of these systems also offer document authoring support. Example of these systems are Powerfolder[6], OwnCloud[7] etc.
- **Development support systems:** These are the range of systems which are developed with the aim to manage code and code alike data which is meant to exhibit special structure, compile and execute. These systems further extend functionality and offer convenient features, e.g. continuous integration and deployment. GitHub[8], GitLab[9], Overleaf[10] and similar authoring and coding systems are examples of such systems. In some cases, these systems, e.g. GitHub might also be used as publication platforms and repositories.
- **Publication platforms and repositories:** These are the range of systems where data is usually parked at the end of its active state. Data in these systems is usually registered to release and make public. There are exceptions that some of these systems might not support multiple versions of the same data. Thus, each submission might be managed independently. Examples of these systems are mediaTUM[11], Zenodo[12]/ InvenioRDM[13], CKAN[14], DSpace[15], Fedora[16], Dataverse[17] etc. The category of publishing systems may also include indexing platforms, e.g., DataCite[18] where researchers could publish their metadata.
- **Virtual Research Environments (VRE):** These are also named as Science Gateways (SG) and Virtual Laboratories (VL). These are

[6] https://www.powerfolder.com
[7] https://owncloud.com
[8] https://github.com
[9] https://gitlab.com
[10] https://www.overleaf.com
[11] https://mediatum.github.io
[12] https://zenodo.org
[13] https://inveniosoftware.org
[14] https://ckan.org
[15] https://dspace.lyrasis.org
[16] https://duraspace.org/fedora
[17] https://dataverse.org
[18] https://datacite.org

relatively new genre of systems to offer range of tools for complete research workflows. Apart from their own storage system, these systems offer integration and interoperability with external systems and infrastructures to aggregate and disseminate data while offering central point for controls. Example of these systems are eWorkbench[19], VRE4EIC[20], OSF[21] etc. In industry similar genre of systems are taking place under the flagship of Hybrid cloud (Marcio et al., 2017).

4.4. DATA ORGANISATION

There are three distinctive ways to organise data in RDM systems, i.e. file based, form based and project based.

- **File based:** In file-based approach data is stored usually under file management system using file objects. In this scheme files are organised under folder or directory hierarchies. Directories are created based upon the themes, e.g. instrument, laboratory, month, topic to organise similar files. For RDM activity a standard file system layout and naming conventions for files are defined which researchers are required to follow. In some cases, it not only includes standard data files but also includes documentation and metadata files. Directories are applied VCS, e.g. Git. In order to maintain folders independent of each other modular approach of VCS, e.g. git submodule are applied (Spreckelsen et al., 2020). Applications like file manager are used to organise and access such data.
- **Form based:** In form based approach data is accessed, visualised and versioned by the means of custom software programs, e.g. data relating to the events is managed by an appointment software module. Modern systems adopt this approach to maintain and organise documentation and data management plan as well as metadata. In this approach data is stored usually in data management systems, e.g. PostgreSQL[22].
- **Project based:** This approach uses both file and form based approaches. It is best suited for large projects consisting of multiple hierarchies of sub projects. It uses project model and employs namespaces concepts to maintain contextual aspects of data and information as well as access management. In this approach, project models are defined and programmed to encapsulate information specific organisation/ tools, e.g. appointment and calendar, files and storage, sub projects, metadata and data management plan.

[19] https://eworkbench.github.io
[20] https://vre4eic.ercim.eu
[21] https://osf.io
[22] https://www.postgresql.org

4.5. DATA DOCUMENTATION

Just like data organisation approaches there have been two basic approaches to document information relating to data and research practices, i.e. file based and form based. Form based approach has advantages of automation due to being supported by custom software program. Whereas, file based approach requires researchers to maintain each and every piece of information in files manually. For example, if metadata is maintained in a file then whenever data is updated, researchers are required to update corresponding fields of metadata in the file manually. However, in case of form based approach log of the files are automatically maintained through the data file updating process. Advance case of documentation of practices in data management plan is discussed in the next section.

5. System design for dynamic DMP

Data Management Plans (DMPs) are described as a key element of good data management. A DMP describes the data management life cycle for the data to be collected, processed and/or generated by a project (European Commission). It is a requirement for all the DFG projects and doctoral theses. It is also one of the key topics of national and international research data initiatives, e.g. NFDI4Ing[23], RDA[24].

DMP consists of the text that describes intentions at the beginning, practices during the investigation process and later the applied approaches that how the data has been handled from first conception of the project till it is archived or, if deemed necessary, deleted.

In the beginning, it is composed by formulating questions. These questions are raised by the funding agencies like DFG, EU or by the competent authorities of the projects or consortiums, e.g. TRR277 AMC[25] for domain specific requirements and then it is offered to their participants. Participants then answers in a free-text form. It is recognised that this approach put an administrative burden on researchers. And the provided information is not as much useful as it should be while considering its anticipated benefits (Smale et al., 2020).

In the following sections, first a review of related work, core features of TUM Workbench as VRE to manage research data, background and

[23] https://nfdi4ing.de
[24] https://www.rd-alliance.org/groups/dmp-common-standards-wg
[25] https://amc-trr277.de

rationale are explained, then a system design for semi-automatic completion of DMP functions is introduced.

5.1. RELATED WORK

The review of existing solutions showed that, at the moment it is a simple document which is available in editable document formats as well as online free-text editable forms (EC H2020, 2018, OpenAIRE, 2017, RDMO). In order to maintain common understanding and consistency of the answers, this document is also offered with some examples of answers and hints for its authors (EC H2020, 2018). There are solutions that help authors to create an accustomed DMP document (CLARIN-D, OpenAIRE and EUDAT, RDMO). In addition to create a custom DMP, it goes to make way to link DMP to data archiving system which takes place at the end of the data life cycle (RDMO).

Due to realisation that DMP is an active document, new trends are emerging to make this document machine actionable by defining application profiles and bridging the gap between data and its corresponding DMP. And to facilitate authors to author this document (Miksa et al., 2019, DCC, 2021, Miksa et al., 2017). There have been efforts to define data model for DMP (Miksa et al., 2021b, Freudenberg et al., 2016) then the definition of automated workflows based on business processes in an institutional context (Miksa et al., 2021a).

The work being presented in this paper relates to a collaborative environment, i.e. VRE in which projects and research may belong to different institutions regardless of a specific location. The design and approach presented in this paper has a potential to semi-automatically complete DMP tasks which have not been demonstrated in other approaches so far, e.g. data collection and selection details. The concept of dynamic DMP already pertains to idea of data model. It is defined as a plan which can adopt or suggest user based on the information available on the associated data part and vice versa.

5.2. TUM WORKBENCH

TUM Workbench [26] is an installation of eWorkbench [27] which is being developed by Technical University of Munich Library. Its technological backend including data backup and archive services are being supported by Leibniz-Supercomputing Centre (LRZ).

[26] https://workbench.ub.tum.de
[27] https://eworkbench.github.io

TUM Workbench offers namespaces concept for user, project, sub project as well as for available tools to manage research data. Thus, hierarchical and composite data management is possible while maintaining inheritance, contexts and access rights. Tools available in TUM Workbench are included storage, file, appointment, calendar, note/ lab book, task, task board, commenting and annotating, notification as well as communication tools. Tools are termed as elements. Access and rights management are realised by assigning role in a project. Rights can be customised for elements on individual basis too. Information and data can be registered in terms of online forms and files. Apart from basic operations over data, i.e. create, read, update, move, TUM Workbench also offers link/ unlink operation to refer to and to present a simple association between elements, e.g. to associate data and corresponding DMP. Other common features of all the elements include unique ID, versioning, change logs, support for DataCite as basic metadata, addition of custom metadata fields, web GUI, support for WebDAV and CalDAV protocols, REST API, plug-in support and management of custom DMP templates. Figure 1 presents a snapshot of web GUI based user dashboard in TUM Workbench.

Based on the above-mentioned features figure 2 presents data management model of AMC in TUM Workbench.

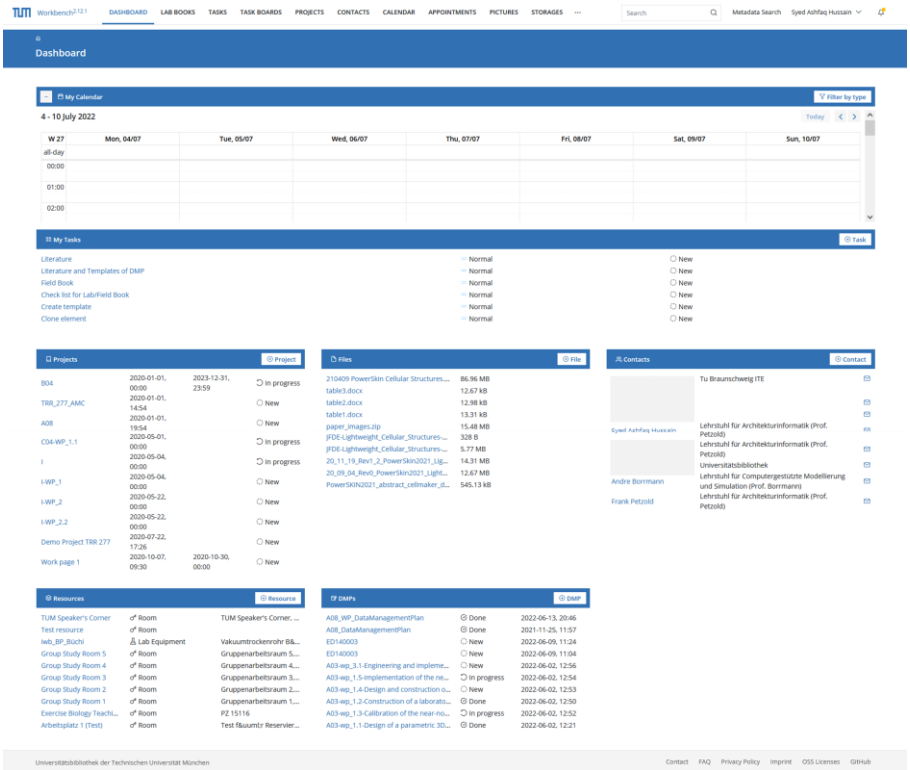

*Figure 1. Snapshot of a user d*ashboard in TUM Workbench.

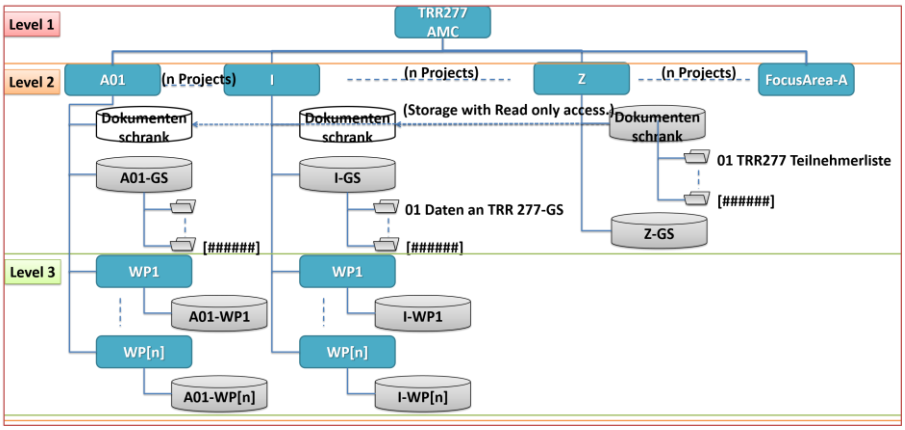

Figure 2. Data management model of AMC in TUM Workbench.

AMC is a trans-regional centre hosted by TU Munich and TU Braunschweig. Whereas, the scientists and labs are situated at different

locations. The research work of the AMC is grouped in three focus areas, i.e. Area A: Materials and Processes, Area B: Computational Modelling and Control, and Area C: Design and Construction[28].

5.3. BACKGROUND AND RATIONALE

It is assumed that during the course of research work while interacting with tools, users generate useful information which may be recorded by means of automation or users' manual insertions. For example, when user create a dataset by using upload feature of the VRE, VRE can record date of creation, size, author's name and contextual information under which data is created etc. And in case of updating an existing data users are required to provide change message which can lead to the information about data processing, changes in data etc. All this information collectively constitutes metadata of the corresponding data as shown in figure 3. This very information can be consumed by associated dynamic DMP either to automate its fulfilment without requiring users to type in the form or by suggesting information based on such data to users to semi-automatically fill the form.

As such, it is assumed that metadata models supported research data management plans could offer an opportunity to reduce the time consuming, repetitive manual processing and often error prone work of documenting DMPs. And increase DMPs' acceptance.

5.4. SYSTEM DESIGN, COMPONENTS AND INTERACTION MODEL

Figure 4 presents system design and respective components of the suggested system. Each component may consist of multiple subcomponents. Following is the explanation of each main component and information flow.

5.4.1. Data

Data component represents dataset with which DMP is associated. In this diagram the hierarchy of the data is presented where all the contextual information may also be retrieved. Depending on the organisation a dataset may consist of single file, storage, project etc.

5.4.2. Metadata

Every dataset in TUM Workbench has associated metadata. Metadata component represents that metadata part. It may vary depending on the

[28] https://amc-trr277.de/amctrr277-research

dataset. Even it may vary for the similar types of datasets. It consists of two parts, i.e. form and metadata model.

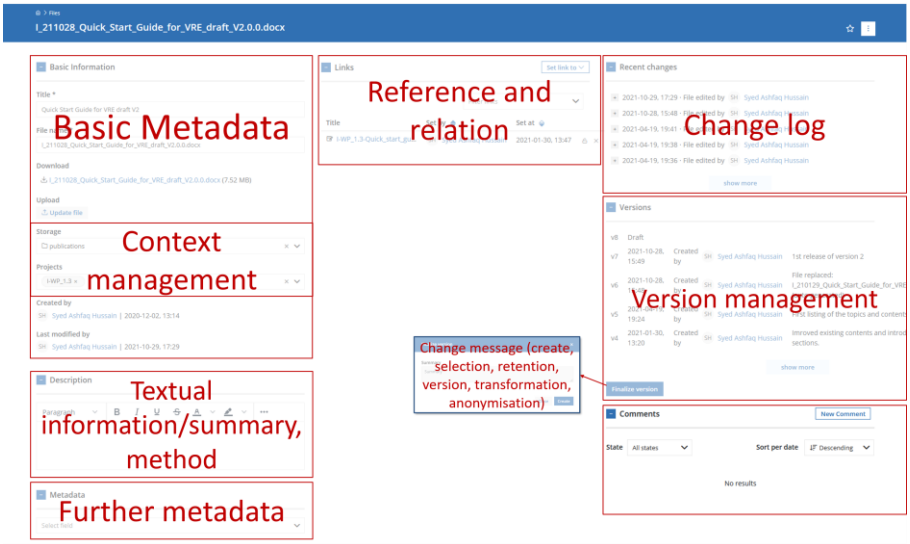

Figure 3. Data file element page presenting fields for auto generated and manual metadata entries.

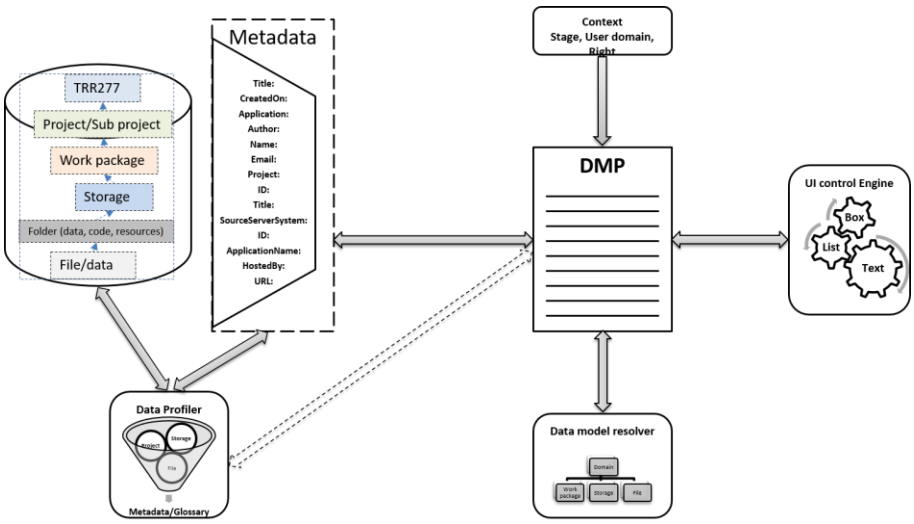

Figure 4. System design, components and interaction model for dynamic DMP.

5.4.3. Data profiler

Profiler component will serve two purposes. On one hand it will iterate through the data and corresponding metadata to create a glossary, on the other hand it will fill the missing metadata fields of the corresponding data automatically or suggest users in case users attempt it manually. It will also serve as an alternate source of information for DMP component.

5.4.4. DMP

DMP component represents DMP form including its data model as well as its controls. DMP controls will be communicating with the metadata component of the associated data. If the required information is available on the data part, the DMP will consume it or suggest the user for input. If the information is missing on the data part, then DMP user as well as data part, e.g. data manager, data system could be informed. Or in an ideal case data could be labelled with such a fact. In some cases, DMP control will also be communicating with profiler component, e.g. if a metadata field is empty then glossary could be consulted or profiling function could be invoked on ad hoc bases etc. DMP component will also have an associated context component which will be governing contextual information and states of DMP.

5.4.5. Data model resolver

Since DMP can be associated with different levels of data, a data model resolver component will resolve DMP form, data model etc. as per corresponding dataset.

5.4.6. UI control engine

Since the values of the DMP are supposed to be dynamic, the user interface components should also be rendered dynamically as per corresponding data models, e.g. checkboxes and lists. Therefore, UI control engine will be resolving form and its components' rendering at the run time.

5.5. METHODOLOGY AND FUTURE WORK

Based on the problem definition, we are following Design Science Research Methodology (Hevner et al., 2004) to produce and evaluate artefacts iteratively. With the inception of AMC in 2020, RDM policy and strategy, custom DMP and corresponding data lifecycle model have already been defined. First the solutions were evaluated and improved based on the feedback of test users who were researchers in the field of architecture. Then the solutions were offered to the community for their real jobs. Data management and organisation is being done using TUM Workbench as VRE

(Shah, 2022). The work on data model based on custom DMP is in progress. After the completion of the data model the proposed system will be implemented. The produced artefacts will be offered to the AMC research community and the evaluation and improvement processes will be started iteratively.

6. Conclusion

This paper discussed two main interrelated topics. First topic about RDM strategies & systems and the second topic about system design for dynamic DMPs. The strategies and systems for RDM have been discussed and categorised based upon complexity and scale in an incremental way. In this way readers could be guided to define their own strategy and selection criteria based on their own use cases and requirements as well as resources. Second section has discussed advanced documentation system, i.e. DMP. The system design has been presented based on an ongoing work. It indicates as to how an integrated DMP could be realized which will be verifiable, semi-automatically updatable and maintainable for common understanding and to increase its acceptance. Further development of features, e.g. integration of data sources like Data Science Storage (DSS) in TUM Workbench are in progress. Although system design for dynamic DMP was presented on the example of TUM Workbench, the approach is system agnostic and could be adopted for any other RDM system exhibiting similar features. Members and the research work of AMC belongs to different disciplines. It would help to generalise and determine the limitations of the proposed system. Therefore, future work would include the discussion of results, challenges, lessons learnt, strength and limitation in handling various types of data based on the proposed strategy.

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DAY 2 - PARALLEL SESSION 4

TOPIC 1 - ARTIFICIAL INTELLIGENCE
TOPIC 2 - INFORMATION MANAGEMENT

GAMIFYING ORIGAMI

Rule-Based Improvisation for Design Exploration

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Abstract. Origami, which originated as a folding paper game in Japan, has turned into a source of learning and inspiration for design and engineering studies. Complex two-dimensional patterns of origami sustain visual rules of space transformation. So, this paper proposes to gamify origami to get users more involved in the design space exploration process. For the gamification of origami, the study alters the origami patterns in a 3D modular composition with rules, scoring, and rounds in a design context. Gamifying origami becomes a tool for a learning experience for first-year architecture students in the early design phases. Accordingly, this paper presents a gaming experience model based on origami for the foundation studios. This model consists of three main stages: start, rounds, and finish. The teaching of the model is the mereological relationship providing continuity concerning improvisations with visual rules. The reward is the model complexity, such as folding numbers, and regular or modified folding. The penalty is losing scores if the continuity is not maintained. The presented experience model is performed twice in the foundation studios. The former is for understanding how much preliminary knowledge is required for the first-year students to grasp and complete the game. The second is for testing the experience. The results of the study prove the role of visual reflection-on/in action by creating pauses during the origami design and the importance of sustaining the visual inference with transformations between individuals to experience form to formation, complexity, unity, and creativity in origami design. This study would contribute to the literature on experimental methods for design pedagogy.

Keywords: *origami, folding, design exploration, gaming experience, visual rules.*

ملخص. تحولت لعبة الأوريجامى التي نشأت كلعبة ورقية قابلة للطي في اليابان إلى مصدر للتعلم والإلهام لدراسات التصميم والهندسة. تدعم أنماط الأوريجامي المعقدة ثنائية الأبعاد القواعد البصرية للتحول الفراغى. لذلك تقترح هذه الورقة استخدام لعبة الأوريجامي لجعل المستخدمين أكثر انخراطًا في عملية استكشاف الفراغ التصميمي. بالنسبة لعملية "تلعيب" الأوريجامي، تعمل الدراسة على تغيير أنماط الأوريجامي في تكوين معياري ثلاثي الأبعاد

باستخدام القواعد والتسجيل والجولات في سياق التصميم. أصبحت تجربة تلعيب الأوريجامى أداة لتجربة تعليمية لطلاب العمارة في السنة الأولى في مراحل التصميم المبكرة. وفقًا لذلك، تقدم هذه الورقة نموذجًا لتجربة الألعاب على أساس الأوريغامي لاستوديوهات التصميم المعمارى فى المراحل التأسيسية. يتكون هذا النموذج من ثلاث مراحل رئيسية: البداية والجولات والنهاية. إن تعليم النموذج هو العلاقة المجردة التي توفر الاستمرارية فيما يتعلق بالارتجال مع القواعد البصرية. وتكمن المكافأة في درجة تعقيد النموذج، مثل الأعداد القابلة للطي، والطي المنتظم أو المعدل، والعقوبة فى خسارة درجات إذا لم يتم الحفاظ على الاستمرارية. تم تنفيذ نموذج التجربة المقدم مرتين في الاستوديوهات التأسيسية. ركزت المرة الأولى على فهم مقدار المعرفة الأولية المطلوبة لطلاب السنة الأولى لفهم اللعبة وإكمالها، والثانية على اختبار التجربة. أثبتت نتائج الدراسة دور الانعكاس البصري على/ في العمل من خلال إنشاء فترات توقف أثناء تصميم الأوريجامي وأهمية الحفاظ على الاستدلال البصري مع التحولات بين الأفراد لتجربة الشكل إلى التكوين والتعقيد والوحدة والإبداع في تصميم الأوريجامي. ستساهم هذه الدراسة في الأدبيات المتعلقة بالطرق التجريبية لعلم أصول التدريس.

الكلمات المفتاحية: *الأوريجامى، تقنية الطى، الاستكشاف التصميمى، تجربة الألعاب، قواعد بصرية.*

1. Introduction

Today, origami began as a figurative folding paper game and has turned into an architectural and engineering discipline. Thanks to its compliant mechanical and structural layouts, origami offers innovative solutions for functional use in engineering problems. The layouts that answer these innovative solutions are mainly based on regular patterns, such as Miura-ori, Ron Resch, and Waterbomb. These regular patterns are widely preferred in existing and emerging literature due to the ease of making two-dimensional patterns and the association of the two-dimensional patterns with three-dimensional free forms through their geometric configuration. These patterns, such as in Figure 1, are repetitively used in early design processes of architecture as well. However, the students, who choose to work with origami in a design process, find it challenging to engage with well-defined origami patterns in a situated and dynamic early design process. Although the design problems are ill-defined and iteratively re-structured throughout the process, the lack of ability to understand and manipulate the complex geometry of regular patterns limits the designers' action parallel to design decisions. Consequently, the resulting designs are limited to the exact copy of the same patterns and poorly adapted to the design context. Beyond copying the same pattern formally, each origami pattern's underlying rules promise to extend the design-space exploration in an early design process.

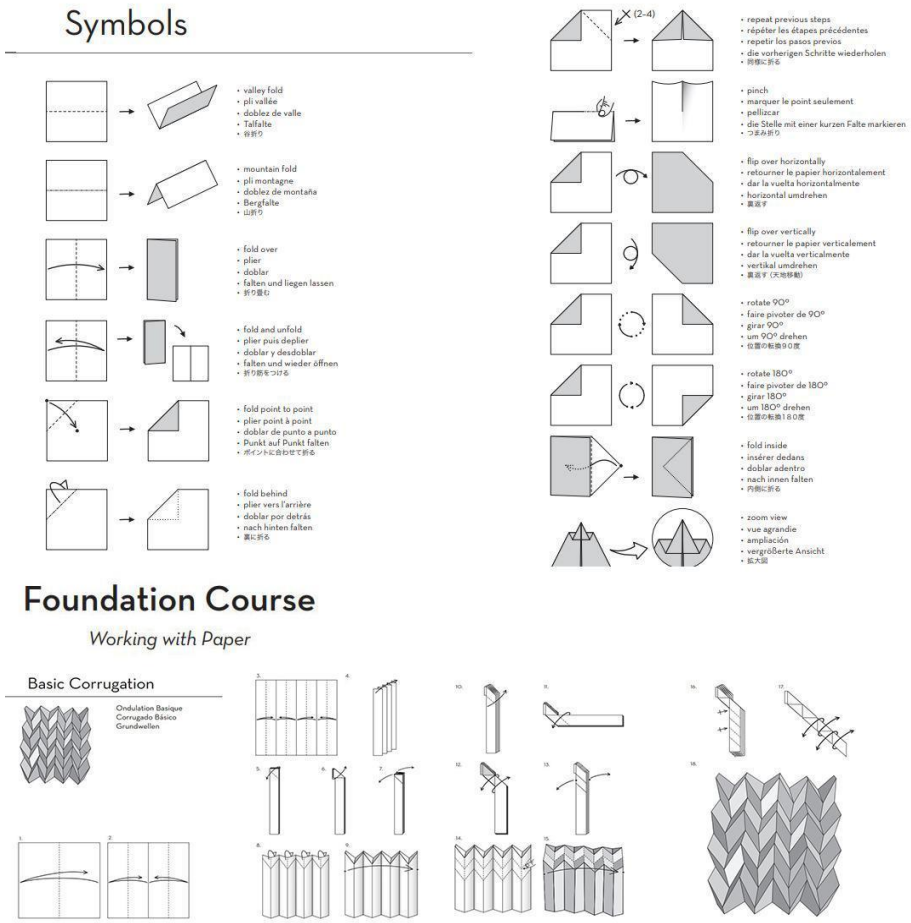

Figure 1. Bauhaus foundation course exercise (source: Gjerde, 2017).

Vyzoviti (2003), Gjerde (2017), and Megahed (2017) studied with architecture students using origami as a source of inspiration for design applications. However, this study questions how to incorporate the visual rules behind origami patterns in early design phases to obtain new forms beyond repetitive patterns. To integrate the catalog of visual rules into the activity of folding, this study proposes gamification as a design method. Gamification refers to the use of game design elements such as scoring, levels, and rules in non-game contexts (Deterding, 2012). In this study, we bring gamification with an aim to get users more involved in the origami design space exploration process. To do this, we propose to change the experience of complex origami patterns through simple origami modules, rules, scoring, and rounds in a design context. Although it is an easy start to use the above-stated repetitive geometric patterns, the difficult part of this process is breaking the pattern

organization if needed. To do this, it is essential to capture the rules that govern patterns' geometric configuration. The rules are the relations between visual design elements such as fold lines and edges, the relations between this visual composition, and the affordances of three-dimensional configuration. Capturing, externalizing, and manipulating the visual rules set the play, improvisation, and exploration.

The objectives of forming a situated bottom-up process from a small starting module with visual rules vs. adapting a structurally complex form had been defined thus:

- Experiencing co-creation of a holistic, consistent, new design product with unpredictable results.
- Describing / externalizing / evaluating what is produced in the process and enabling the student to discover new ideas and ways of doing.
- Seeing the possibilities of actions by doing together as a group enriches the design space, students' experience, and learning.

The significance of the aforementioned objectives for education has been defined thus:

- learning by doing
- learning by each other
- reflection in-on action
- idiosyncratic expression through sensory experience
- externalizing individuals' sensations through rule-based expression
- taking advantage of uncertainty
- shifting from form to formation
- retrospective thinking
- reverse engineering

Moreover, its significance for the basic design has been defined thus:

- The importance of visual rule-based composition in design-space exploration
- mereological relationship
  - seed-motif-pattern
  - continuity
  - boundary, inner-outer
  - volumetric and spatial transformation

2. Background

Paper folding has been widely used in the education context. Fredrich Froebel is the most recognized pedagogue who adopted paper folding to enhance kindergarten students' self-expression, social participation, creativity, and motor skills. He formulated three-category of exercises: The first one, "folds of truth," aids the students with the basics of geometrical principles; the

second category, which is called "folds of life," consists of figurative models; The final exercise, named "folds of beauty," are based on manipulating the learned figurative model for a new creation (Fiol et al., 2011). Froebel teaches abstract concepts by showing students how to use them first-hand in action, then scaffolds students with figurative models; lastly, he asks them to apply these concepts in free will to form their own creations. Another notable teacher, Josef Albers in Figure 2, asks students for open-ended experimenting and spontaneous playful tinkering with paper through folding as the initial exercise of the Bauhaus preliminary course (Barker, 2011). Folding paper, Moholy-Nagy (1938) declares as one of the means of the method of Bauhaus is to keep in the work of grown-up the sincerity of emotion, the truth of the observation, fantasy, and creativeness of the child. While the Bauhaus model emphasizes the individuals' idiosyncratic perception and sensation experience for creativity, they teach to externalize and regulate their sensations, and perceptions through visual and other forms of expressions. These rule-based expressions, in turn, teach students how to interpret things in relation, how to focus the parts' relation to the whole, and how to abstract the whole in different forms. As Barker (2011) states, the objective within Albers's Vorkurs was not to create finished works of art but was how to design and explore the duality and latent potential of materials. Moreover, externally expressing students' exploration is critical to furthering their design exploration.

Figure 2. Josef Albers and Volkurs (source: Wingler, 1978).

The expression of origami art and externalization of its production process is always a part of origami when one needs to transfer knowledge. Robert Lang, who designs very complex origami figures, makes the calculation of these intricate patterns with his software and brings origami as a solution to many engineering and science applications. Lang (2011) depicts the basic origami actions (such as valley-mountain fold, fold point to point, pleat fold, fold and unfold, repeat the previous step, pinch, rotate, turn over, fold inside, inside reverse fold, sink a corner, inside crimp fold, rabbit ear fold); He uses them to diagram the production process of figurative designs in his publications. These expressions are aimed to use for producing a final product. The novice designers cannot transform and modify these steps and go outside of the boundary of a pre-defined product. However, Jackson (2011) proposes to depict the techniques and strategies for transforming one's action, instead of the production of final figures. In other words, he expresses not the form but the formation by showing the continuity between each folding action with visual rules. When we go back to the method of Froebel, we can say that Lang's focus is on the "folds of truth" and "folds of life", Jackson centers on the method for "folds of beauty". From a designer perspective, Jackson presents folding techniques by discussing how a single sheet of paper can transform into distinct formal expressions that can be used by designers. On the other hand, prominent researchers, such as Demain et al. (2011), tightly engage in the mathematics of origami regarding 3D transformations of folding types. These studies are significant in understanding relative relations and formations among the fold lines and surfaces during deployment.

Based on this background study and our teaching experience at Istanbul Technical University, we deduce the importance of first-hand experience (1), self-expression (2), self-reflection on action (3), and abstraction of regulating rules based on reflections (4) both for the unity and the creativity of origami designs. Moreover, we observed that peer learning is another factor to enhance the students' experience. To bring the aforementioned factors and strategies into experiencing origami design, we find a solution to gamify origami activity.

To experience origami design as a situated formation process:

- We propose to play origami as a modular step-by-step game.
- We offer a digestible origami module by starting with a simple pattern and asking students to depict the pattern with visual rules.
- We asked students to pause in each action; depict each module production with visual rules.

To enrich the design space and students' experience and to arrive at unity and complexity:

- we asked students to observe the depiction and 3D module production of another student.

- We demanded to add a new module by transforming the other students' 3D modules based on his/her visual rules.

3. Methodology

The first-year architecture students are asked to retrieve visual rule sets of the 3D patterns based on protocol analysis and think-aloud techniques. These rules are further evaluated to generate new formal alternatives. The participants' direct engagements with the paper intend to rely on Husserl's phenomenological epoche/bracketing method, which demands the existence of the object satisfying the content of the intentional act (Husserl, 1962). The gaming model is shaped according to the pre-experiment with the first-year students to understand the required level of knowledge that should be given to the students to grasp and finish the gaming experience. Three students' production made during the pre-experiment session are shown in Figure 3. According to the pre-experiment session, difficulties are determined to develop the model.

The results of the pre-experiment determine the difficulties that occurred during the experiment. The main difficulties are briefly listed below.

- grasping the examples demonstrated over pictures
- understanding and interpreting the 2D pattern to fold and 3D folding pattern created as a result of deployment
- breaking the folding pattern's rules to differentiate it
- the complexity and size of the module

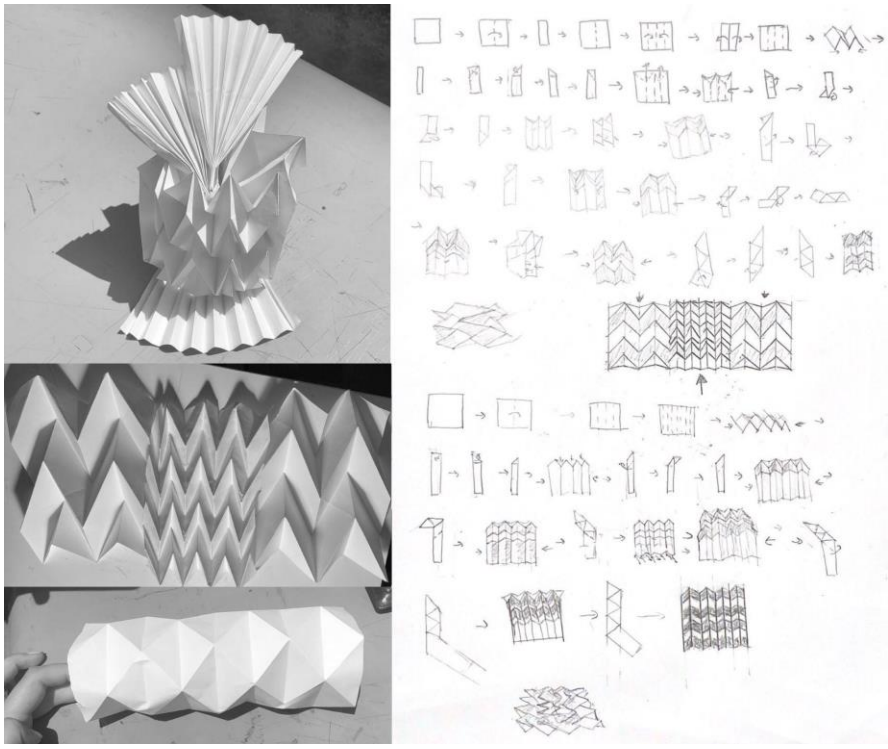

Figure 3. Three student productions from the preliminary physical experiment.

Decisions are taken after the preliminary physical experiment, and they are indicated as follows.

- reduce the model complexity and component redundancy
- start with smaller modules
- start by giving a 3D module as a folded model instead of a 2D pattern
- increase the module diversity and count
- make the sample pool consisting of well-defined folding modules
- give a limited time to the students to complete a module
- shift the folding module to the next person on their right to differentiate the pattern

The game framework is established taking into account the difficulties and decisions stated above. Accordingly, the following principles are defined.

- teaching: mereological relationship providing continuity, 3D transitions, and understanding the idea of form to formation.
- reward: based on the model complexity, such as folding numbers and being a regular or a modified folding pattern.
- penalty: if passed with empty submission or if the lines and surface slopes are not maintained, they get -2 points.

- definition of the module: the transformation of the previous module (isometric transformations like reflection and rotation, changing, number of folds, type, and direction, type of curve, etc.).
- result output: 3D modular composition

In light of the pre-experiment, the gaming process is created based on 3 main stages: start, rounds, and finish, which are briefly illustrated in Figure 5. Groups of four students are formed, and the students in each group are assigned numbers as nicknames. Students are expected to choose a base module from the pool in the first stage. The pool is indeed a box consisting of orthogonal and curved folding modules. The base modules can be seen in Figure 4. Orthogonal folding modules are distributed to odd-numbered students, whereas curvilinear folding modules are distributed to even-numbered students. Curvilinear and orthogonal folding modules are thus evenly distributed.

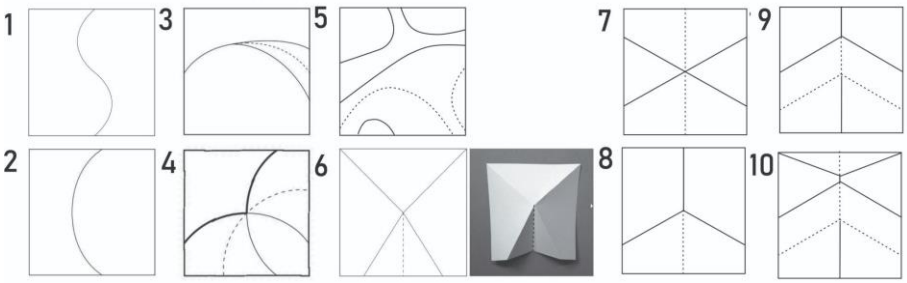

Figure 4. The two-dimensional templates of the base modules were folded. Each student chose one of the folded module to start the game.

In the second stage, a rule is defined for the students, who are expected to create a new module accordingly (Secondary modules can be seen in Figure 5). This study describes this rule as maintaining continuity and part-whole relationship to develop a new module. That is, spatial organizations should ensure the continuity of lines or surface slopes concerning continuity, unity, and design variety for 3D geometric compositions. The developed module becomes a cell in the 3D pattern composition and is attached to the previous module. At the same time, students define the visual rules with keywords. They get points for the composition when the process is completed, or time runs out. After scoring, students forward the module they created to the person on their right. In this way, the first round is over, and this iteration ends after the 4th round.

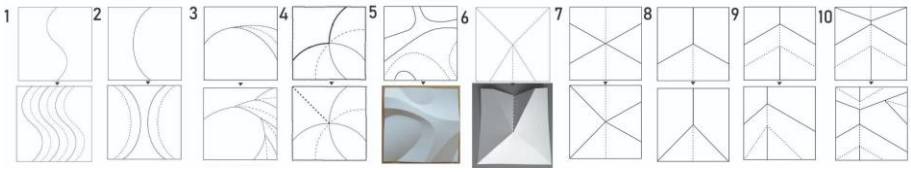

Figure 5. New modules were added at the second round. The visual rules show the transformation of the constitutive elements from the based module into the second module.

All the points are calculated after the rounds are completed. They get +2 points if successful, -2 points if passed, and -1 points if wrong. Afterward, students examine the visual rules and composition. They give feedback on sketch paper.

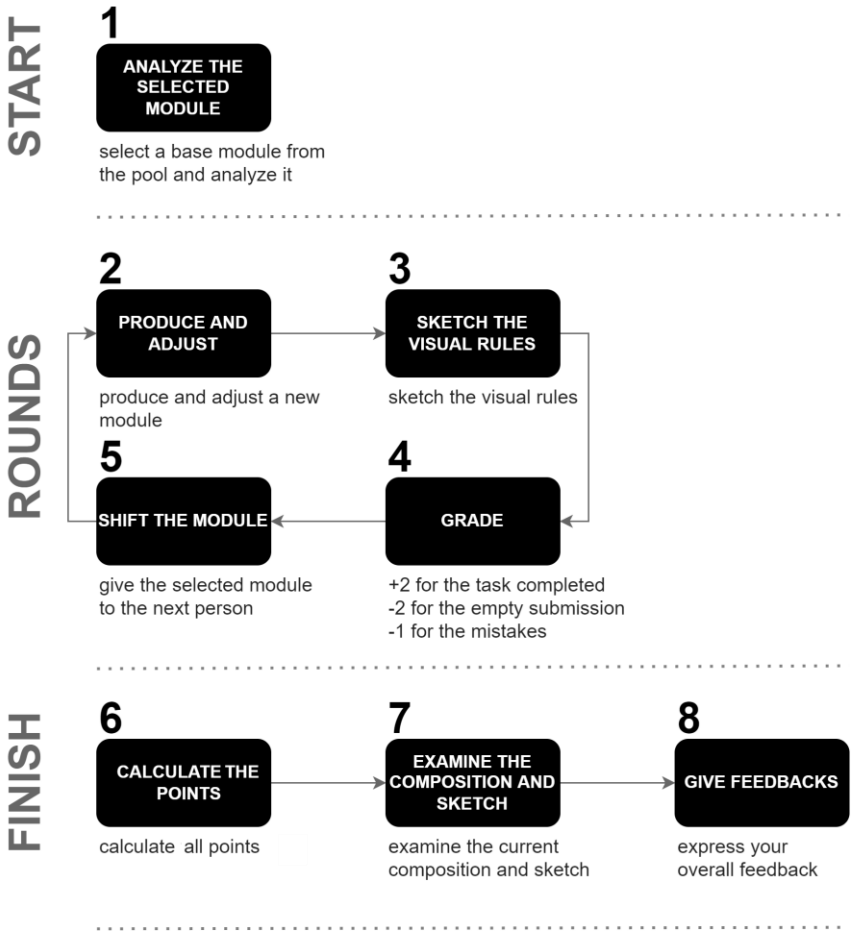

Figure 6. The process diagram

4. Results and Conclusion

The process diagram in Figure 6 was implemented as a one-hour exercise by thirty students which were divided into several small groups of four to five.

Each student started with a base module and an empty paper for depicting their visual reflections in/on actions. Firstly, each student observed and depicted the composition of the base module with the aim to understand the visual and spatial relations of the base composition. She/he numbered the first depiction with the number 1. Later, she/he continued to add new modules, depicted each modular action step by step, and numbered each depiction incrementally. After she/he added several modules, some of the students went back to previous steps and modified the composition of the previous module. In that case, she/he depicted this action as well and used the previous number of that module in her/his depiction. The purpose of pausing the origami process through making depictions was to enhance the students' conception of the continuity between each modular element and the unity of the whole composition. At the end of the rounds, each student finished one origami design configuration (three of them can be seen in Figure 7). Each origami design configuration diverged from regular patterns and the process of formation can be traced by students 'visual and verbal depictions. Based on students' origami design configuration and visual & verbal depictions, we grouped tendencies in students. The tendencies of the students are summarized below.

- The final origami configurations and the transformation types between modules differ between groups and are similar between group members' production. This shows the influences and learning from each other.
- While driving the design decision with visual rules maintained the continuity of two-dimensional origami modules, the continuity in three-dimension was not succeeded in a couple of groups of works.
- A difference between students' ways of thinking when they are explaining the visual rules has been obtained. Some of them express with analogies such as "create a winding road", the others with mathematical terms such as "turned 90 degrees and increased the curvature of a curve", or some of them use the geometrical elements of modules such as "added another wavy mountain folds"; moreover, the ones integrate the appearance and affordances of materials into their expressions such as "add two curved folded modules to get stiffness".
- Shifting the eye between micro to macro and cyclic movements between the parts and the whole has been read in the students' depiction of visual rules. Some students referenced the whole composition when they express the relations between design elements; Others solely focused on the properties and the relations between the parts of single modules.
- While the first module ruled the whole process in a group of works, the other groups' choice of the transformation type caused to fade the dominancy of the first module. Moreover, the complexity level of the processes varied between groups.

- As the complexity of the origami design increased through the progressive rounds, the interaction between students raised. Even though the students were responsible to transform a single module, some of them intervene in the previous module and transform the adjacent modules according to his/her visual rule.

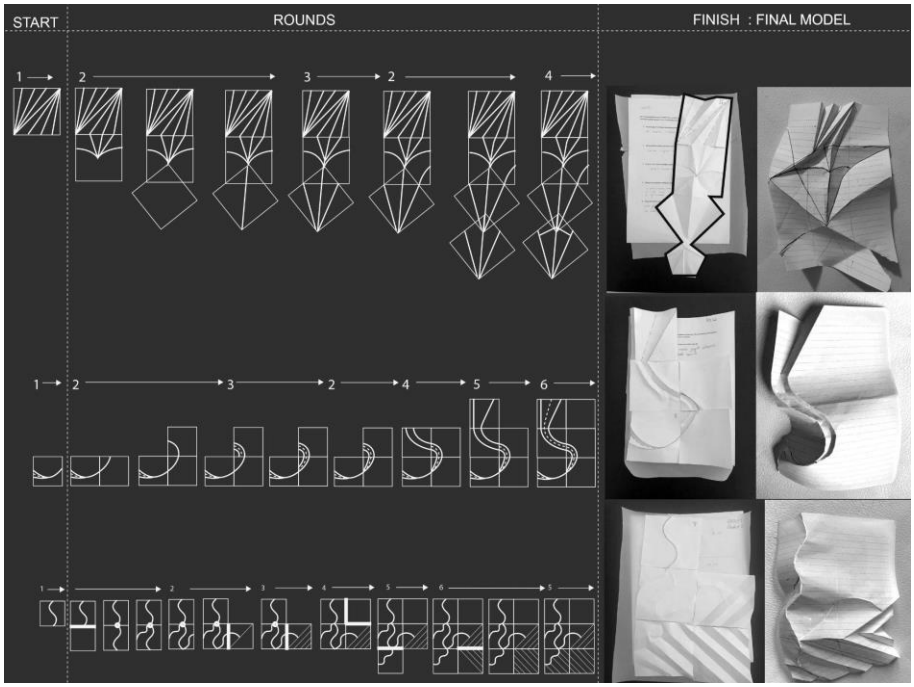

Figure 7. Three selected examples out of thirty student productions.

The result of the study proves the potential of gamifying origami for the early design process. Accordingly, this study would contribute design space explorations with novice designers in finding new forms through low-fidelity prototyping. This gain extends the students' perception and abstraction ability by being aware of the underlying geometric organization with visual rules.

The limitations of this study are the limited number of students and time constraints. We kept the rule of each set equal. Changing the rule can be aimed to teach a module from the basic design education. Further study can consider integrating the following categories to the rule sets: material, color, light/shadow, solid / void relationship, and structure.

New concepts and rules can be integrated as exemplified below.

a. pre-conceptive aids (samples of geometric properties, relations, and transformations)

b. make

c. evaluate and explain (applying pre-conceptive aids to the creation and transformation of rules, integrating the affordances of three-dimensional configuration to the visual rules)
d. re-make

This study would contribute to the literature in model making provoking creativity, and detail development, and is significant for gaining 3D thinking over visual rules and increasing design variety in design studios. Folding, as a means of connecting mind and hands, fuels the imagination. Seeing and explaining the folded composition in an unanticipated way is the definition of imagination and the sign of creativity. Depicting what is seen with visual rules and sharing it with others scaffolds the continuity of the design process and promotes its transformation and diversion. Besides, the transformation of two-dimensional patterns to three-dimensional configurations with folding operations, students discover materials' possibilities and become conscious of volume and space.

Acknowledgments

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EXPLORING VIRTUAL REALITY AS AN APPROACH TO RESURRECT DESTROYED HISTORICAL BUILDINGS

An Approach to Revive the Destroyed "Egg Building" through VR

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Abstract. An important part of a city, that gives it a sense of community and character, is its history. One way of acknowledging this heritage is by preserving historic building and structures. Old buildings are witnesses to the aesthetic and cultural history of a city, helping to give people a sense of place and connection to the past. Unfortunately, despite their importance within the city, historical buildings are most of the time subject to demolition and to be replaced- leaving behind stories told and untold of what use to be. The paper, therefore, aims to explore the capability of the metaverse, using virtual reality touring, to revive the memory of historical buildings that are subject to fade. Where preserving historical buildings can not only act as a symbol of grandeur but is also vital for reviving the community's collective memory. The case study focused upon in the research paper shows a first step in the development of an immersive virtual tour for the significant building of "The Egg" or "Beirut City Center" in Downtown- which is a building that witnessed a series of unfortunate events that lead to destruction, erasure, and demolition of the building. Therefore, examining the recovery and revival of this unique historic site in an unconventional way which is in the metaverse, specifically the Virtual Reality (VR). The paper assumes that virtual reality, as the main metaverse approach, would help people 'remember' and 'mentally revive' the destroyed historical buildings that once acted as the building blocks in the impacted city. To prove this hypothesis, two different methodologies will be used, by theorical analysis and literature review, such as analyzing the main keyword, and analyzing datum from previous works. The second method will rely on the physical methodology, where virtual 3D Models will be built in a computer software, Autodesk Revit, then imported within a

EXPLORING VIRTUAL REALITY AS AN APPROACH TO RESURRECT DESTROYED HISTORICAL BUILDINGS

VR experience for an enhanced experience within the historical site to preserve the historic buildings and revive the collective memory within the community, enabling people to view how these historic sites once were and how they have now become.

Keywords: *Historical buildings, Metaverse, Virtual reality, Preservation, Architecture, Collective memory.*

ملخص. يعتبر التاريخ جزءا مهما من المدينة والذى يمنحها إحساسًا بالمجتمع والشخصية. تتمثل إحدى طرق الاعتراف بهذا التراث في الحفاظ على المباني والمنشآت التاريخية. وتعتبر المباني القديمة شاهدة على التاريخ الجمالي والثقافي للمدينة، مما يساعد على منح البشر إحساسًا بالمكان والارتباط بالماضي. ولسوء الحظ، وعلى الرغم من أهميتها داخل المدينة، فإن المباني التاريخية تخضع في معظم الأحيان للهدم والاستبدال - تاركة وراءها قصصًا رويت ولم تروى معبرة عما كانت عليه المدينة. ولذلك تهدف هذه الورقة البحثية إلى استكشاف قدرة الميتافرس على إحياء ذاكرة المباني التاريخية المعرضة للتلاشي، وذلك باستخدام جولات الواقع الافتراضي. حيث لا يمكن أن يكون الحفاظ على المباني التاريخية بمثابة رمز للعظمة فحسب، بل يعد أيضًا أمرًا حيويًا لإحياء الذاكرة الجمعية للمجتمع. تُظهر دراسة الحالة التي ركزت عليها الورقة البحثية خطوة أولية في تطوير جولة افتراضية غامرة للمبنى الهام "البيضة" أو "وسط مدينة بيروت" في وسط المدينة - وهو مبنى شهد سلسلة من الأحداث المؤسفة التي أدت إلى تدمير ومحو وهدم المبنى. ولذلك، يتم فحص استعادة وإحياء هذا الموقع التاريخي الفريد بطريقة غير تقليدية في الميتافرس، وتحديداً الواقع الافتراضي. تفترض الورقة أن الواقع الافتراضي، باعتباره النهج الأساسي الرئيسي للميتافرس، من شأنه أن يساعد الناس على "تذكر" المباني التاريخية المدمرة و"الإحياء العقلي" لها والتي كانت بمثابة اللبنات الأساسية في المدينة المتضررة. لإثبات هذه الفرضية، سيتم استخدام منهجيتين مختلفتين، من خلال التحليل النظري ومراجعة الأدبيات، مثل تحليل الكلمات المفتاحية الرئيسية، وتحليل الأعمال السابقة. ستعتمد الطريقة الثانية على المنهجية المادية، حيث سيتم إنشاء نماذج ثلاثية الأبعاد افتراضية في برنامج أوتوديسك ريفيت، ثم استيرادها ضمن تجربة واقع افتراضى لتحسينها داخل الموقع التاريخي للحفاظ على المباني التاريخية وإحياء الذاكرة الجمعية داخل المجتمع، مما يمكن الناس من مشاهدة كيف كانت هذه المواقع التاريخية وكيف أصبحت الآن.

الكلمات المفتاحية: *المبانى التاريخية، الميتافرس، الواقع الافتراضى، الحفاظ، العمارة، الذاكرة الجمعية.*

1. Introduction

Virtual reality technology plays an important role in realizing Tele-sensation, where viewers can enter a certain ‘artificial space’ and walk through- even handle virtual objects. The virtual world allows us a stereoscopic view from front or side, depending on our viewpoint, just as in the real world. The ability to enter and walk through the virtual world and handle virtual objects using hand gestures makes VR interactive, and this is one of its most important features. Communication can be:

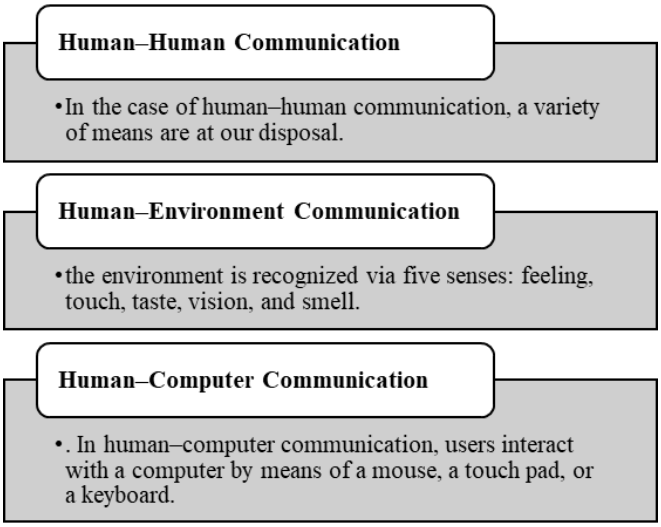

Figure 1: Various ways of Communication

Human–human communication and human–environment communication has been developed over a long history of interaction. It is desirable to provide human beings with a human-friendly environment where the interaction with computers is just as easy as the human–human communication or human–environment communication.
The paper, nevertheless, aids in providing human beings in the present and future generations with a virtual environment where they can interact with a computer- by dealing with virtual historical buildings/ elements. Which inevitably enables users to remember or view a town or city's culture and interesting past. These old buildings are visual reminders of an area's cultural heritage and the people and industries that once played a key role in establishing the area and making it what it is today.

1.1. RESEARCH APPROACH

As it is generally known, historical buildings convey a huge part of our cities. Preserving historic buildings and landmarks of communities contribute greatly to keeping its unique values, character, and momentous beauty. Restoration of history, in all its forms, preserves the identity and roots of people and their communities, where it not only benefits in the nation's cultural worth, but also benefits educational, environmental, and economic advantages. Unfortunately, many historical buildings around the world are being demolished, neglected, and forgotten, especially when they have been destroyed by natural or man-made disasters. Therefore, many techniques of historic preservation are essential such as transforming old and deserted buildings into more modern facilities, while keeping their historic

architectural value and worth, another technique revolves around how virtual reality is able to bring historical sites to life (Agnello, Avella, 2019).

> *"If the purpose of museums is to build a bridge between the past and present, then VR is surely one of the most innovative construction tools at their disposal."*
>
> -Rebecca Carlsson, 2020

In this well-known quote stated by the Rebecca Carlsson- a professor in Stanford University- which claims that virtual reality, or VR, is exactly as the name suggests: technology that audibly and visually transports the users to another place or time. (Carlsson, 2020) Virtual reality (VR) is a powerful resource that has recently gained popularity in sectors like video gaming, but there are also an increasing number of museums and heritage sites that are putting VR to good use. (Levy, 2017) Here lies the question of, how can virtual reality resurrect historical sites?

With the aid of digital technology, virtual reality is an engaging feature that allows users to virtually engage with others in urban spaces and encounter with them on a human scale. The main reason why VR differs from other multimedia technologies is its ability to generate a sense of presence. Experiencing historical buildings (past) gives individuals the ability to immerse themselves completely in important historical events. Therefore, it is considered vital to a) create an archive for future generations to view the historical buildings that have been damaged and b) enhance the people's collective memory and ignite their sense of belonging within the city, as Palmer Luckey- founder of Oculus Rift stated: "VR is a way to escape the real world into something more fantastic". It has the potential to be the "most social technology of all time." There are a wide variety of applications for virtual reality which include: architecture, medicine, entertainment, sport, arts; this paper will pursue to explore the connection between virtual reality and historical sites, which will be later discussed.

1.2. PROBLEM DEFINITION

Since natural disasters and human conflict have destroyed our global heritage, several challenges erupt that disrupts the architectural elements within the building and negatively impact the collective memory of the citizens. Unfortunately, after a disaster occurrence, there is little to no sufficient data available where users can view how these site/ buildings once were'4 and how much they had an impact within the city. The availability of these images would aid in reviving the historical buildings by creating a realistic platform where people can engage and feel a sense of belonging to their culture, while enhancing their collective memory.

Viewing something that 'has once been there' in modern times using innovative technology, will not only facilitate the approach for the users to revive and compare how buildings once were and have now become, but also allow a sense of belonging that is recently declining. Moreover, the reviving, or 'preservation' of historical buildings virtually allows to educate citizens and elevate their sense of pride.

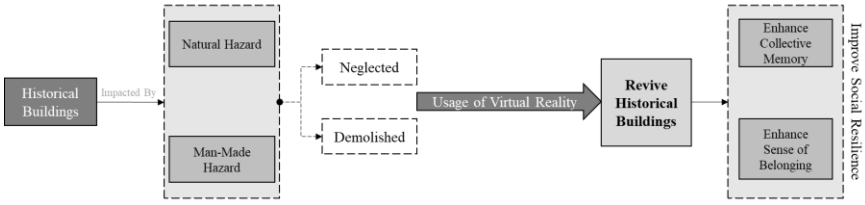

Figure 2: Process of VR to Mentally Revive Historical Buildings

1.3. AIM OF THE STUDY

The aim of this research is:
"Exploring the ability of virtual reality as the main metaverse approach, which contributes to resurrecting historical buildings that have been destroyed"
Some objectives below are used to help achieve the aim:
- Showcasing the importance of historical buildings within the city.
- Shows the lasting hyperlink among historical building -past- and virtual reality -future-, to illustrate the images of the before and after within the built environment.
- Focus on the outcomes of virtual reality images in the 'after' state to enhance the people's collective memory of historical sites. In addition, this paper shows a case study that historical building vision in virtual reality will be a part of a 360 virtual tour to relive the past stage of a historical building.

1.4. RESEARCH HYPOTHESIS

The paper assumes that virtual reality, as the main metaverse approach, would help people 'remember' and 'mentally revive' the destroyed historical buildings that once acted as the building blocks in the impacted city. Frank Gehry once stated: "Architecture should speak of its time and place, but yearn for timelessness", which relates to the usage of innovative techniques- such as virtual reality- to allow the memories of historical building to last and not fade with time. (Gehry, 2007).

2. Literature Review

Virtual reality is inhabited by many people who share various experiences. However, what is the relation between Virtual reality (VR) and the Metaverse? VR is one of the many technologies that the term 'metaverse' is designed to cover. Metaverse, on one hand, could refer to any other technology that recreates or augments real-world experiences with technology, where VR is the most immersive experience available today, where it creates a unique opportunity for enhancing the people's memory of what "the city once was". The paper explains one type of metaverse (VR) and how users interact with it to view the destroyed historical buildings.

Historical buildings and virtual reality are prominently two contradicting entities, that when brought together can have extraordinary urban planning potential. Historical sites are known to be static and fixes, whereas virtual reality is more flexible, dynamic, and have the ability to represent any given space/ form. The adoption and realization that virtual reality is a vital component to revive what 'have once been there' to create a realistic vision for users of how historical buildings impacted the citizens. Moreover, it gives them a chance to compare between 'before' and 'after' images that would even allow the users to navigate within the given space. Virtual reality has been frequently discussed over the last few years. With people inventing newer technologies and presentation methods, virtual reality has now set its foundation on the ground of architectural design. Surprisingly, although virtual reality has the ability to create unlimited possibilities in design, according to American Institute of Architects (AIA) Firm Survey Report 2018, 16% of architecture firms only are currently using virtual reality in their practice (AIA, 2018).

However, there are many well-known publications that clearly manifested in the field of 'virtual reality' written by urban planners and architects such as: Richard Levy, John Bonnett, CyArk, and Philip Rosedale, where these pioneers created several proposals and initiations for the integration of virtual reality amongst historical architecture and sites:

> *"3D environments are instruments, and if properly exploited they stand to provide historians with substantial gains in their capacity to teach, represent and analyse the past."*
>
> John Bonnett, 2003

Remarkably, Bonnett foresaw some of the most recent advancements in virtual reality and augmented reality technology in his vision on the future of 3D environments. Nevertheless, it is of great importance to acknowledge the definition of the main keyword, that is 'virtual reality' (Bonnett, 2003).

2.1. VIRTUAL REALITY – CONCEPT AND DEFINITION

Virtual reality has been notoriously challenging to define over the years. However, it is apparent that there are two main words to define which are 'virtual' which means unreal, and 'reality' which refers to the real world. Thus, virtual reality is an artificial environment that is produced by software and presented to the user in such a way that causes the user to suspend belief and accepts it as a real environment. Thomas B. Sheridan describes this as a "sense of being physically present with visual, auditory, or force displays generated by a computer" (Thomas, 2000). VR is commonly defined as the use of computer-generated 3D environment. Inevitably, three proposed key elements are known to characterize VR which are: (a) Visualisation, the ability to look around, usually with the use of a head-mounted display; (b) Immersion, suspension of belief and physical representation of objects; (c) Interactivity, degree of control over the experience, usually achieved with sensors and an input device like joysticks or keyboards (CruzNeira, Sandin, DeFanti, Kenyon, & Hart, 1992; Williams & Hobson, 1995). Where the main question is how can VR have the potential to generate a sense of the presence of the past?

Since its appearance, VR has been used in different fields, as for gaming (Zyda, 2005; Meldrum et al., 2012), military training (Alexander et al., 2017), architectural design (Song et al., 2017), education (Englund et al., 2017), learning and social skills training (Schmidt et al., 2017), simulations of surgical procedures (Gallagher et al., 2005), assistance to the elderly or psychological treatments are other fields in which VR is bursting strongly (Freeman et al., 2017; Neri et al., 2017).

TABLE 1. Various fields where virtual reality is used

%	Frequency	Subject category (for all the period)
42,15	9131	Computer Science, 1990–2016
28,66	6210	Engineering, 1990–2016
8,21	1779	Psychology, 1990–2016
7,15	1548	Neurosciences and Neurology, 1992–2016
6,55	1418	Surgery, 1992–2016
5,85	1267	Automation and Control Systems, 1993–2016
4,80	1040	Neurosciences, 1992–2016
4,74	1027	Imaging Science and Photographic Technology, 1992–2016
4,30	931	Education and Educational Research, 1993–2016
3,92	849	Robotics, 1992–2016
%	**Frequency**	**Subject category (for the last 5 years)**
29,80	2311	Computer Science, 2011–2016
25,44	1973	Engineering, 2011–2016
11,10	861	Neurosciences and Neurology, 2011–2016
9,32	723	Psychology, 2011–2016
7,70	597	Surgery, 2011–2016
7,53	584	Neurosciences, 2011–2016
6,02	467	Education and Educational Research, 2011–2016
5,54	430	Rehabilitation, 2011–2016
4,42	343	Clinical Neurology, 2011–2016
3,92	304	Materials Science, 2011–2016

As it is apparent in table 1 above, VR relates to various field of study, however this paper adopts the educational approach for VR to allow people and students or researchers to learn about their past or other city's past. Some related work is demonstrated of how various VR technologies are used to recreate how the city once was and how the buildings that are destroyed have 'come back to life' (Chen, 2010).

The user's VR experience could also be revealed by evaluating the levels of presence, realism, and reality. In virtual reality, "presence" is a psychological concept that encompasses the experience of physically being there, as well as the ability to behave and react as though the user were in the actual world (Heeter, 1992). Similar to this, the degree of realism reflects the user's expectations of the stimuli and experience (Baus et al., 2014). Therefore, the users' sense of belonging to their surrounding would be enhanced through higher sense of realism generated through VR.

2.2. VR TECHNOLOGIES TO RESURRECT HISTORICAL SITES

In terms of technology, the tools used in virtual environments are crucial for producing great virtual experiences. Input and output devices can be distinguished, according to the literature (Burdea et al., 1996; Burdea and Coiffet, 2003). The user's ability to interact with a virtual environment is enabled by input devices, which can be anything from a simple joystick or keyboard to a glove that can record finger movements or a tracker that can record postures. In more detail, the keyboard, mouse, trackball, and joystick represent the simple-to-use desktop input devices that let a user send a continuous stream of commands or discrete movements to the environment (Juan, 2007). Other input devices can be represented by trackers that can follow a user's movements in the real world and convert them into the virtual environment, bend-sensing gloves that record hand movements, postures, and gestures, or pinch gloves that detect finger movements. On the other hand, the output devices enable the user to experience every aspect of the virtual environment, including vision, sound, smell, and touch (Kim, 2005).

As was already established, there are many different visual devices available, ranging from the most basic or least immersive (a computer monitor) to the most immersive (VR goggles, helmets, HMD, or CAVE systems). Additionally, haptic, audio, and speaker output devices can stimulate bodily sensations to provide a more authentic virtual experience. Haptic devices, for instance, can stimulate the user's sense of touch and force models (Mazuryk, 1996).

However, the Oculus Setup is currently the most popular piece of VR equipment. Users may interact with 3D virtual environments naturally due to the head-mounted Oculus device. Despite having only been released at the end of March 2016, it has already surpassed other consumer VR technologies in terms of popularity.

The Oculus Quest is one of the best-selling VR headsets that can provide you with a great experience at a low price. When you put on the headset, the functionality allows you to look around the outside world to understand exactly where you are before immersing yourself in the virtual world. You can play games or browse multimedia even on the go. In addition, you can participate in interactive training in a virtual environment (Luckerson, 2014).

2.3. THE ROLE OF VR IN REVIVING HISTORICAL SITES

The architectural heritage is essential for the preservation and cultural evolution of any country, as it is necessary to preserve it as part of our tradition. There are various methods and technologies that have been used over time to preserve and present the architectural structure. One of these is 3D modeling. Two-dimensional drawings and architectural representations are now integrated into 3D models and formed by 3D digital methods and tools enabling a faithful reproduction of buildings that are part of the

national cultural heritage. Virtual reality, like many other technologies before it, holds the potential to improve history education. Usually, virtual reality is primarily experienced through two of the five senses: sight and sound. Virtual reality can be divided into (VRML, 2015):

- The simulation of a real environment for training and education.
- The development of an imagined environment for a game or interactive story.

The creation of historically and culturally significant sites and artifacts using 3D models and virtual reality technologies is known as virtual heritage (VH). Virtual heritages are a combination of computer-generated reality innovation, virtual reality technology, and historical and cultural heritage knowledge (Addison, 2000). Virtual Heritage during the 1990s and mid-2000s were used by archaeologists- as main clients (Bretz, 2017). In general, VH technologies can aid relive the past by offering an affordable way to visit and study lost historic sites. Through the use of cutting-edge technology, virtual heritage settings are designed to preserve, replicate, and display history (Rahim et al, 2017).

2.3.1. Related Work

Rome is one of the most historical cities in the word- where it is a place that greets people at every corner, including sites like the Trevi Fountain, the Pantheon, and the Colosseum. Accordingly, the Australian archaeologist, Simon Young, aimed to bring the past to the visitors of Rome like never before, by using VR. Young's company, Lithodomos VR, creates immersive virtual recreations of iconic ruins via smartphone headsets. Ruins like the Temple of Venus and Rome and the Arènes de Lutèce, both located in Italy's capital. "It's 360-degree 3D virtual reality," says Young. "It really helps you to place yourself back in time". The reason for this is to allow people to walk away with an idea of what these places looked like before. Hence, it is educational and generates better learning outcomes to kids, researchers, citizens, and tourists (Wexelblat, 2014).

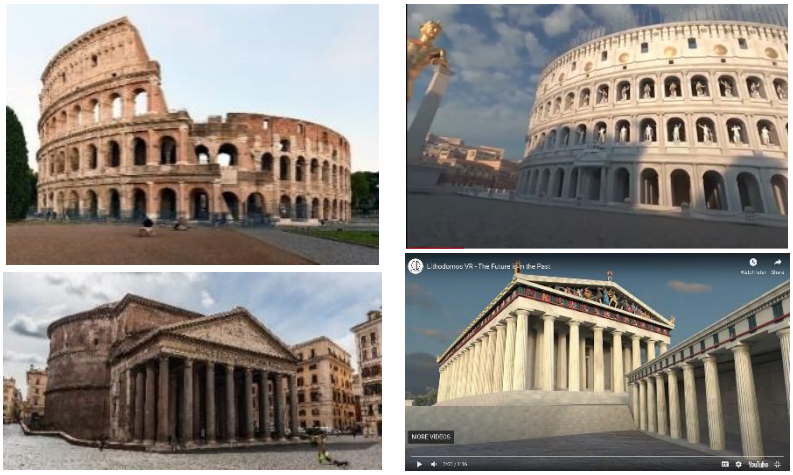

Figure 3: Process of VR to Mentally Revive Historical Buildings
Source: Steve young, Lithodomos VR

Some related work that showcases how preserving historical landmarks in VR should be a priority include Google, spherical photography archive of Google Street View allows users to see the future potential of VR for historical analysis. (Kheraj, 2020) Nevertheless, Google recently created a tool within Street View to enable users to "travel to the past" by accessing images from the past decade of the Street View project, through Google Maps and Street View, users can explore the temples of the ancient city of Angkor as an example, as shown in figure 4 (a).
It is taken for the fact that most architects and even urban planners are aware of the role of virtual reality in architecture. VR headset manufacturers and application developers have already been pushing the idea of using this technology for teaching (Sundar, 2010).

Figure 4 (a): Street View from Google Maps to show the temples of the ancient city of Angkor
Source: Google Maps, 2019

Another example is reviving the 'Notre Dame Cathedral' in Paris, France that suffered a devastating fire which caused significant, lasting damage to the 12 Century building. "Although French authorities were able to save the

bulk of the structure, including the two rectangular towers, a large portion of the frame was destroyed, along with the entirety of the landmarks iconic spire "Preserving Historical Landmarks in VR Should Be a Priority". However, the historic French site was recently 'immortalized' in 360 degrees, by TARGO, a VR studio specializing in immersive documentaries. as shown in figure 4 (b).

Companies like TARGO have begun using immersive technology to digitally capture the greatest landmarks, historical sites, and monuments and preserve them for future generations- as an attempt to immortalize the efforts of the human race. (Melnick, 2019) Although it is not an easy task, recent advances in spatial capture technology, such as photogrammetry and spatial mapping, have resulted in more photo realistic virtual experiences.

Figure 4 (b): Exterior and Interior 360 VR visit of Notre Dame de Paris
Source: TARGO Company, 2020

This highlights an important point about the use of VR in heritage spaces. As well as being immersive, it must be accurate and faithful to reality; Simply using entertainment value as a way to rewrite the history books and use creative licence can open up many pitfalls.

3. Methodology

In this study, certain data were obtained that aided in creating a vision for the past building that have been demolished or destroyed by several events throughout decades. First, was through analytical research for understanding the definition of Virtual Reality and its relationship with history. Second, the attempt to capture the 'present' situation of the impacted building was done through taking a variety of images from several points by the "Trisio 2 Lite 360 Camera", alongside collecting architectural drawings- plan, sections, and elevations. Finally, these images were then used as a guideline begin the 3D modelling phase for resurrecting the 'past' or 'before' situation of the historical building using Autodesk (Revit), then converting it to OBJ file to be viewed in the VR Headset, where in this case is the Oculus Quest- enabling a wider range of interaction within the environment.

Figure 5: Research Methodology Process

The case study chosen in this paper is "The Dome City Center" or "The Egg" or "Metropole Cinema" in Downtown Beirut- During the Lebanese civil war, it was damaged and a big part of it was destroyed. Since that time, the Lebanese government left the building as a historical place.

3.1. CRITERIA OF SELECTION

As an introduction, the "Egg" of Beirut is a heavily scarred monument that is drastically imbued by Lebanon's socio-political history. Only a part of the supposed multi-use complex "Beirut City Center" was built in an egg-like structure- that is where the name was derived. The "Egg" or "Dome" was designed by architect Joseph Philippe Karam (1923-1976), this recreation center located in the heart of Beirut, next to the iconic Martyr's Square- that is a space where the Martyrs were executed under the Ottoman Rule (Higginbottom, 2020).

The set of criteria of why this case study was chosen is due to:

- It is a building that can be viewed as a multi-factorial compromise between its users, intentions of architect, economic, political, and many other inputs (Zeveloff, 2014).
- It acts as a mirror of its era and thus a symbol of rebellion, revolution, and resilience (Archileb,2020).
- The purpose of the building changed from being a luxurious attraction point to being a space of conflict throughout the decades.
- It's iconic location within Downtown Beirut which hold rich historical significance- as part of the demarcation line that divided the city in the two opponents of the Civil War: East and West Berirut. Additionally, along its axis, resides the iconic Mohamad Al Amin Mosque and Saint-George Cathedral symbolizing Beirut's religious diversity (Abdul Reda, 2020).

- The building's intent was only a glimpse of what this structure has served for and was driven by its surrounding and visitors. and its one-of-a-kind structure (consisting of platforms and pilotis) 'at that time'.

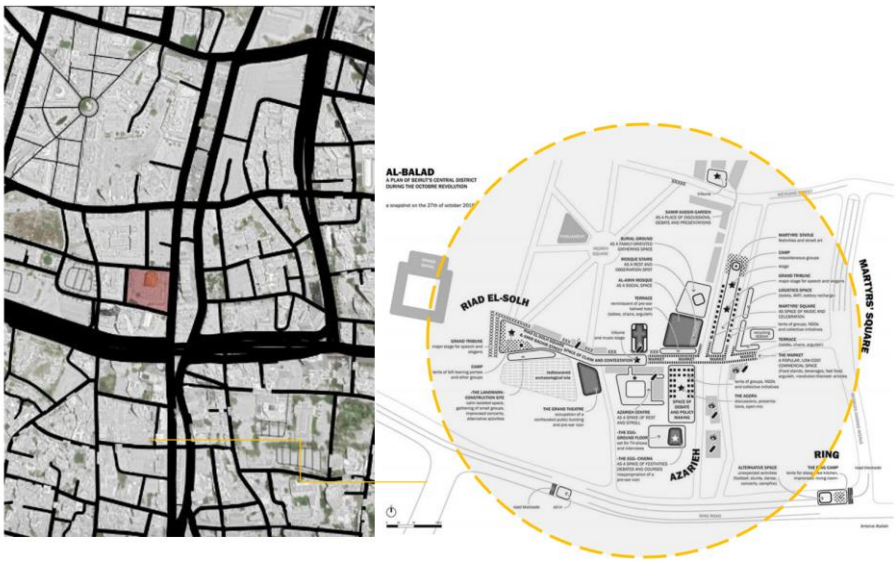

Figure 6: Site Plan Showcasing the Unique Location of "The Egg" in Beirut (L'Orient Le Jour Newspaper, 2019)

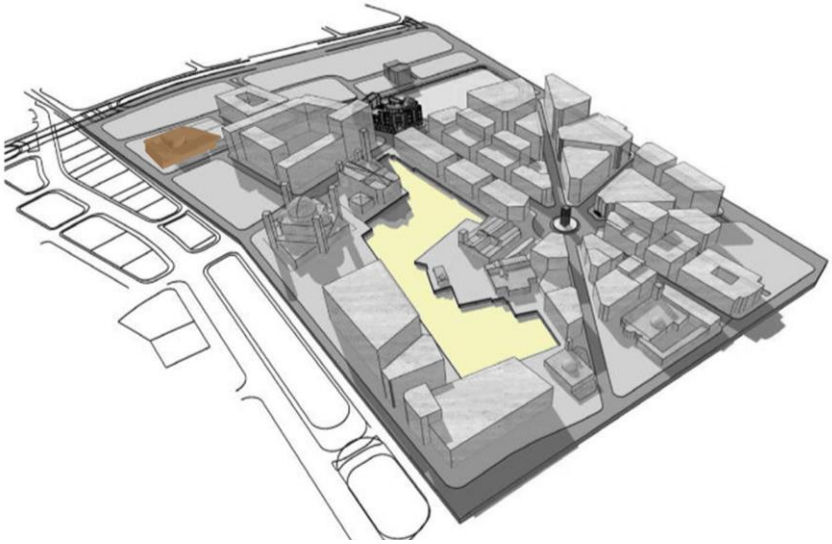

Figure 7: 3D Site for Viewing the Surrounding Built Environment (Yara Rizk, 2020)

"The Egg" have been through a number of disasters throughout the years, as seen in figure 8. Since the Civil War, the city's been in constant state of emergency, whether due to the corrupt political and economic instability, following many other devastating conflicts and war, the Lebanese Revolution and Economic Crisis, and most recently, the Beirut Port Explosion (Hirst, 2005).

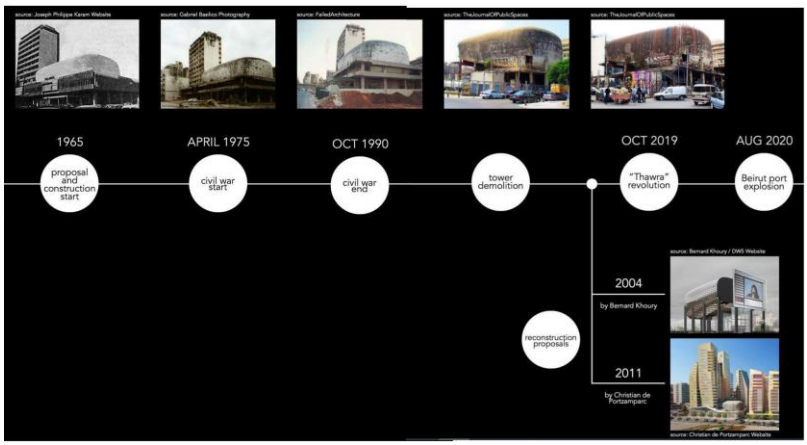

Figure 8: Timeline Showcasing the Historical Events of "Beirut City Center" (Yasmine Baddoura, 2021)

3.2. BUILDING THE 3D MODEL

The first step in building the 3D Model was take photographs along several points within the urban context to investigate the 'after' situation of the building. Moreover, collecting various photos from the past to view how 'The Beirut City Center' was "before" the war as a guideline to begin building the 3D Model (Rasmi, 2019).

The current state of "The Egg" is considered a "forgotten space" and a space that is neglected, demolished, and destroyed. People, especially tourists, enjoy viewing this monument and can undoubtedly sense the historical richness it has due to its exterior façade (Ward, 2019).

The images, drawings, and artifacts, like the literature study, were highly important since they enabled us to envision and examine all of the elements of the building outside, particularly those connected to the architectural style and texture (Sawaya, 2019).

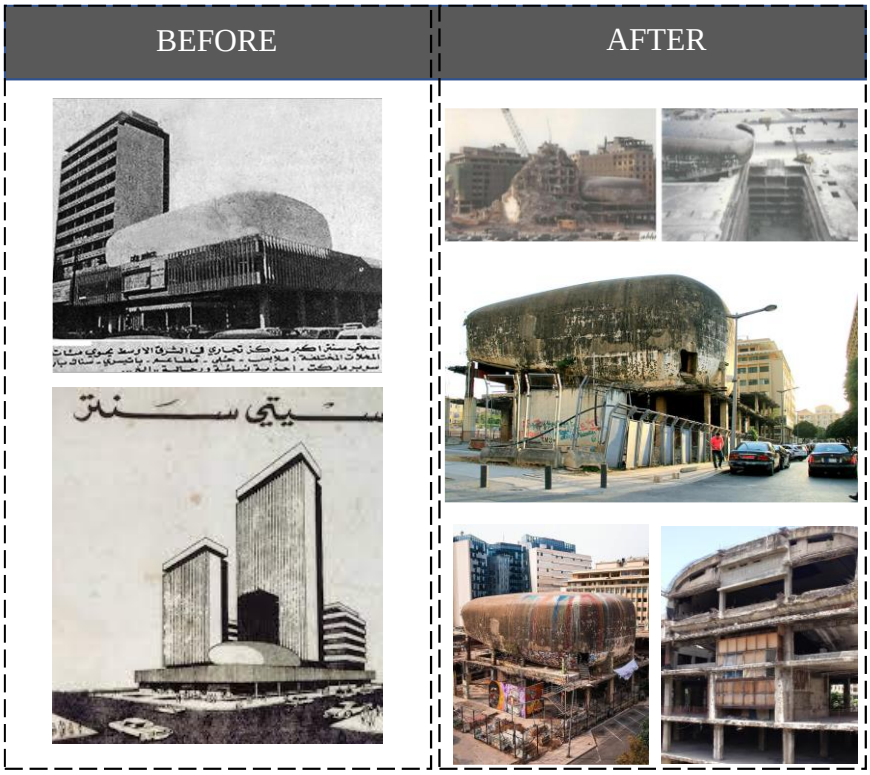

Figure 9: Demonstrating the 'Before' and 'After' Images of the Building and how it Deteriorated Over Time

Figure 10 below showcases the South-West Isometric View of the existing/ current state of the building done by 3D Scan and Zero Symptoms to further understand its physical shape.

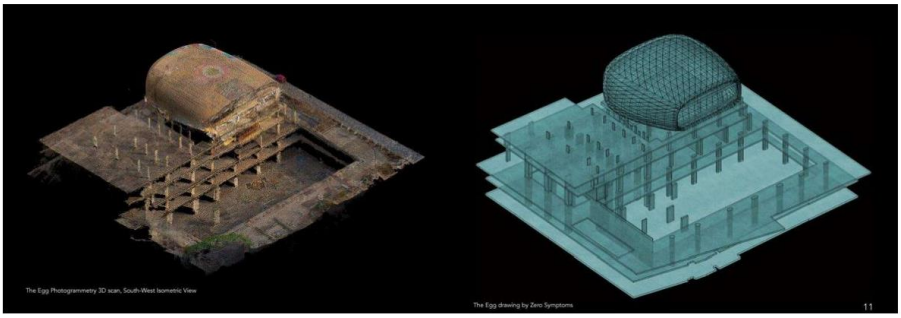

Figure 10: The Egg Photogrammetry 3D scan and Drawing (Zero Symptoms, 2019)

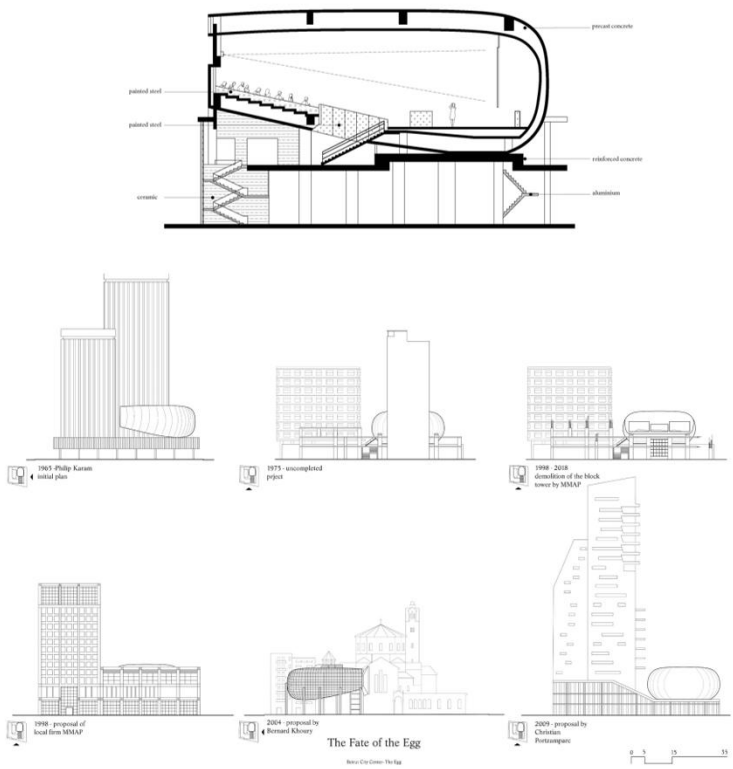

Figure 11: Architectural Drawings -Sections and Elevations- of how the building was or 'could have been' (Charlotte Malterre- Barthes Website, 2018)

The preparation of 2D designs for the building is the next phase in the 3D reconstruction process once all necessary information about building measurements, architectural style, building components, materials, and texture has been gathered (Sewell, 2020). The AutoCAD 2D designs and drawings including sections and elevations of the ''anticipated building of how it should have been' were used to load into 3D modeling software to produce the exterior's 3D geometry of the buildings.

3.3. THE VIRTUAL REALITY EXPERIENCE OF "THE EGG"

An abandoned concrete building in the heart of Beirut, Lebanon (known as The Egg) has been everything from a movie theater to a bomb shelter to a water tank, but this intervention would revive the historical buildings and allow people to engage within the significant building's environment through the usage of computer software's. A fully immersive VR experience gives you a sense of scale, depth and spatial awareness that simply cannot be

matched by a rendering, walkthrough, or physical scale model. Users have the freedom to explore a building at their own pace, to understand how it will feel and function (Walsh et al., 2016).

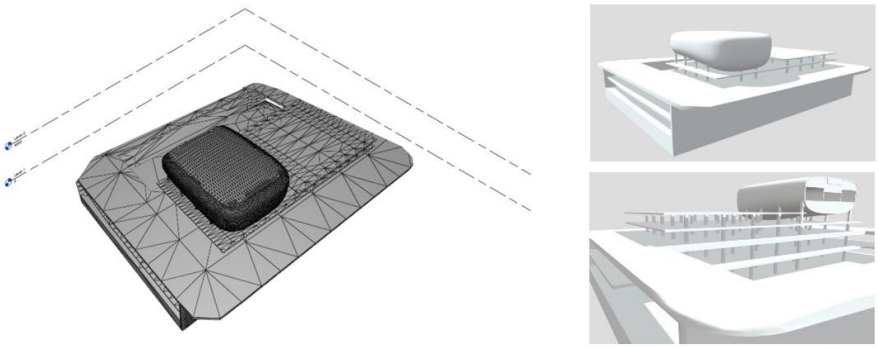

Figure 12: The Process of 3D Model Building in Autodesk Revit 2020

The users will be able to experience the significance of this "Beirut City Center" as it was before the war and unfortunate events. Based on previous data collection -2D and 3D drawings- the author created 3D model in the Autodesk Revit. After the model was created, it was then converted into an OBJ file by the add-on '**OBJ Importer for Autodesk® Revit®'** which exports solid bodies and sketches (Abdelmonem, 2017).
The OBJ file is then viewed in Virtual Reality for a more enhanced user experience within its environment in "that past time". The building can be then viewed primarily from a computer as shown in figure 13.

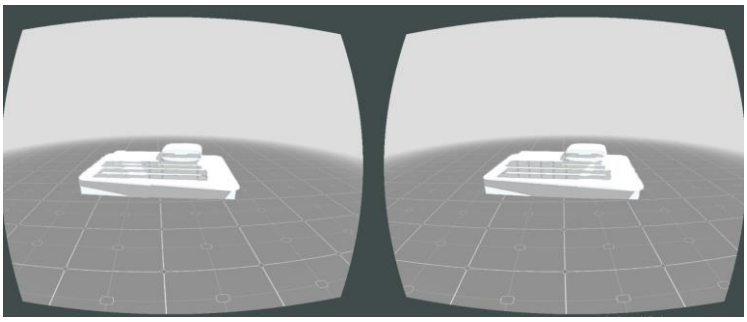

Figure 13: VR Experience through a Computer

However, another way for viewing the 3D model in virtual reality is through The Oculus Rift VR device (Oculus VR, LLC., Irvine, California, USA)

which was used in this study. The device comprised a lightweight (0.44 kg) headset that completely covered the field of view. The headset included separate displays for each eye, each with 960 × 1080 resolution, yielding a 100-degree-horizontal field of view (Karlsson, 2013). A fixed-degree convex lens was in front of each display rendered display content at optical infinity. Immersive 360° environments allow participants to feel as though they are inside the environment while non-immersive environments only allow participants to see the contents based on how the device in use – PC, smartphone, or tablet – is held and moved. In this case, an immersive mode is created to allow people and students to view and rotate freely throughout the building and its environment. As shown in figure 14, "The Beirut City Center" appears in VR using the Oculus Quest so that users can explore and navigate- showcasing how it once was within the impacted city.

Figure 14: Navigation through Beirut City Center using the Oculus Rift VR Device

3.4. EVALUATION OF THE USERS' EXPERIENCE IN HISTORICAL BUILDINGS

In order to review the users' feedback, a sample size of 20 individuals - mainly university students- tried the VR experience through Oculus to benefit from their feedbacks and comments.

The outcomes uncovered an abundance of data of how people perceived historical buildings in their city and if they were willing to try the experience again as shown in figure 15.

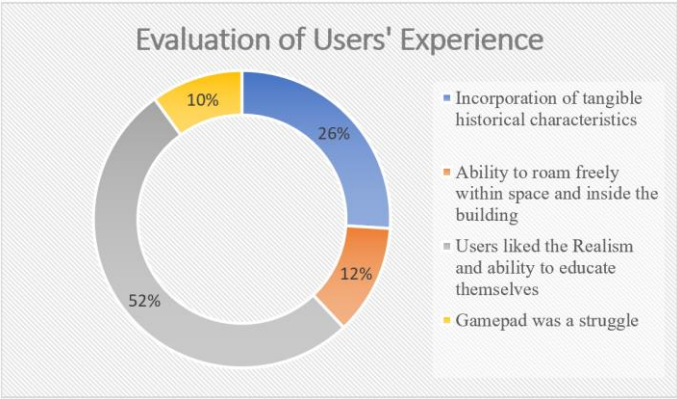

Figure 15: Feedback of users' experience for Virtual Heritage

More than half of users enjoyed the experience and how they felt like the 'knew their city' like never before. They felt in touch with their past, and even some felt emotional where they felt a sense of belonging to their city.
Nevertheless, realism in this case, explain how the single participant was allowed to envision the structure and their grandeur within the city, as well as they felt cultural presence. The viewpoint of users in a virtual heritage environment varies depending on their topic knowledge and technological skill (Walsh et al., 2016).

4. Conclusion and Future Work

This study discusses how virtual 3D models allow to modernize some buildings according to the old design influences with the possibility to restore the citizen's 'image of the city' and their collective memory. This study looks at the several viewpoints that are needed to create a 3D model and the process integrated it within a VR environment. The users' cultural learning experience might be enhanced as well by creating a virtual heritage milieu that efficiently incorporates the variables and components stated in this paper.

Given the change in human needs throughout time, calls for changes in the approaches of education, therefore, VR in this case holds great power and infinite opportunities that allows people -especially for educational purposes- to widen their scope of knowledge and indulge within the built environment of historical buildings.
The results suggest that while creating VH applications, a mix of information design, content delivery, user experience, and guidance system

were addressed by users and should be taken into consideration in further studies.

These components and aspects might be utilized as design guiding principle for the creation of virtual heritage settings based on historic structures that have been lost.

Furthermore, when used efficiently and with accuracy, VR can serve the purpose to build a bridge that have been long gone, not only between the past and the present, but also between the site and the visitor. This leads, to stronger social ties within the city, that can be achieved through innovative technology, and would even aid in economic significance on the long run.

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A NOVEL DESIGN-BASED OPTIMIZATION SOLUTION FOR BUILDING BY SENSITIVITY ANALYSIS

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Abstract. The important objective of a building must be to provide a comfortable environment for people. Heating, ventilation and air conditioning (HVAC) systems provide a comfortable environment, but they are using high energy consumption, therefore, designing an energy-efficient building that balances energy performance and thermal comfort is necessary. To achieve this subject is important to choose the effective parameters for energy performance. This research aim is to produce a methodology for multi-objective optimization of daylight and thermal comfort in order to study the effect of wall material and shading of an office building (Tehran a basic-location). The building simulation was developed and validated by comparing predicted daylight hours and thermal comfort hour based on test and training on Jupiter Notebook (Anaconda3). The sensitivity analysis uses a multiple linear regression (MLR) method. Secondly, optimization is based on a genetic algorithm (GA) with the effective parameters to optimize the daylight and thermal comfort performance. For this, we developed a parametric model using the Grasshopper plugin for Rhino and then use Honeybee and Ladybug plugins to simulate thermal comfort and daylight, at the end use the Octopus engine to find an optimization solution. The result of this paper is essential as a preliminary analysis for shading devices, window-to-wall ratios, and wall construction optimization in the open-plan office.

Keywords: *Thermal comfort, designerly approach to daylighting, multi-objective optimization, sensitivity analysis.*

ملخص. يجب أن يكون الهدف الأهم للمبنى هو توفير بيئة مريحة للناس. توفر أنظمة التهوية والتدفئة وتكييف الهواء بيئة مريحة ولكنها تستخدم استهلاكًا عاليًا للطاقة، وبالتالي فإن تصميم مبنى موفر للطاقة يوازن بين أداء الطاقة والراحة الحرارية أمر ضروري. لتحقيق هذا الغرض من المهم اختيار المتغيرات الفعالة لأداء الطاقة. يهدف هذا البحث إلى إنتاج منهجية للتحسين متعدد الأهداف للإضاءة الطبيعية والراحة الحرارية من أجل دراسة تأثير مواد الجدار وتظليل لمبنى المكاتب (اختيار طهران كموقع أساسي). تم تطوير محاكاة المبنى والتحقق من صحتها من خلال مقارنة ساعات النهار المتوقعة وساعة الراحة الحرارية بناءً على الاختبار والتدريب على Jupiter Notebook (Anaconda3). تم استخدام تحليل الحساسية عن طريق طريقة الانحدار الخطي المتعدد (MLR). ثانيًا، يعتمد التحسين على الخوارزمية الجينية (GA) مع المتغيرات الفعالة لتحسين أداء الإضاءة الطبيعية والراحة الحرارية. لهذا، قمنا بتطوير نموذج بارامترى باستخدام البرنامج المساعد Grasshopper لـ Rhino ثم استخدم مكونات Honeybee و Ladybug لمحاكاة الراحة الحرارية وضوء النهار، ثم في النهاية استخدم محرك Octopus لإيجاد حل أمثل. تعتبر نتيجة هذه الورقة ضرورية كتحليل أولي لأجهزة التظليل، ونسب النافذة إلى الجدار، وتحسين بناء الجدار في فراغات المكاتب المفتوحة.

الكلمات المفتاحية: *الراحة الحرارية، توجه تصميمى للإضاءة الطبيعية، تحسين متعدد الأهداف، تحليل حساسية.*

1. Introduction

Increasing the environmental challenges can lead to global warming, the energy efficiency of buildings has an effective role in architectural design. Today global approaches want to reduce energy consumption to achieve a sustainable environment (Raturi, 2019). Solar radiation has a crucial role in hot climate regions that can lead to excessive energy consumption. Sustainable building attends to increase the quality of the environments. (Chiazor, 2009), (Yoon, 2008). Good buildings have thermal and lighting comfort conditions in places because they have a fundamental impact on building performance (US Department of Energy, 2011), However many researcher foci on thermal comfort and daylight but unfortunately, many researchers proposed the theoretical results that are not useful for buildings (Moon, 2016), (Lodi, et al., 2017). A place that has thermal comfort are a condition that people in place are satisfied with. The Predicted Mean Vote (PMV) and Percentage of Persons Dissatisfied (PPD) are the popular indices for thermal comfort (Hawila, 2021), (Enescu, 2017). These indices are calculated based on environmental parameters, such as relative humidity, air velocity, air temperature and mean radiant temperature, and occupant-related parameters such as metabolic rate and clothing insulation. (ISO, 2005), (Enescu, 2017).

The important purpose of proper design is to improve energy and daylight. On the other hand, building optimization is one of the cost-effective solutions to increase building performance. (Rajagopalan, 2015).

Windows performance overall heat transfer is usually about five times greater than other building components, but designer usual use a high window-to-wall ratio in their project (Lau et.al, 2016). The experiments and research indicate that measure of U-value, Solare Heat Gain Coeeficient (SHGC), visible transmit (VT), glass, double-layer glass and window size could increase thermal comfort (Zhao, 2020), (Pagliolico, et al., 2019). Solar shading devices have a perform considerable advantage in the Confrontation with solar radiation (Goia, et al., 2013), (Freewan, 2014).

Due to relatively little knowledge about optimization and uncertainties of design parameters, designers the default values should confidante about the parameters, significantly affecting the simulation result. This effect will be small if the purpose is to compare several design options. If these parameters are examined for the optimization process, the effect will be longer; therefore, if these parameters are not selected correctly, simulation time and design cost will be increased. Also, due to the time-consuming optimization process and the uncertainty of the desired parameters, it is necessary to SA before optimization (Hensen, 2011).

- Sensitivity analysis in building

Sensitivity analysis (SA) is the statistical method that can calculate the relationship between input and output parameters. (Mangkuto et al., 2016). Statistical methods examine the effect of these parameters by examining many output parameters relative to the input parameter (Frey, et al., 2003). SA has a significant effect on understanding building simulation. SA's purpose is to predict the performance of design parameters, also a research on these parameters is useful to achieve the optimal building (Gagnon, et al., 2018), (Sanchez, et al., 2014).

- Optimization Methodology

In recent years optimization algorithms have much attention to solving the optimization problems in building design. Optimization is a process of finding the best solution or solutions between different alternatives. Building optimization is performed automatically by simulation and stochastic population-based optimization algorithms, including genetics and particle swarm (Kheiri, 2018), (Nguyen, 2013).

1.1. AIM AND MOTIVATION

This research bridges the knowledge gaps about the effect of sensitivity analysis in building simulation. The SA objective is to find the most influential design parameters with multiple linear regression and the optimization objective is to find the most optimum solutions which is usual a

simple approach proposed by ranking the solutions on the Pareto frontiers. The optimization process is performed based on a genetic algorithm with the Octopus plugin. (Roudsari, et al., 2013) (Fig1).

This paper established a method for the office building, this method considered the effect of building design for thermal comfort and daylight with Honeybee and Ladybug plugins and python ability. The variable parameter in this study is wall construction (R-Value), WWR, Window frame thickness, SHGC, Shading Reflectance and Shading Depth. The parameters have been proposed by many researchers, but these parameters are not always fully accounted for in the SA and optimization process. These parameters can interact with each other.

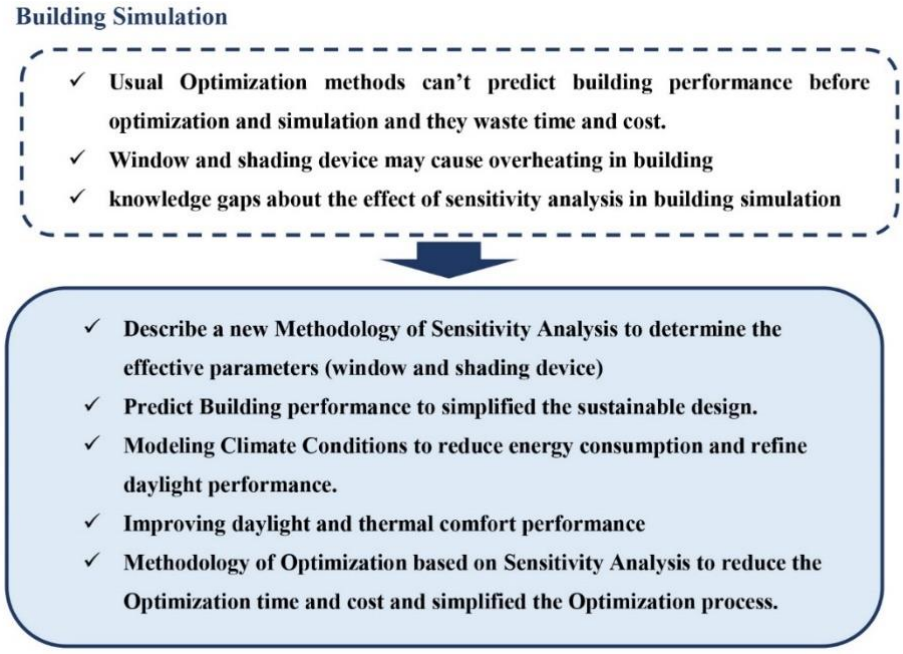

Figure 1. Strategy of research aim.

2. Methodology

2.1. SOFTWARE

This research is modeled in the Grasshopper plugin parametric environment that has been developed in Rhinoceros software. Honeybee and Ladybug plugins have been developed to simulate building performance; The present study, using the parametric potential of these plugins, has

completed the optimization solution process more quickly and flexibly (Roudsari, et al., 2013).

2.2. MODEL DESCRIPTION AND MATERIALS

The building is located at Tehran. The office is occupied daily from 8 AM to 6 PM. The base case building represents the typology of the Reinhart office (Reinhart, 2013). The selected office is located on the ground floor with a total area of 29.52m^2 (Fig2).

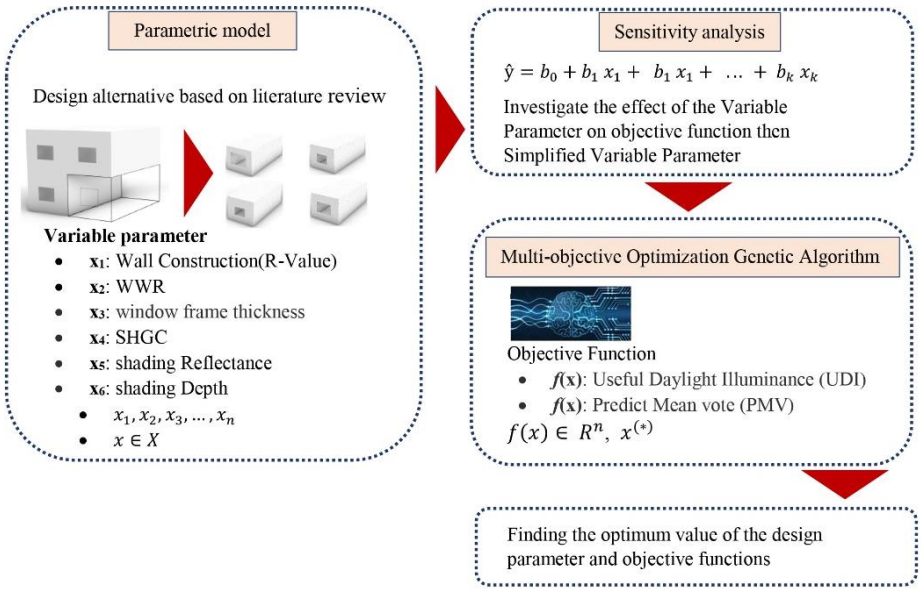

Figure 2. Case study design process.

The shading system position is above the window that is located on the south façade. More details about the building construction are given in Table1.

TABLE 1. The detailed building construction information

Component	Description
Exterior wall (W/m^2・K)	Concrete brick
Roof (W/m^2・K)	Concrete 0.10
Exterior window (W/m^2・K)	Double glazing Window
Floor (W/m^2・K)	Concrete 11.76

The number of people per area (occupant density) is 0.06 (people/m2). The Lighting density is 2.235 (W/m2). Daylight sensors are placed on a grid 0.8 cm above the floor and the grid size is 0.40*0.40 cm. Lighting measurement IES LM-82-12 promotes climate-based daylighting metric (Iesna, 2012).

It is generally considered that if the indoor illuminance were above 500 lx the indoor lighting requirements can provide. The range of design parameters selected by test and train. Table2 shows this information for the building performance.

TABLE 2. Design variables parameters for sensitivity analysis

Parameter	Variable
Wall Construction(R-Value)	0.09, 0.14, 0.19
WWR (%)	14, 26, 32, 43, 52, 56
window frame thickness(m)	0.06, 0.07
SHGC(%)	0.35, 0.39, 0.46, 0.50
shading Reflectance	30, 40, 50
shading Depth(m)	0.05, 0.09, 0.15

Response variables are the average yearly, UDI, PMV and PPD values. PMV index based on environmental parameters. Table3 reports the considered parameters and their corresponding levels.

TABLE 3. Investigated factors and their corresponding levels for thermal comfort simulation

Factor	Unit	Level
Clothing level	Clo	0.8-1.5
Metabolic rate	W.m^{-2}	58-125

2.3. SOLVING SIMULATION PROCESS

Considering the objective of this research is the MOO of daylight and thermal comfort so this objective can maximize the PMV and Useful Daylight Illuminance (UDI) and optimize the energy and daylight was performance. The research framework performed in three main steps Fig3. And at the first designed the geometry model, based on the variable parameter then perform the SA, at the end performed the optimization based on a simplified variable parameter. Sample size taken by test and train on Jupiter notebook based on Python language. According to the range of each parameter that is between 0-1 the sample size is selected. In this research, all parameter range is between 0-1 so we don't need to standardize the data range. The SA is generally related to the design parameters of building components they are wall (material, insulation) window- to-wall-ratio, windows (window frame thickness and SHGC) and shading (reflectance, depth).

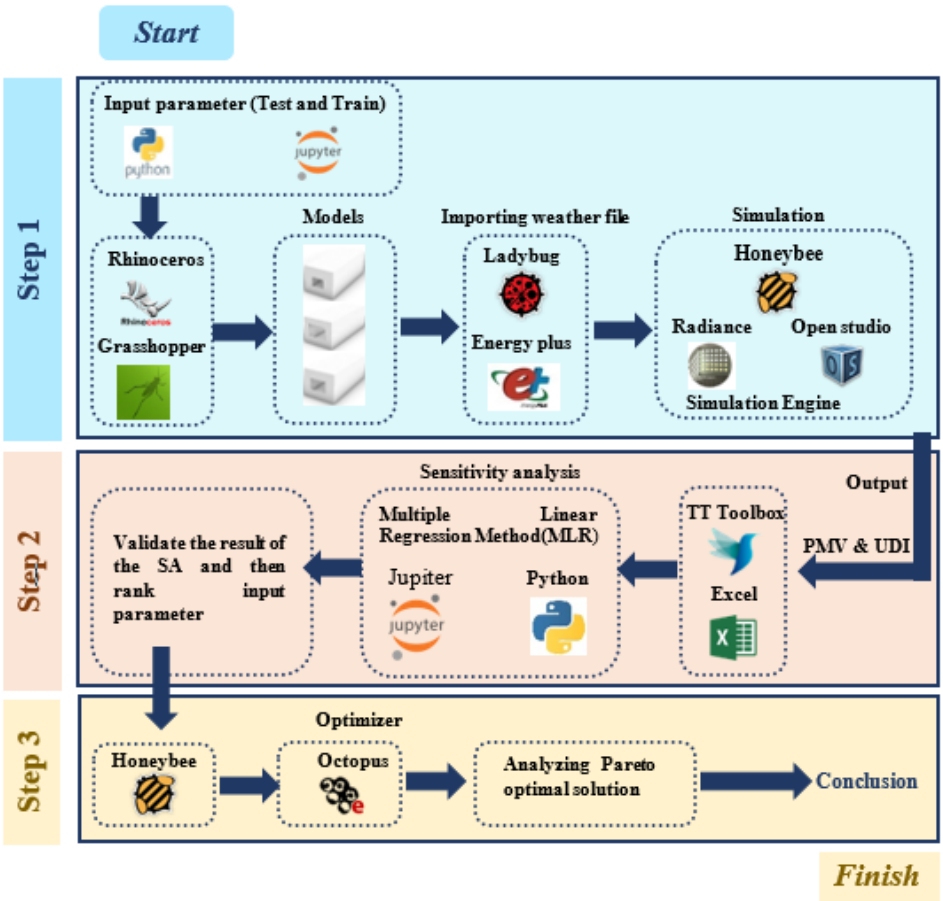

Figure 3. Overall methodology process

2.4. SENSITIVITY ANALYSIS

After designing the model, the model was simulated based on the input parameters of a honeybee. The daylight index in this research is UDI. Which was proposed by (Nabil, 2005). This factor is a dynamic daylight performance. The purpose of it is to determine when daylight levels are useful for the occupant. The suggested range of this index is 2000 lx and 100 lx. it means (<100) lx is too dark and (>2000lx) is too bright (Nabil, 2005), (Reinhart et.al, 2006).

The thermal comfort index in this research is PMV and PPD (Fanger, 1970). The PMV index is the quantitative prediction for the average vote of individuals on a thermal sensation scale that ranges from −3 to +3; where −3 is very cold, 0 is neutral and +3 is very hot. The recommendations range for

maintaining a PMV between −0.5 and +0.5. The discomfort hours were not assessed when PPD was higher than 20%. The PMV index calculate based on Eq1 and each component of this index is calculated based on Eq (2-6).

$$PMV = (0.303^{e-0.036m} + 0.028)\,[(M - W) - H - E_C - C_{rec} - E_{rec}] \quad (1)$$

$$E = 3.05 * 10^{-3}\,(256_{tsk} - 3373 - P_a) + E_{sw} \quad (2)$$

$$E_c = 3.05 * 10^{-3}\,[(5733 - 6.99 * 9M - W) - P_a] + 0.42\,(M - W - 58.15) \quad (3)$$

$$C_{rec} = 0.0014M\,(34 - T_a) \quad (4)$$

$$E_{rec} = 1.72 * 10^{-5}\,M(5867 - P_a) \quad (5)$$

$$H = K_{cl} = t_{sk} - t_{cl} / I_{cl} \quad (6)$$

Also the PPD index calculate based on (Eq7) (Matzarakis, et al., 2007).

$$PPD = 100 - 95e\,(-0.03353 * PMV^4 - 0.2179 * PMV^2) \quad (7)$$

This research performed SA using a sampling-based method. SA was used in different fields and performed in different methods. This research performed based on MLR method Eq8 show the MLR, is about the best fitting model.

$$\hat{y} = b_0 + b_1\,x_1 + b_1\,x_1 + \ldots + b_k\,x_k \quad (8)$$

To calculate the variability of the data often use the measure of distance from the mean or description of the data range. Total variability (SST) is a summation of and unexplained variability explained variability. SST is a measure total variability of a dataset. SSR is a measure explained by variability by your line. SSE is a measure of unexplained variability by the regression. The division of SSR on SST is equal to R2 Eq (9-13).

$$SST = SSE + SSR \quad (9)$$

$$SST = \sum_{i=1}^{n}(y_i - \bar{y})^2 \quad (10)$$

$$SSR = \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2 \quad (11)$$

$$SSR = \sum_{i=1}^{n} {e_i}^2 \tag{12}$$

$$R^2 = \frac{SSR}{SST} \tag{13}$$

Given that the R2 always increases with increasing the dependent parameter, this is while the new parameter may not have a significant impact, Therefore, it is necessary to use the Adjusted R2, and increasing it means increasing the efficiency of the model. In the other word Adjusted R2 increases only when the new parameter has a significant impact in the model Eq14.

$$\bar{R}^2 < R^2 \tag{14}$$

Low R2 indicates a poor fit of the regression model with the outcome of the building model. The value range of R2 is between -1.0 and +1.0 (Menberg, et al., 2016), (Allam, et al., 2020).

SA performed on Jupiter notebook based on MLR. Jupiter notebook. The SA was performed by the coupling of python language and honeybee and ladybug. The First simulation result (PPD and UDI 100-2000) is stored in a CSV file by TT Toolbox. Then each set of input variables and simulation results was read from the CSV file and written to the Jupiter notebook in turn by means of python language. The SA consists of two loops: the honeybee plugin performed a full-year simulation in time step and the python performed MLR. At the first, we need to standardize the input parameter to be able to rank them. Then the accuracy of the method was evaluated with F-statistic. The closer F-statistic is to 0, the accuracy of the model is lower and our model is not good Eq15.

$$H_o = b_1 = b_2 = \ldots = b_k = 0 \tag{15}$$

In the next step, the effective parameter is determined with compare the R2 range. Also, due to the time-consuming optimization process and the uncertainty of the desired parameters, it is necessary to perform SA before optimization. While Using SA, the effective parameters can be set in optimization. After all the parameters are obtained from the RSA, the next step is the optimization phase. The parameter obtained from the previous step is plugged into a Multi-Objective Optimization (MOO).

2.5. OPTIMIZATION

Building optimization is a process that is performed by using simulation and based on a stochastic algorithm such as genetic algorithms (GA),

particle swarm, and evolutionary. (Fang, 2019). The GA is inspired by the selection process that is based on search. This algorithm can solve non-linear optimization problems and also they follow global optimum and do not get stuck in local optimum (Reynold, 2018). The most important limitation of GA is to need for many cost functions to achieve the optimum solutions. Building simulation often uses the honeybee plugin and Galapagos engine, Energy Plus, TRNSYS, etc. (Magnier, 2010) (Fig4).

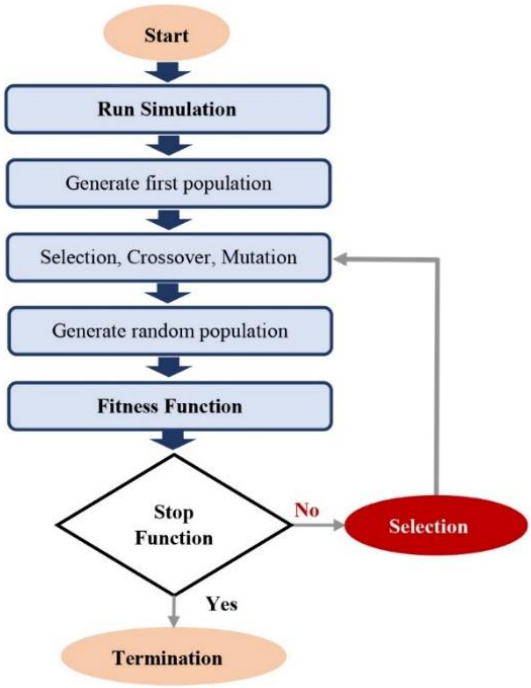

Figure 4. Genetic algorithm process.

The evolutionary solver determines the optimum genome that is based on GA. Population with several individuals creates a new generation and when new generations were created the best population is kept until the children get closer to the best value. An individual is a genome. (Rutten, 2010).

The multi-objective optimization (MOO) is a method to identify a series of thesolution ,not a single solution. The best solution can't find based on just one parameter such as energy performance, daylight, or thermal comfort, the best solution should consider all conditions (De Angelis, et al., 2013). The optimization process used Octopus a Grasshopper plugin. The design input parameters are connected to GA for the Octopus engine, and the

results of daylight and thermal comfort is connected to the fitness input parameter. Building geometry is connected to Grasshopper, and material connected to Honeybee and Ladybug plugin to perform the analysis. The result of each solution in the optimization automatically exports to an Excel file using TT Toolbox (Deb, 2011). This file is used to create a data plot and find the best solotion. In the octopus, Pareto plot can click on each solution and reinstate the solution to find the best solution.

3. Results and Discussion

As mentioned in the methodology the simulation procedure is divided into two parts: the SA and optimization. The result was reported as three sub-subjects. The PMV, PPD (thermal comfort index), and daylighting are considered as objective functions in the one zone. The SA is a process to investigate the objective function through comprehensive research. The simulation is run 11296 times and is generated and executed until it obtains valid values.

The response variables are the average yearly, maximum, and minimum of PMV and PPD. The reason for using the average yearly value is that it changes during the day; in addition, the average value can replace the hourly values. However, checking the average value alone is not enough to check the occupants feeling. Fig5 the range of simulation results.

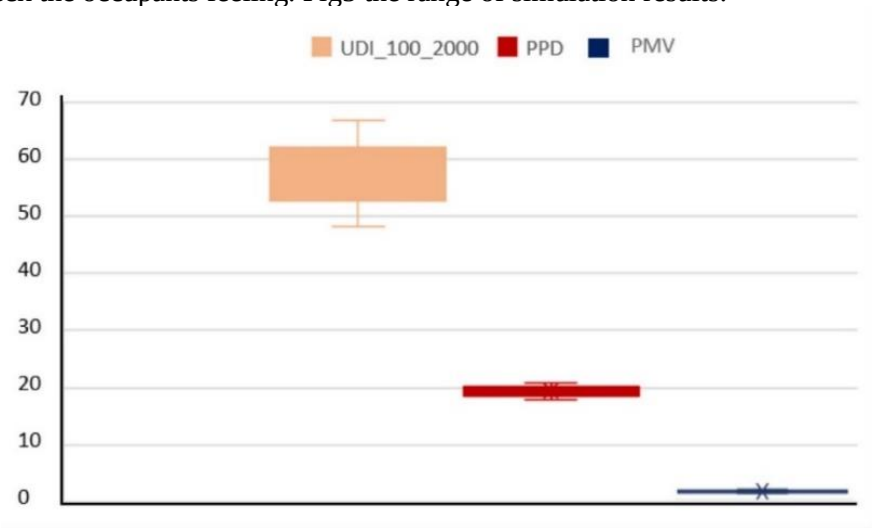

Figure 5. Comparison of the results range of UDI, PPD, and PMV for SA

The best fitting model of linear regression equations that describe the PMV, PPD, and UDI values are given by Eq (16-18) respectively.

$$UDI_{ave} = 42.6860 + 5.796\, e^{-14} * shade\ depth + 3.187\, e^{-14} * shade\ reflectance + 4.263\, e^{-14} * SHGC + 43.5976 * south\ WWR + 1.137\, e^{-13} * window\ frame\ thickness + 5.31\, e^{-13} * wall\ R - value \quad (16)$$

$$PMV_{ave} = 0.5914 + 0.5683 * shade\ depth + 0.0030 * shade\ reflectance + 3.608\, e^{-16} * SHGC + 0.1233 * south\ WWR + 1.332\, e^{-15} * window\ frame\ thickness + 0.0524 * wall\ R - value \quad (17)$$

$$PPD_{ave} = 32.0742 + 2.2170 * shade\ depth + 0.0109 * shade\ reflectance + 2.309\, e^{-14}\, SHGC + 0.0799 * south\ WWR + 1.705\, e^{-13} window\ frame\ thickness + 12.4492\, wall\ R - value \quad (18)$$

Based on the six selected design parameter the R2, Adjusted R2 coefficients and F-statistic of the UDI (100-2000 Lux), PMV and PPD for each parameter was reported. Table 4 shows this information for the SA.

TABLE 4. Result comparison of sensitivity analysis between the design parameters

Design Parameter	UDI 100-2000(%)			PPD			PMV		
	R^2	Adjusted R^2	F-statistic	R^2	Adjusted R^2	F-statistic	R^2	Adjusted R^2	F-statistic
Wall R-Value	0	$1*10^{-3}$	-1.74e-13	0.94	0.94	2.17e+04	$5*10^{-3}$	$1*10^{-3}$	6.128
South WWR	0.98	0.98	8.11e+04	$1*10^{-3}$	0	0.65	0.33	$1*10^{-3}$	661.8
window frame thickness	0	$1*10^{-3}$	-3.48e-13	0	$1*10^{-3}$	0	0	$1*10^{-3}$	2.28e-13
SHGC	0	$1*10^{-3}$	0	0	$1*10^{-3}$	0	0	$1*10^{-3}$	2.28e-13
Shading reflectance	0	$1*10^{-3}$	-1.74e-13	0	$1*10^{-3}$	$3*10^{-3}$	0	$1*10^{-3}$	0.077
Shading depth	0	$1*10^{-3}$	-1.74e-13	0.03	0.03	40.47	0.56	0.56	16.5

The result of the model indicates good performance with F-statistic for all parameter, so it means that the predicted model is correct and the data is standard. The Predicted R^2 is in reasonable agreement with the Adjusted-R^2.

The value of adjusted R^2 for UDI indicates that more than 98% of the total factor is associated with the south WWR. The value of adjusted R^2 for PPD indicates that more than 94% of the total factor is associated with the wall construction. The value of adjusted R^2 for PMV indicates that more than 56% of the total factor is associated with the shading Depth (Fig6).

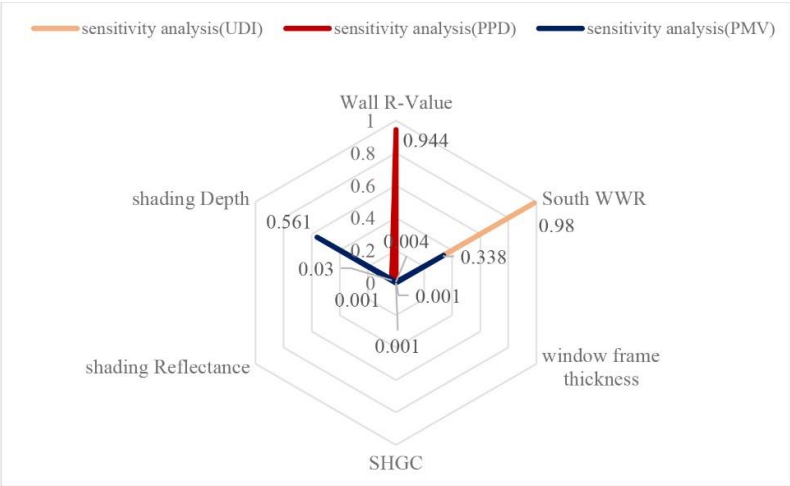

Figure 5. Sensitivity analysis for design parameter on PMV, UDI and PPD.

Finally, optimization is carried out by using the obtained MLR. The objective is to maintain these values within the best range. The acceptable range for thermal comfort (PPD index) is less than 20%.

The results show that the WWR has the potential to greatly improve building daylight and thermal comfort (PMV index) efficiency, the shading depth has the potential to greatly improve thermal comfort (PMV index) efficiency, and the wall construction R-value has the potential to greatly improve thermal comfort (PPD index) efficiency in the Tehran Table (5 – 7).

TABLE 5. UDI, PMV and PPD between different WWR

WWR	UDI	PMV	PPD
14	48.24	0.25	18.26
26	54.93	0.24	18.28
32	57.05	0.23	17.75
43	60.06	0.23	17.77
52	66.18	0.23	17.75
56	68.86	0.24	18.10

TABLE 6. UDI, PMV and PPD between different shading depths

Shading depths	UDI	PMV	PPD
0.05	66.18	0.25	18.77
0.09	66.18	0.23	18.28
0.15	66.18	0.21	17.79

TABLE 7. UDI, PMV and PPD between different wall R-value

wall R-value	UDI	PMV	PPD
0.09	66.18	0.25	18.77
0.14	66.18	0.29	19.54
0.19	66.18	0.29	19.09

Pareto plots were developed based on the 600 simulations. Each point show one design option. Since the best UDI 100-2000 lux is not when the WWR is very large. Fig7 shows that the highest UDI value is achieved when the WWR is more than 50%. The best solution demonstrated the opposite trend of UDI and PPD so the best solution appeared in minimum PPD and maximum UDI. There are 4 variable parameters in this study and the relationship between them may be complicated so interpreting them using Pareto plots lonely is hard.

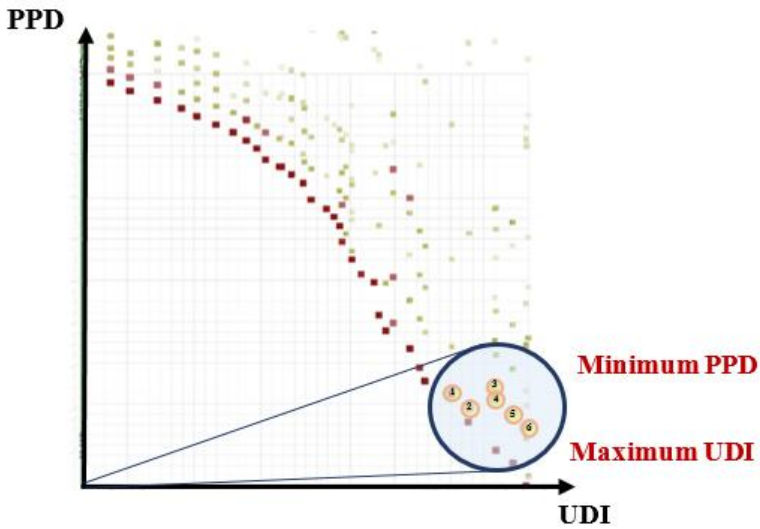

Figure 6. Pareto plot based on UDI and PPD

For showing the best solution for MOO, the region was selected based on maximum UDI and minimum PPD. Each optimal solution is visually compared to the other candidate solution. Finally, 6 best solution candidates for the optimal solution.

The Pareto plot is based on UDI and PPD values in the 6 examples, most UDI values are about 63 to 66, most PPD value are18.50 to 18.70 most PMV values are about 0.24 to 0.25 Fig 8 and 9.

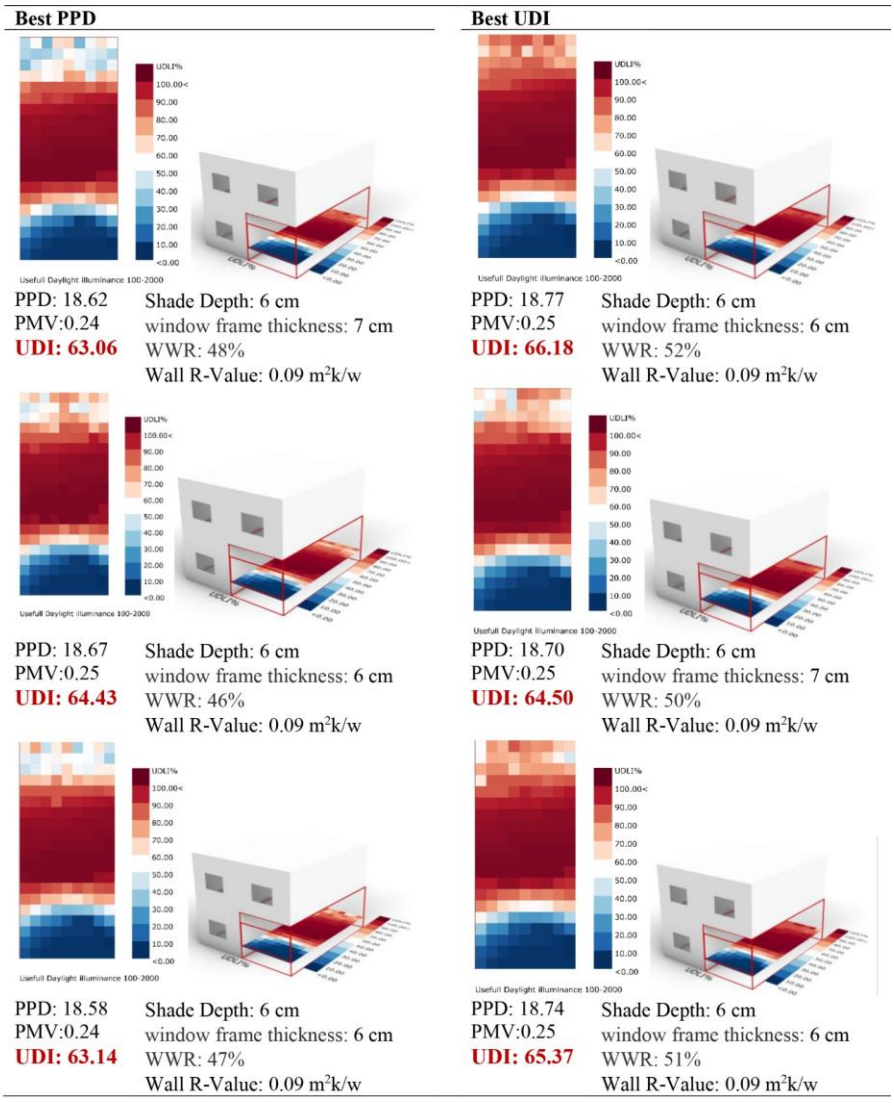

*Figure 7.*The UDI 100-2000 lux of optimum design solutions in terms of Best UDI and PMV at each solution

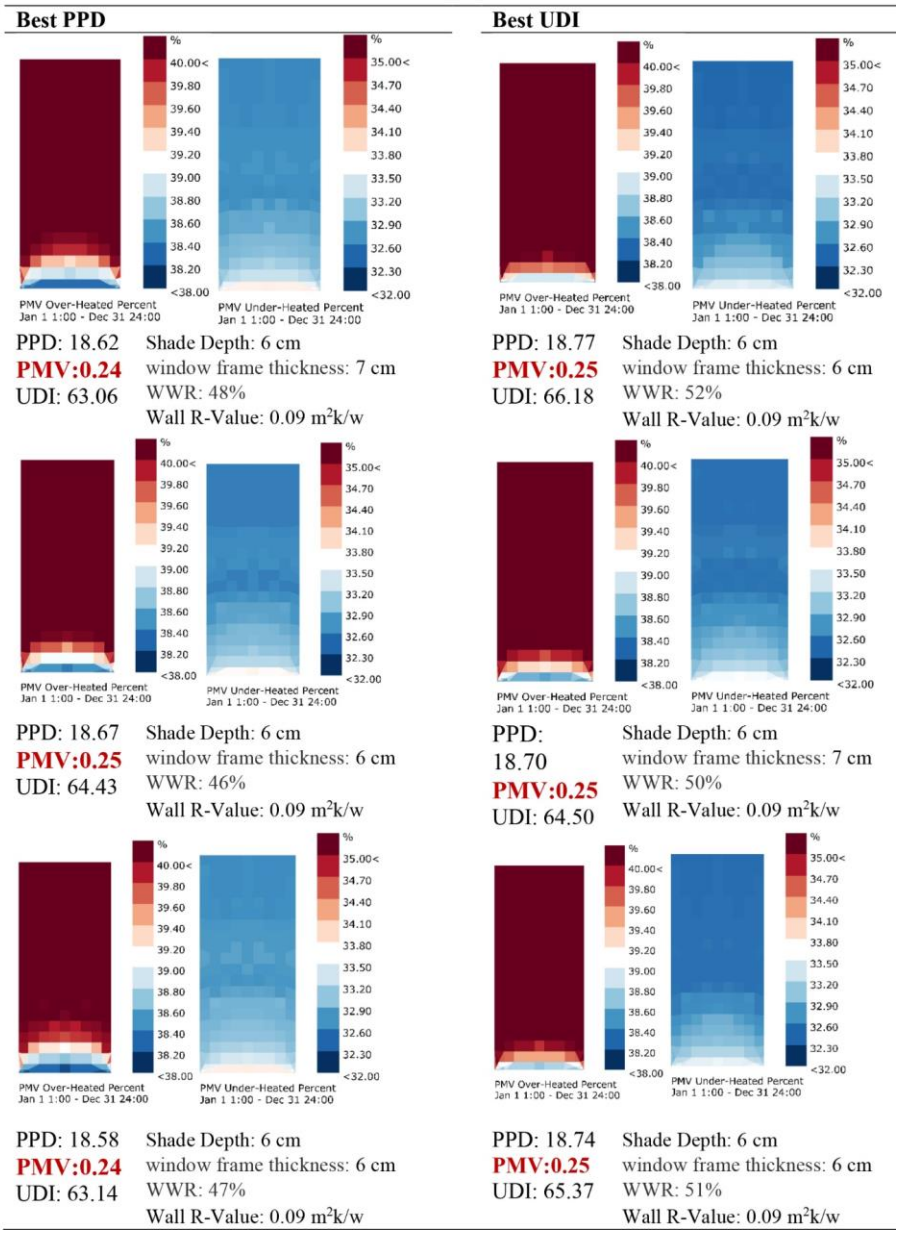

*Figure 8.*The PMV over heat and under heat of optimum design solutions in terms of Best UDI and PMV at each solution

4. Conclusion

In this study, we proposed a comprehensive methodology that can use in different locations. The proposed method is the coupling between a GA optimization tool and SA. A genetic algorithm is used to search the time-to-time output to find the optimal strategy. SA can find the effective parameter. The method for Sais the Multiple Linear Regression. By comparing the magnitude of Adjusted R2 the most significant parameter can be defined. Based on the result of MLR the variable parameters are determined and then simplified for optimization.

The methodology of this research is applied to a simple case to improve the occupant's thermal comfort and daylight. For this purpose we consider shading device that is one of the best techniques to reduce the overheating of the building caused by solar heat gain.

From this study the crucial conclusions that can be obtained are as follow:

- The result of SA indicates that the SHGC, shading reflectance, and window frame have no significant effect on the UDI, PPD, and PMV. So the parameters didn't need to consider as the variable parameters for the optimization process.
- South WWR has a significant effect on the UDI, Wall R-value has significant effect on the PPD and Shading depth, and then south WWR has a significant effect on the PMV.
- Wall R-Value and shading depth for the best solutions of PPD and UDI are not different and that is 0.09 m2k/w
- Using F-Statistics proves that the accuracy of the model is acceptable and leads to the use of standard data and the appropriate percentage range for testing and training.

the standard data for SA help to increase the proposed Finally, developing a tool that allows the combined use of, python and honeybee for optimization and SA, would make the application of the proposed method very useful for designers and decision-makers of building. This method can develop for other propose such as optimizing EUI, view, etc.

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A PIXELS-BASED DESIGN APPROACH FOR PARAMETRIC THINKING IN PATTERNING DYNAMIC FAÇADES

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Abstract. In today's Architectural design process, there has been considerable advancements in design computation tools that empowers designer to explore and configure the building façades schemes. However, one could formally argue that some processes are prescribed, lacks automation and are only for the purpose of visualizing the aesthetic design concepts. As a result, these design concept explorations are driven manually to exhibit variations between schemes. To overcome such limitations, the development presented here describes a proactive approach to incorporate parametric design thinking process and Building Information Modeling (BIM).

This paper reports on an ongoing development in computational design and its potential application in exploring an interactive façade pattern. The objective is to present the developed approach for exploring façade patterns that responds parametrically to design-performance attractors. Examples of these attractors are solar exposure, interior privacy importance, and aesthetics. It introduces a paradigm-shift in the development of design tools and theory of parameterization in architecture.

This work utilizes programming script to manipulate the logic behind placement of faced panels. The placement and sizes for the building facade 3D parametric panels react to variety of Analytical Image Data (AID) as a source for the design-performance data (e.g.: solar exposure, interior privacy importance, and aesthetics). Accordingly, this research developed the PatternGen(c) add-on in Autodesk ® Revit that utilizes a merge (or an overlay) of AID images as a source to dynamically pattern the building façade and generate the façade panels arrangement rules panels on the building exterior.

This work concludes by a project case study assessment, that the methodology of applying AID would be an effective dynamic approach to patterning façades. A case-study design project is presented to show the use of the AID pixel-gradient range from Red, Green and Blue as information source value. In light of the general

objectives in this study, this work highlights how future designers may shift to a hybrid design process.

Keywords: *Computational Design, Analytical Image Data, Image Pixels, Parametric Geometry, BIM, Building Façade, Patterning.*

ملخص. هناك تطورات كبيرة في عملية التصميم المعماري باستخدام أدوات التصميم بالحاسوب التي تمكن المصمم من استكشاف مخططات واجهات المبنى وتكوينها. ومع ذلك ، يمكننا استدراج ان بعض التصميمات المستخرجة بأنها عمليات وصفية وقد تفتقر إلى التشغيل التلقائي وان بعض نتائجها فقط لغرض تصور مفاهيم التصميم الجمالي. نتيجة لذلك ، يتم توجيه استكشافات مفهوم التصميم هذه يدويًا لعرض الاختلافات بين التصميمات. للتغلب على هذه القيود، تصف ورقة البحث هنا طرحاً لدمج عملية التفكير التصميمي المعياري ونمذجة معلومات البناء (BIM).

تقدم هذه الورقة تقريراً عن التطور المستمر في التصميم الحسابي وتطبيقه المحتمل في استكشاف انماط لواجهة المبنى ومن ناحية تفاعلية .الهدف هو تقديم النهج المطور لاستكشاف أنماط لواجهة المبنى التي تتفاعل بشكل ما وخاصية الأداء التصميمي. ومن الأمثلة على هذه العوامل التفاعلية هي التعرض لأشعة الشمس، أهمية الخصوصية الداخلية، والنتيجة الجمالية. تقدم هذه الورقة نقلة نوعية في تطوير أدوات التصميم ونظرية البارامترية في الهندسة المعمارية.

يستخدم هذا العمل نص برمجي للمعالجة الكامنة وراء وضع الألواح في واجهات المبنى. يتفاعل موضع وأحجام الألواح البارامترية ثلاثية الأبعاد لواجهة المبنى مع مجموعة متنوعة من بيانات الصور التحليلية (AID) كمصدر لبيانات أداء التصميم (على سبيل المثال: التعرض للشمس وأهمية الخصوصية الداخلية والجماليات). وفقًا لذلك ، طور هذا البحث برنامج إضافي بمسمى PatternGen (c) في Autodesk ® Revit التي تستخدم دمجًا (أو تراكبًا) لصور AID كمصدر لتكوين نمط ديناميكي لواجهة المبنى وإنشاء لوحات قواعد ترتيب لوحات الواجهة على السطح الخارجي للمبنى .

يختتم هذا العمل من خلال تقييم البرنامج وتطبيقاته على مشروع مختار ودراسة منهجية تطبيق AID ستكون نهجًا ديناميكيًا فعالاً لتزيين الواجهات. يتم تقديم المشروع مختار تصميم كحالة تصميم دراسي لإظهار استخدام نطاق تدرج البكسل AID من الأحمر والأخضر والأزرق كقيمة لمصدر المعلومات. في ضوء الأهداف العامة لهذه الدراسة ، يسلط هذا العمل الضوء على كيفية تحول المصممين المستقبليين إلى عملية التصميم المختلط متوازن.

الكلمات المفتاحية: *التصميم بالحاسوب، بيانات الصورة التحليلية ، بكسلات الصورة ، الهندسة البارامترية ، BIM ، واجهة المبنى ، الأنماط الزخرفية.*

1.0 INTRODUCTION

1.1 DESIGN CYCLE: ANALYSES + SYNTHESIZE + EVALUATE

Designers consider the paneling of facades as a significant exterior building feature to achieve the desired design goals and aesthetics. Typically, they depend on their design thinking skills (aesthetic, visual and function) for example, but with some constrained criteria to inform the design (Rorig, et. al, 2014). At present, architectural firms and many academic architectural

programs are indeed embracing parametric modelling into the early design stages to produce different design representation. As illustrated in figure 1, this changes the mindset of designers because it requires embedding certain logic in relation with façade penalization geometry and the output (Turrin, et. al, 2012). As far as façade paneling is the goal here, the articulation considers the geometry of the façade such as: pattern, form, boundary, panel size and types of panels to represent the intended design function. Consequently, this work is motivated about how to explore a proposed approach for combining parametric thinking and Analytical Image Data (AID) images as a creative method to assist in understanding of the fundamental issues that strengthen the theory to produce and express complex façade architecture.

Park et. al. (2004) believes that computational design can address the proposition that architectural design is transitioning to an analytical process of inter-connected factors, and it makes it a new phenomenon. From an industrial product design and development perspective, one may consider the building as a product. In fact, a LEAN thinking method used in other engineering fields can be applied in architecture to encourage the analysis + synthesizes + evaluate design cycle when paneling building facades. Some precedent examples are from structural and mechanical engineering fields dealing with visualizing design and performance for the design of structural elements based on stress/load color visual analysis. The case is different in Architecture where there were long overwhelmed due to cost and complexity in design practices (Luebkeman and Shea, 2005). Along these lines, what is essential to this work is crossing over any barrier among research and practice to grow the ability to expand expertise in the patterning of dynamic facades being executed based on parametric modelling.

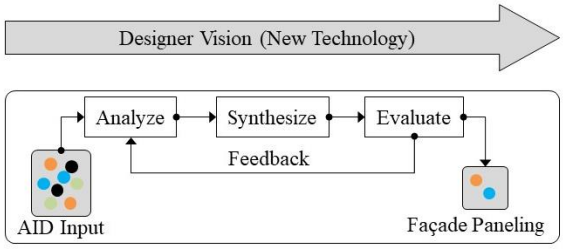
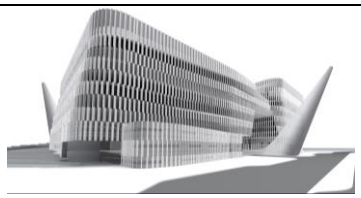


Figure 1: Mindset Diagram and Color-Base Analysis Example

1.2 ARCHITECTURAL SKETCHING AND PARAMETRIC DESIGN LANGUAGE

Architectural design sketching is fundamental to the creative idea production process, and it resembles a focal effort for emerging design ideas that is

stimulated by the designer's creative imagination. It is a process that is dynamically relying on interacting with illustrations as design language. McFadzean (2000) described that hand-drawn sketching are a significant piece of the entire design process and that it engages the use of past experiences or thoughts. This work reports that this sketching procedure can be seen as a trigger instrument for recalling design moments or style. This is a 'marks retrieving' action and can be identified with the designer's style and potentially distinguishes key factors in design direction. In this regard, the proposition in this paper recognizes that parametric design can be seen as visual design language to permit designers to think with shapes and forms as marks to be part of the conceptual design process.



Hill County Sez Office Complex by SOM (Source: Mark Igou, https://src.lafargeholcim-foundation.org/)

Thematic Pavilion by SOMA (Source: https://www.designboom.com/)

Figure 2: Examples of Architecture of new avant-garde

The capacity to utilize complex rules for shape configuration are linked with the ability to initiate a 'creative triggers and to engage inventiveness (Barrionuevo et. al. 2004). The mechanism for triggering creativity inspires the design process and can be anything: an object, geometrical combinations, spatial relationship, aesthetic, etc. Scholars like Lionel March suggested that shape configuration rules and computational design mechanism prompts surprise and serendipity (Earl, 2000). A key thought in this work is to present parametric modelling as an approach to formulate a language for modern façade emergence, especially as seen in the new avant-garde that emerged within the span of the last ten years (figure 2). Reputable architectural firms are known of demonstrating the merits from utilizing parametric expression. One can see a shift from the conventional surfaces to tectonic surfaces and developed exterior envelopes that we call now the post-digital age. For example, this process is notable in the example projects shown in figure 2 whereby dynamic façade is represented by different aspects: surfaces type, repetition, panel geometry (shape and size), pattern configuration, material, and design concept. John Frazer (1995) described the metaphor for such imaginative shape configuration process as:

"Using the computer - like genii in the bottle – to compress evolutionary space and time so that complexity and emergent architectural forms are able to develop. The computer of our imagination is also a source of inspiration – an electronic muse".

1.3 PARAMETRIC UTILITY AND DESIGN TRANSFORMATION

Every designer uses a variety of methods to work out the relationships between the elements of the architectural facade. This may involve several design modifications such as: adjustments, refinements, structuring, and representation in a way to visualise and conveys the works (Harfmann, 2012). However, the manual editing of object-to-object relationships in most CAD systems to alter the geometry clearly is isolated from design-automation as well as being subjective to the designer's implementation.

Nowadays, parametric modelling is embedded inside Building Information Modelling (BIM) as a master model comprising parts and sub-parts within the BIM model (Park and Holt, 2010). The BIM model contains the parametric values for every 3D object and its relationship to other objects and is adaptive to the continuous design state. The core concept in parametric modelling is that objects and sub-items are related to each other through parametric rules and as a connected framework (figure 3). Any modification to one object would affect the current design state which has far reaching effects on the way designers reaches a design scheme.

In recent years, connectivity between parametric modelling tools and integration with external platforms have matured and made data-flow possible between data source and parametric objects. Parametric modelling platforms like Autodesk ® Revit, Rhino ® Grasshopper, CATIA®, Bentley ® Generative Components are available tools for designers to implement such data flow integration. Hence, such collaboration tools require a well-structured computational design workflow as it becomes more and more in the hands of the designers (Aish and Woodbury 2005). To this, the utilization of different source data stored in Excel or CSV text files can assist designers to alter the shape/size of the parametric façade panels. This paper focuses on the interactive rules between the designer and the parametric utility as channel for creativity and means for representing design ideas. This work utilizes Autodesk ® Revit BIM tool and the embedded Application Programming Interface (API) scripting. It developed an add-on with rules to change the properties of the 3D façade parametric objects. The add-on utilizes an Analytical Image Data (AID) as a data source input to configure the building façade panels. The goal is to allow designers to

interact with facade patterning using parametric-driven design process and to enrich their creativity thru viable performance data. The proposition here is from a practical view and is implemented in an architectural project.

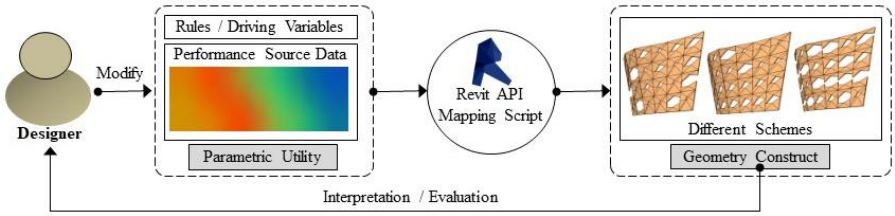


Figure 3: Parametric utility framework with designer interpretation loop.

1.4 RESEARCH MOTIVATION AND OBJECTIVE

Even though dynamic façade patterning design feature is spreading, most designers depend on other specialized users with their parametric scripting skills. These tools deploy scripting environment such as: Maya Embedded Language (MEL), Revit API, Dynamo, C# programming language, Rhino Grasshopper, Visual Basic in Bentley Generative Components, etc. Even though the tools offer great degree of creativity and generative design exploration, they are expensive methods relating to intense scripted programming. These scripted programming are relatively new to architectural community and are based on mathematical code, coded instructions, formulas, creating macros, etc.

Consequently, the motivation in this work was to develop a computational design add-on as well as an approach to dynamically control façade panels. A relevant motivation also comes from the need for a hybrid design process is inherently parametric, it is important that designers use a tool with “simple” user interface. Not only this, the hybrid design style could maintain its promise for innovative advances in design articulation and how it is conceived. The goal of AID design approach is to illustrate the technical evolution from utilizing the dynamic patterning of the building facade and as an exploration tool in the early design phases. This work offers designers an understanding of the fundamental process that drives the building facade patterning while attaining to an approach for facilitating the early-stage design process.

This paper focuses on exploring the application of AID overlay images with main goals such as:

- To provide a generic tool for facade-patterning and design exploration.
- To demonstrate a simplified method for managing a complex parametric model and facade components where scripted program captures processes for the inherent performative logic.
- To automate the modification of façade panels in response to AID images.
- To report on new levels of complexity that might create unexpected aesthetic from the emerging design output.
- To define the computational workflow and process in support for architectural practice and academia especially when it comes to implementing computational design technologies.

2.0 Methodology for Designing with Computation Logic

This section elaborates on the methodology for creating an AID driven facade configuration in order to understand relationships between AID image overlay and facade panelization design process. The methodology includes these three major phases described below to achieve the dynamic façade patterning.

2.1 PHASE (1) - TILING AND PATTERNING THE FAÇADES

The beginning phase is the construction of a surface mesh geometry that has “U-direction” and “V-direction” 2D divisions (figure 4). These divisions resemble the initial 2D grid layout for receiving and organizing the panellized façade components. The figure 4 below shows an illustration of a wall prototype with sample rectangular 3D brick component. The initial wall surface and form presented in figure 4 below was created using the “Divided Surface” feature available in the Autodesk ® Revit massing environment. The Revit 3D conceptual massing environment is mainly used to apply the “UV” divisions (i.e. rectangular pattern) necessary to the façade panels. The designer can control the size (for example 10 X 15) and position of the “UV” 2D layout to describe the initial layout of the façade design. In this study we focus the development on the UV-grid limited to the rectangular patterned surfaces. As illustrated in figure 4, it is a laborious process to even alter manually a generic parameter “X” of a length type.

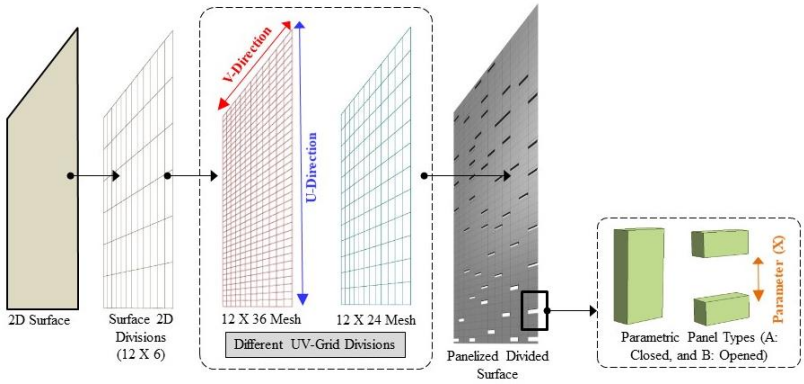


Figure 4: Revit Divided Surface UV-Grid Layout and Tiling (Phase 1)

2.2 PHASE (2) - IMAGE PIXELS: DATA, VALUES, CODING AND MAPPING

For simplification purposes, one may consider the building façade as a basic layout made of X and Y grid system connected like the one shown on figure 5 below. The façade panels responsiveness is driven by the different AID sources from a variety of performance sources like: panel placement by program, solar exposure, visual aesthetics, etc. (Madeddu, 2011). For example, tools like Autodesk Revit Insight ® solar analysis plug-in, and design sketches in PhotoShop ® can produce AID bitmap image. In the same manner, each AID bitmap image has an X and Y grid made of pixels (e.g. 10X10) and each pixel Red Green Blue (RGB) values can be obtained and mapped on the facade X and Y grid system (i.e. Revit Divided Surface panels). As illustrated in figure 5 below, phase 2 in this work implemented C# programming language available in the Revit API to handles the data-values RGB value of pixels to the façade panel mapping.

As explained earlier, we are focusing on exploring the overlay of AID data sources as driver for façade panelization. We utilize a generic façade example as shown in figure 5 below to illustrate how a facade panel “X” parameter reacts to an overlay of three AID and produces a dynamic facade pattern. The designer will utilize this image-to-facade mapping approach and produces completely different variance of styles. The C# routines used would retrieve the input values of the AID pixels and convert them as greyscale values also known as ranging from White to Black with any shades of grey in between. In the context of manipulating the facade component parametrically, it is possible to manipulate the “X” dimension parameter based on the greyscale gradient image pixel values. The designer can assign any given criteria for “X” parameter to act as a manipulation mechanism for the facade panel properties such as: size, offset, depth,

length, width, angular twist, etc. Therefore, informed decisions when exploring dynamic façade patterning is achieved thru the computational logic with using AID images.

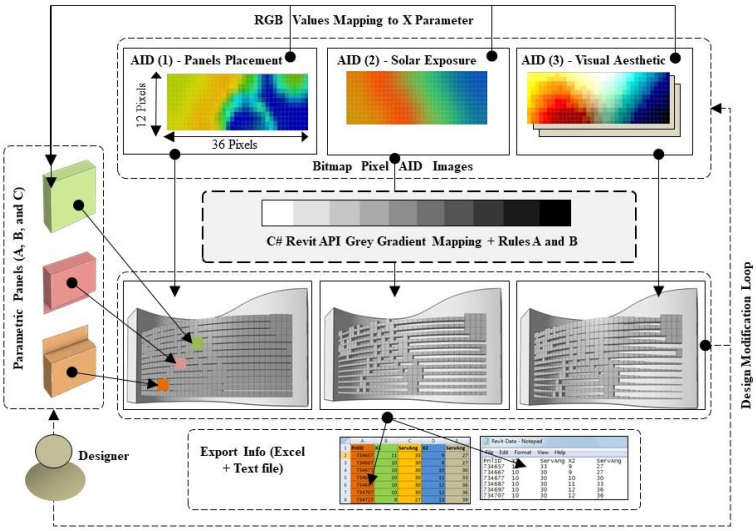


Figure 5: Facade manipulation phases and dynamic computation logic (Phase 2 and 3)

2.3 PHASE (3) – PARAMETRIC PATTERNING

In this phase, the AID paneling approach mentioned above extends the possibility of varying the patterning rules for the building facade. This approach allows the encoding of façade patterns rules according to set of "Xn" parameters which are embedded inside the facade parametric panel. The objective is to assist the designer to explore a range of façade modifications using a generic parameter inside the parametric panel object. Here, the proposed patterning rules are the connecting relationship between the 2D AID bitmap pixel values which changes the value of the parameters "Xn". This is a semi-automated mechanism to alter the values of the "Xn" to see the patterning result on the façade. This work implemented the two rules (A) and (B) as described below, in Revit ® API C# routines to extract the difference in the greyscale colours of each pixel values to controls the "Xn" parametric values (see figure 5).

Rule (A) – Panel Type Selection and Placement:
In many situations, designers utilize aspects like practicality, aesthetic, visual privacy for the positioning of various facade panels. The iterations and management between these three aspects play a vital role in the

parametric thinking process. (Hudson, 2009). For example, three different types of façade panels can be used: solid panel, panel with top opening and panel with bottom opening. For the purpose of panel placement rule "A", solid panel types can be placed on the façade location where there is service/storage space behind it. In addition, the designer can choose to place a panel type with bottom opening if the interior space is public space (e.g. living room). The panel type and selection control mechanism are also driven from the greyscale percentage values in the AID image. Greyscale value corresponds with the panel type to be used. The figure 5 below shows how individual pixels with greyscale values from AID (1) can be coordinated to control placement of the panels.

Rule (B) – Xn Parameter Value Change:
The logic in this rule is very important because it controls the value of a specific "Xn" parameter. We limited the implementation of "Xn" generic parameters in this work to be applied as "X1" and "X2" for dimension "Length" type Revit parameters and "X3" of "Angular" degrees type parameters. Initiating this rule will extract the greyscale value for the specific pixel from the AID image. Then the greyscale intensity of a pixel is expressed in percentages within a given range between (0%) for white color and (100%) for solid black. The use-case listed below shall explain how this works when the user assigns "X1 =1 meter" as maximum value:

- If the greyscale of a pixel is 100%, then "X1" value remains as it is.
- If the greyscale value is (0%) then "X1" value becomes "0".
- When the greyscale value is (50%) then "X1" value becomes "0.5 meter".
- And so on it can be applied similarly for the parametric values of "X2" and "X3".

Rules A and B are integrated in this work to help automating and updating façade schemes as the layout evolve from one scenario to another. This is a generic approach that serves the ideal world of designers and engineer to interact with a parametric thinking process by simply updating the AID images and overcomes the manual method of updating and re-drawing dynamic building facade in a BIM environment.

3.0 The PatternGen(c) Add-on Development

The main development environment for the PatternGen(c) add-on in this work is the C# programming language and .NET Visual Studio. The C# routines uses the open Revit ® API features to manipulate panels in the

façade geometry and the AID image mapping data transfer. A real-time data exchange is facilitated between the AID overlay of images thru the PatternGen(c) user interface as shown in figure 6 below. This in turn provides designers to alter the façade panel configuration dynamically and visualize their design concepts thru the Conceptual Mass modelling in Revit ®. The goals is essential to assist the design team to quickly view design options and make some basic informed decisions.

Nowadays, the designers can generate different AID bitmap images from analysis tools like Daysim®, Revit ® Solar Radiation Add-on and Revit ® Insight. The background and conclusions form the literature observation in this work indeed anticipates assisting most designers by reducing the time, tedious process and special coding to modify facade components parametrically. As a result, the different parts for the PatternGen(c) add-on user interface are developed for simple input use like: loading an AID image, and applying the patterning rules mentioned previously. With this in mind, the user interface parts were necessary to allow the automated patterning and tiling of the facade panel components.

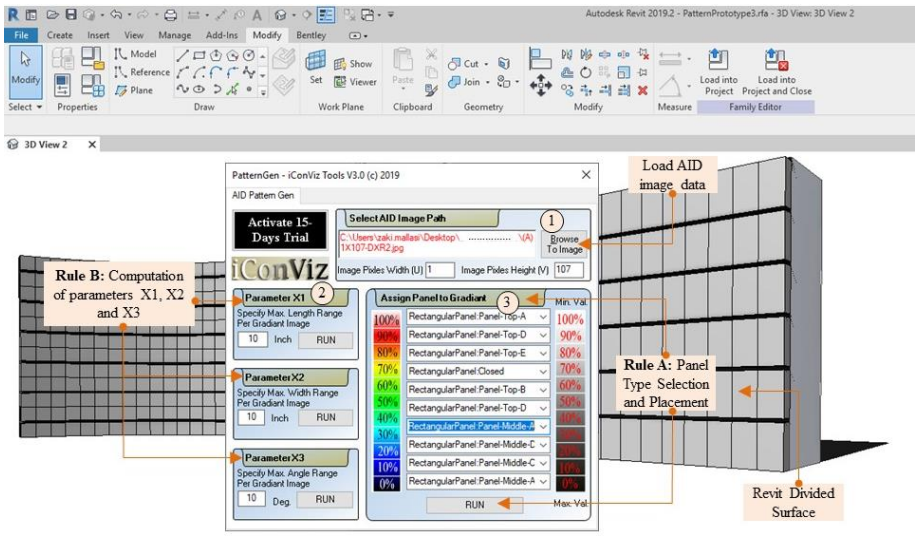


Figure 6: The PatternGen(c) main user interface parts developed by the author.

3.1 PATTERNGEN(C) USER INTERFACE PARTS AND CONTROLS

The PatternGen(c) development as add-on to the existing Revit® parametric environment provides a number of benefits from a developer point of view and to the end user. As shown in figure 6-1 previously, the PatternGen(c)

user interface comprises a window application floating on top of Revit® that has access to the Revit® API functionality. In fact, this user interface has been developed from multiple feedback from users and a number of features were added which are more accessible to the user. As shown in figure 6 above, the add-on three parts facilitate the following controls and execution of rules A and B:

- **Part One:** allows the designer to select the AID image to be utilized in the façade panelling and also as the datat source for the desired pattern. This is the first crucial step because when the AID image is loaded, the tool retrieves the pixel data for mapping on the "Divided Surface" Revit geometry. Not only that, the add-on displays confirmation that the AID pixel size and orientation is similar to the "Divided Surface" UV grid 2D layout. For example, an image of Pixel Size Width (10) by Height (20) is mapped on a "Divided Surface" of U=10 by V=20.

- **Part Two:** manipulates the change of values for "X1", "X2" and "X3" parameters based on applying Rule "B". As mentioned before, these values represent the greyscale of the AID pixilation mapped on the parametric panel values.

- **Part Three:** lets the designer to apply Rule "A" after loading the AIM image to begin panel type selection and placement per the greyscale AID pixilation range. In this regard, the panel types and placement choices are driven from the design function or the aesthetic requirements. As shown in figure 6, while the panel types assignment is done manually by the designer, they are however placed in an automated fashion per the AID greyscale range. Then the add-on will compute the placement of the panel type on the "Divided Surface" according to the AID pixels.

3.2 STEPS FOR PATTERNING A FAÇADE

We define in the following the workflow for dynamically patterning a façade depending on the two main AID images: aesthetic and solar exposure. The flowchart shown in figure 7 below demonstrates such process taking into considerations three important steps to accomplish a practical workflow for a typical facade dynamic patterning.

The First Step makes usage all the functionalities of the parametric geometry and facade envelope that are modelled within the Revit ® Conceptual

Design Framework. Here the designer models the 2D geometrical surface for the facade and subdivides it into UV tiles such as U=6 by V=30. The designer will produce the solar exposure AID image using the built-in Revit ® "Solar Radiation" functionality. Some of the benefits from using Revit ® Conceptual Design Environment is the ease of its 3D geometric modelling environment and the ability to obtain facade solar exposure internally without having to perform the analysis on external analysis tools.

In the Second Step, the user models the Revit ® Curtain Panel object which contains “Xn” parameters. In this way, each panel object would contain three panels types such as: A, B and C where each of the types has implemented “X1” and “X2” parameters to control the panel depth and/or opening size. The designer ultimately makes the decision to apply the AID driven computational logic either on “X1” or “X1”. These parameters were intentionally named in such generic naming convention for easy of application and to abstract the parameters naming. In other words, another user for example may utilize “X1” for controlling the thickness or length sizes of a Revit ® Curtain Panel component.

The Third Step requires the user to hit any of the “Run” buttons to begin executing the patterning mechanism. This will initiate the dynamic patterning routines by applying the previously describes rules (A) or (B). Then, the values for the “X1”, “X2” and “X” parameters is adjusted depending on the pixel/greyscale values obtained from the AID. The facade panel objects would reconfigure to execute the patterning results based on the computed/mapped greyscale. Furthermore, the designer can explore additional façade studies when applying different aesthetic AID images. The iterative process for this workflow can be seen as an abstract conceptual façade sketch where the designer can edit the AID image pixels areas to reflect and control panels on the façade. This was used to produce a facade model that is aesthetically evaluated part of the design process.

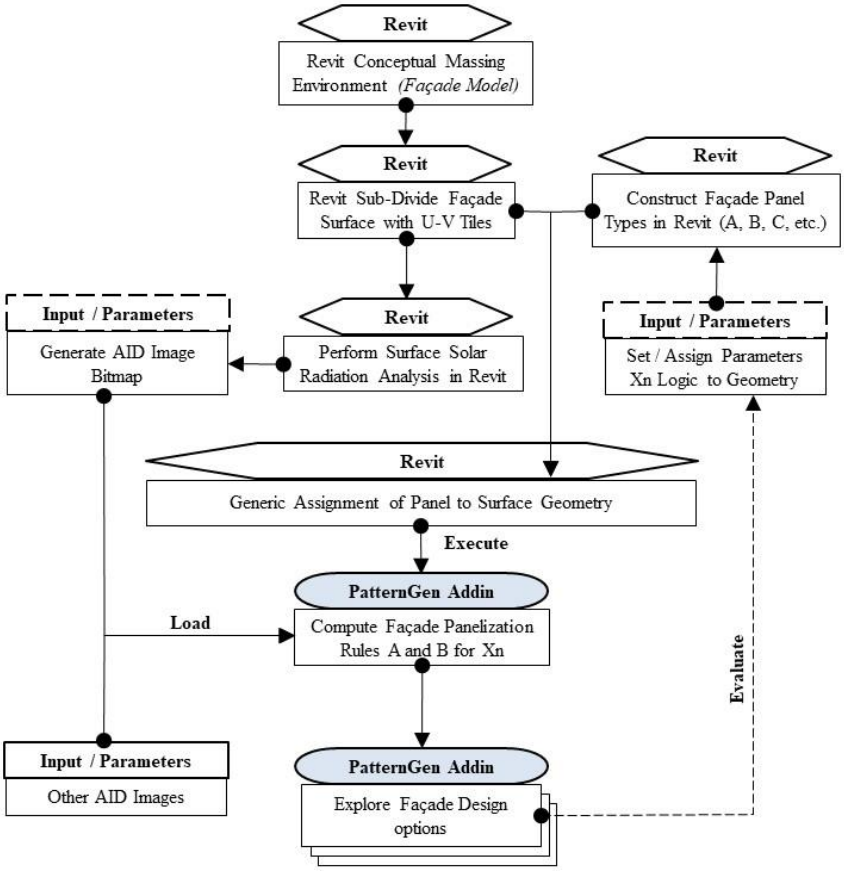


Figure 7: Proposed Computational Design Workflow Using the Add-on.

4.0 Application on a Real Project Design Scheme

Computational design is a problem-solving and a dynamic process that demands the coordination between different goals. There are environmental, functional, aesthetics, and visual privacy to be considered before the production of an architectural artefact. Primarily, the focus when applying our proposed computational design approach in this work is to create architectural design output which recognizes the above coordination items. In addition, it is crucial for a complex design transformation to be created in BIM to leverage the integration of such process into future architectural design practice.

A real architectural project involved a design task for exterior façade of a small VIP Airport Terminal building constituting of four floors a total floor

area of 6,800m2. The building is dedicated to be a world-class spaces to service passengers such as: check-in counters, arrival lounges, departure gates, duty free zones, food services areas, and supporting services. The project building exterior envelope comprised numerous challenges in terms of sun screening, views enhancement and façade function. The project is forming part of the overall airport client's newly constructed projects to enhance the passenger experience, create a facility that is modern and well-functioning.

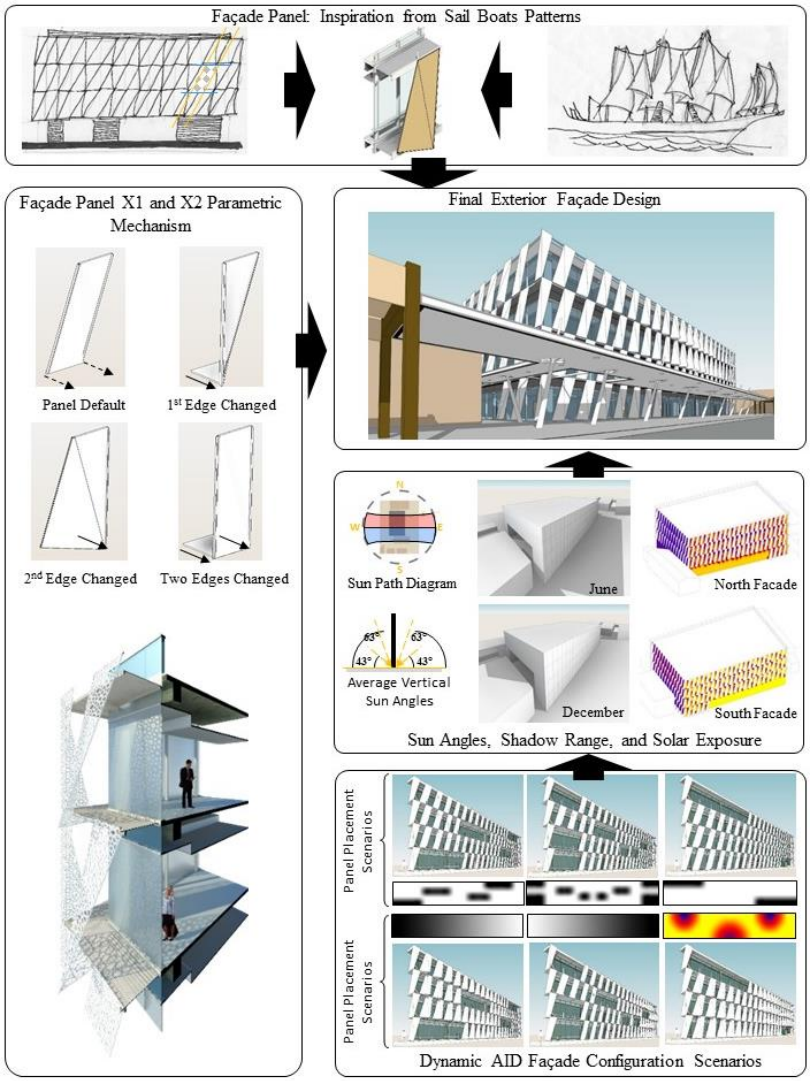


Figure 8: The case study project: facade boundary outline, parametric panel mechanism, and Boat sail pattern inspiration.

The general building envelope concept is illustrated in figure 8 below and is driven by several aspects. They are mainly an inspirational response to the interlaced grid pattern which mimics Yachts sails surface areas and responds to the hot climate. The formed exterior panels are emphasized from the effect of patterned panels that dynamically gives an effect of an overlapping sails. The façade will have a visible contemporary presence as well as appreciating the traditional local culture. Among several design schemes presented to the client were focusing on articulating the building envelope to read as contemporary and in harmony with the surrounding sea-life/boats traditional local culture. The author, as being the Lead Designer on the project, embraced the opportunity to experiment with the AID performance-based design approach on this project. Most of these schemes presented here formed a prototype for experimenting with parametric thinking for Configuring and Designing Dynamic Building Façade. The exterior façade is climate-aware in terms of utilizing a simple exterior façade panel made of perforated panels to reduce overall exterior solar exposure while maximizing view from inside to the outside.

4.1 PIXELS MAPPING SCENARIO ON THE FAÇADE PANELIZATION

In this project, the placement of the panels on the exterior façade is of a static nature and plays a major role as a shading system inspired by the overlapping of the Boat latticework (figure 8 – shows only panel mechanism). Since the project is located on the northern hemisphere and close to the equator line, one of the design challenges was to reduce the solar exposure especially on the north and south facades. This required a performance-driven design analysis approach in order to offset the solar exposure amount. Therefore, with the sun position in mind, this façade panel will have flexible parametric geometry and its size will be affected so that the higher solar radiation, the smaller the stretch mechanism will be. The different design variations for the façade paneling utilized in this building envelope considered a more responsiveness to the environment which can influence the interior space.

The geometry for the parametric facade panel types is created in Revit ® and positioned to wrap the building envelope of the building. The configuration of panels introduces the definition of fabric-like covering the building mass. The facades are occupied by a simple rectangular panel types (figure 8). The bottom two edges of the panel are assigned “X1” and “X2” parameters so that to stretch and retract and control the size of the opening/shading area. Each panel within the facade sub-divide surface (UV tiles) is assigned a panel definition according to two AID values to describe the variation of the

solar exposure and privacy values. Using the RGB colour values from AID image, several design iterations are produced for the facade fabric.

Most of this work depended on the execution of the rules previously mentioned in sections 2.3 and integrated into the PattternGen add-on to express the façade pattern. The explorations of different patterning scenarios in the project case study were the product of traditional feedback interaction between the design team based on a variety of AID images. Most of the variations in parametric panel size added to the building facades were combinations of reaction to solar exposure, as well as preserving the interior space privacy. Such combinations also introduced to this workflow a more flexible configuration to the design process. The ability to provide more views from inside to outside has been achieved by the stretch/retract mechanism in the panel geometry. Similarly, the different panels were positioned on the façade in accordance with the AID image pixel properties which maps the adds/remove panel placement per the greyscale used in the AID image.

5.0 Applicability and Known Limitations

There are several application and limitations relating to this work in its current development and the how it may shape the current state of architectural design practice. The AID-image overlay approach here is a proof-of-concept and is based on interaction between the user and the computational design process. The practical application of this approach over intense code-based computation approaches are the following:

1) Reducing the gap between theory and application in practice by means of integrating interface without interfering with the normal design process workflow. Designers would have the tendency to adopt it as they require more comfort level and familiarity with the initial set-up of the program.
2) Exploration of different schemes is likely to be more anticipated since the approach needs less design computation skills that many designers do not have. This approach allows them to focus on design tasks and less on software coding.
3) The required level of design-abstraction to iteratively explore complex geometry is appreciated especially when the design concepts are still in an early scheme development.
4) The generations of executed design schemes are within the same Revit BIM environment which makes it practical to transition easily to a later more developed design stage.

5) The AID-image overlay approach creates a simple computational design workflow for best practice and allows the user to iterate design test-runs development.

The current limitations and areas for improvement are provided below:
1) As explained earlier, the customized PatternGen add-on is developed to work with Autodesk Revit Architecture application which demands that users have familiarity with Revit conceptual/parametric modelling environment.
2) Although the current development was geared towards using a simple rectangular "UV" facade grid pannelization, our experiments with other Revit default "UV" surface patterns like (triangular, diamond, rhomboid, etc.) were successful. This development figures out the problem when applying non-rectangular "UV" grid is due to incompatibility between the image pixel counts and the total facade panels' count.
3) Like the development of many parametric tools at initial phase - the AID approach focused on setting a framework for generating façade design alternatives. Peter (2012) explained that a detailed daylight analysis or energy façade modelling at very early design stages may be inappropriate and time-consuming. Therefore, the simplified framework was structured around AID image overlays as common rule-of-thumb that might assist the generation of façade design alternatives. In the long run, this development can transition to further embed fast, numeric, quantitative optimization feedback loop. Rules and constraints can be added for optimization purposes to compare decisions between alternatives against specific design criteria. However, this research will not emphasize on these issues due to the limitations of its scope.

6.0 Conclusions and Future Directions

This paper presented a computational design approach for dynamic façade patterning design based on parametric thinking. An automated façade panelization control mechanism approach and custom add-on tool have been described that implements generic parametric rules to overcome the complex methods relying on heavy scripted programming. In this regard, several illustrations for the design method supported with a case study have shown the potential in the generation and exploration of design alternatives by directly linking external AID values to patterning the facade surface. The case study also provided an applicable example of attempting to rationalize the method of parametric thinking to reduce the lengthy time spent when creating the desired design directions. The designer can alter the panelization

of the façade by setting up a parametric process combined with the rules and image-pixel data while maintaining promise for architectural articulation to be discovered

The proposed AID overlay approach for panelling the building facades triggers design ideas as a practical method for exploring new types of shapes as an interface between digital design, process, and analytical data. The work here also attempted to build on the research works gathered to expand BIM capabilities by providing a hybrid design processes. Although computational design methods and software tools are widely spread in academia, the greater picture of parametric thinking encounters much challenge in professional practice. This work identified that AID is one of the approaches to manage facade patterning iterations interactively. It also showed that the ability to deal with design complexity effectively at early design phase. Incorporating parametric tools has provided a new way for exploring façade design and automation.

With regards to future work, the new generations of design specialists will need to be educated on the knowledge of computational geometry, scripting, and parametric data model management. This also will require an appropriate time and commitment to multidisciplinary team collaboration. Another implication from the vision in this work is that design professionals may act as a tools-makers dealing with complex design tasks which may open broader opportunities for abstracting parametric design thinking functions and operation. Indeed, the PatternGen(c) add-on development demonstrated the advantages customizing design application software like Autodesk ® Revit that are widely used by architectural designers, but hardly utilized in computational design field. This in turn can supports further extensibility for its capabilities and incorporating further features of interactive computation design. One desirable future extension to this work would be to incorporate further aspects such as a feedback loop of optimizing the results from the configured façade. To this matter, attempts can be made to use the saved façade parametric panel properties in order to further assist the designer with decision making based on optimization and analysis of different scenarios. One of our intents is to expand the scope of this AID overlay approach and include other relevant features such as: (1) to have seamless digital connection with kinetic façade prototype, (2) more research into performance-based design.

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A CRYPTO-TWIN FRAMEWORK FOR THE AEC INDUSTRY

Enabling Digital Twins with Blockchain technologies.

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Abstract. The paper describes a conceptual framework and the smart contract architecture for Crypto-Twins (CT) in the AEC industry, i.e. blockchain (BC) enabled digital twins. We describe the background, terminology of technologies involved, while the methodology follows design science research patterns to construct the framework and architecture of the Crypto-Twin. Further avenues for prototype development and validation of the framework are proposed in the conclusion.

Keywords: *Blockchain, Digital Twin, Smart Contracts, Metaverse*

ملخص. تصف هذه الورقة البحثية إطارًا مفاهيميًا وبنية لعقود ذكية للتوائم التشفيرية في مجال العمارة والهندسة والتشييد، أي التوائم الرقمية التي يتم تمكينها من خلال تقنية البلوكتشين. نصف فى هذا البحث الخلفيات ومصطلحات التقنيات المعنية، بينما تتبع المنهجية أنماط بحث علوم التصميم لبناء إطار لبنى التوائم التشفيرية. تم اقتراح المزيد من السبل لتطوير النموذج الأولي والتحقق من صحة الإطار في الخاتمة.

الكلمات المفتاحية: *تقنية البلوكتشين، التوائم الرقمية، العقود الذكية، الميتافرس.*

1. Introduction

One of the most important innovations since the integration of smart devices and the internet has been established is the possibility to constantly

receive up-to-date information about an almost complete range of aspects that affect our lives. Flight schedules, bank transactions and product delivery are nowadays uninterruptedly tracked with precision by both customers and companies, with a view toward enhancing the quality of the experience of the final users. In this context, in which data play a paramount role in the future, the built environment is starting its transformation from a conservative static immutable entity to a more dynamic field in which information is shared between buildings and their digital twins.

While the digital model of a building has been till now primarily interpreted as a database in which to store as much information as possible, as in a classic Building Information Modeling capacity, the next step for designers as well as for contractors is to point toward the creation of a digital twin of the existing building who can inform itself with real-time data collected via sensors or other technologies able to read and communicate information such as structural performance, environmental behaviour, user interaction. Thus, data sharing affects not only the design stage but, being generated from components in a real building, also the operations that occur during its whole life representing a powerful platform for planning maintenance, upgrades and future retrofitting operations.

This huge amount of data that must be created combining both those coming from the real-time database and the geometrical information of the building require at the same time to be secured from potential risks as theft, and shared with all stakeholders involved in the post-occupancy maintenance in a trustful manner. The dual nature of the data, at the same time private and public, raises the necessity of adopting digital systems that allow a transparent, secure, and efficient manner of handling that data and the subsequent governance of those systems.

The combination of the physical built environment, digital twin and data encryption creates a new level of trustworthy infrastructure that shifts the way in which design and operations are planned, setting economic goals, time frames and protecting the ownership of each design decision. Within the paper, we develop a framework for integrating blockchain (BC) technologies and their crypto-economics design with digital twins (DT) within the Architecture, Engineering and Construction (AEC) Industry. We envision this Crypto-Digital Twin as the cornerstone of a blockchain-enabled shift in AEC operations, where smart contracts (SC) and crypto-economic incentives integrate and optimize the performance of the AEC industry.

2. Terminology, Motivation and Objectives

We briefly describe terminology, then explain our motivation behind the paper and the objectives of the research.

2.1. DIGITAL TWINS

The concept of the digital twin (Information Digital Twin) was first introduced by Michael Grieves at the University of Minnesota in 2003 as the digital information equivalent of a physical product, mentioned first as a "product avatar" [Grieves 2003].

It is a digital entity representing the digital information equivalent of a physical object, set however within its environment. The DT behaves exactly as the physical product/object and can be used to simulate the behaviour and performance of the product allowing thus the possibility to predict various scenarios and then apply the best decision possible. There are certain conditions and constraints in terms of the definition and existence of the digital twin. A real-time connection between DT and physical reality might be desirable, but it is not an unquestionable requirement, as the DT might be operating without real time data. Another key feature of DTs is the fact that the DT starts existing the moment one develops the designs for the physical product/object/building, the DT exists even before the physical artefact is constructed. Within the early design stages, the digital twin currently might be called something else, for example, Building Information Model, simulation model, design or similar. This introduces another unique feature of the DTs: the twin metaphor, where the physical artefact and the DT are connected through the concepts of duality and strong similarity [Grieves 2022 speech], i.e. the DT is a digital doppelganger of the physical construct and is of course similar to the physical product, but not always identical. As such, there is a requirement, according to Grieves, that the DT exists at some point of the lifecycle of the physical construct, but there is no requirement that the DT exists prior to or after the physical construct and vice – versa. [Grieves 2022]. In fact, there have started to appear DTs where a Physical construct does not exist, for example, when one builds a DT of a supply chain. There the processes involved are the ones twined. As such, we can also anticipate that the DT can also exist after the end of the lifecycle of the construct, allowing us to use the data and insight the DT has provided in a future variation or production.

Grieves defines three stages and levels in the DT lifecycle: Prototype, Instance, and Aggregate (figure 1)

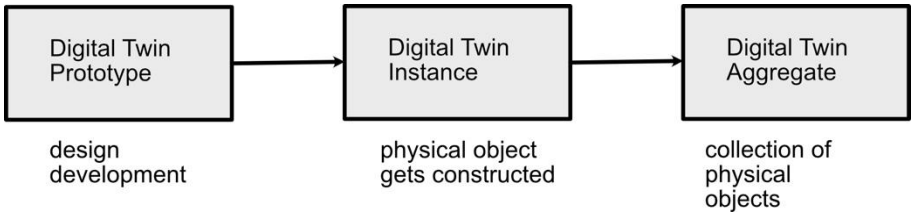

Figure 1. The Digital Twin Lifecycle, *drawn by the first author.*

DT prototype is the DT during design development, where the characteristics that differentiate it from any model development are those that enable the Digital Twin metaphor, and thus can be used as a litmus test on whether a prototype is destined to become or is a DT. A DT instance is the DT that corresponds to a particular physical construct, i.e. DT instance is operated at some point in tandem with the physical counterpart, while a DT aggregate is the aggregation of multiple DT instances; for example, a DT aggregate of a city has as components DT instances of buildings.

2.2. BLOCKCHAIN TECHNOLOGIES, SMART CONTRACTS, TOKENS AND DAOS

Blockchain is a distributed network of computing nodes that maintain a decentralised ledger of transactions, with an algorithmic consensus mechanism to synchronise the ledger between them. The consensus does not need a central coordinating node but emerges using a variety of algorithms, for example, proof of work, proof of stake, and proof of authority. In most public consensus blockchain algorithms, participation is incentivised in terms of good behaviour. In most cases, the blockchain designs [Buterin 2014, Nakamoto 2009], transactions are recorded on a Merkle tree, in a manner where each transaction is paired with another and the result is cryptographically hashed, with the root of the tree of transactions gets also cryptographically hashed and embedded into a block of transactions. Each block also contains the cryptographic hash of the previous block. The chain of cryptographic hashes, the distributed nature of the ledger amongst a plethora of computing nodes and the (dis)incentives encouraging the correct behaviour of nodes make the deleting or changing of information of transactions that have taken place in the past very difficult to impossible.
The careful reader will note that transitions usually consist of addition and subtraction; however, one can expand the paradigm and include in transactions all programmable directions, i.e. software code. Hence, the second generation of blockchains incorporate the idea of smart contracts, i.e. the execution of software classes of code from a distributed stack machine that

runs on each blockchain node in an autonomous manner, i.e. without the need for human intervention.

The name smart contracts is due to the implicit guarantee that the code will be executed every time as written (Szabo 1994). Consequently, the three most important characteristics of blockchains are the concept of a trust medium, as agents and parties can record to them information without it ever being changed or deleted, the concept of incentivised participation, i.e. one gets rewarded for contributing to the common pool resources of the system, and the concept of automatic execution of code in the form of smart contracts. These ideas are then the foundation of modern cryptoeconomics, i.e., economic systems that run through blockchain code. Most economic constructs on blockchain take the form of tokens, i.e. special smart contracts that represent either some kind of uniqueness, have some utility in specific contexts, or encapsulate some value in other contexts. For example, a particular community might issue their own fungible token that is used for transactions within the community, while another might issue a non-fungible token that grants the holder governance rights over common pool resources or the organizations. In other examples, tokens might have the function of securities, i.e. they represent the ownership of an asset of value, for example, a building or a stock.

Figure 2. Ethereum Blockchain and Smart Contracts *visualization from Ethviewer, captured by first author.*

Extending this idea of common pool resources, one can develop smart contracts that provide the underlying computer protocol to run an organisation, called Decentralised Autonomous Organization [Huvhenvicz thesis 2022]. It is decentralised since there is no need to ask for permission to participate and autonomous in the sense that the smart contracts operating it do not need human interaction or deliberation to execute.

2.3. MOTIVATION, RESEARCH QUESTION AND OBJECTIVES

The research question we attempt to address is to determine the potential architecture for the use of BC in DTs in the AEC industry, i.e. in the creation of a Crypto-Twin for Buildings. Inherent within the question lies the primary interrogation of whether BC has any affinity with DTs technologies, i.e. is it really needed compared to just using trusted third parties? The motivation behind our research lies in the attempt to use BC and SC technologies to integrate, make more productive and better performing the AEC industry. Earlier work by the authors [Dounas et al 2020] has examined the use of BC to coordinate a BIM performative solution, but also on how to incentivise through collective digital design tools the creation of extremely performing architectural designs in terms of carbon, waste, building performance, only via the use of tokens and smart contracts [Dounas et al 2021]. Thus BC/SC in DTs can be used to integrate not only the DT instance of a single building but be the end point of a continuous process, where an AEC project is developed transparently from commission to design, to construction, operation and decommissioning, via its BC enabled digital twin, with clear benefits of better security, performance, lower carbon and waste. This lies along the lines of a conceptual framework for information management via decentralised infrastructures along the entire lifecycle of a constructed asset [Jaskula et al.] and with the use of decentralised infrastructure of smart contracts and the Interplanetary Filesystem of decentralised building information modelling [Dounas 2020]

We also have observed a similar line of work by [Hunhenvicz et al.] in creating smart contracts for digital twins, in addition to further developing and prototyping the first Decentralised Autonomous Space, i.e. a cyber-physical construct that extends the Decentralised Autonomous Organisation to include the physical structure. [Hunhevicz et al., Wang et al.]. Thus, we believe that a DT based on BC and smart contracts should be one of the technical core elements of digitization in developing AEC projects, as part of an effort to develop digital factories for the AEC industry. As such the objective of this paper is to develop the conceptual paper of the BC-enabled DT, the CryptoTwin, setting a clear stage of implementation for research and industry.

3. Methodology

We have used hybrid methods in our approach to constructing the framework of the Crypto-Twin. On one side, we reviewed selected literature to determine the affinity of blockchain with the concept of the digital twins in the AEC industry and then used the results from earlier software prototype tools for blockchain in the AEC industry to develop the proposed framework for the development of Crypto-Twins [Dounas et al, 2019, 2020, 2021, Lombardi et al, 2020]. The development of this framework has followed principles of design for research [Rendel 2004] from the point of view of the AEC industry, i.e. on how to best position the prototypical framework so that its schema is general enough to be developed in multiple varied iterations by others, while in parallel we used Design Science Research methods [Peffers, K. et al., 2006] for problem identification and motivation, the determination of the objectives of the solution and the design and development of the conceptual framework. At the discussion and conclusion, we present possible avenues for the further design and development, demonstration, evaluation and communication of the impact of an artefact consisting of the Crypto-Twin model to the research community.

4. The Crypto-Twin Framework

4.1 WHAT IS A CRYPTO-TWIN

A Crypto-Twin (CT) is a blockchain and smart contract-enabled intelligent digital twin. This means that Crypto-twins are a sub-set of intelligent digital twins and, in many cases, will include a series of other advanced digital technologies that embody the fourth industrial revolution, such as machine learning algorithms and the Internet of Things. The distinctive characteristic though of the CryptoTwin is that the backbone of the automation of the DT is provided via smart contracts, compared to an intelligent digital twin. A second characteristic that differentiates a Crypto-Twin from an intelligent twin is the existence of collective-and-incentives-based crypto-governance. A third, not necessary but capable extension is the existence of mechanisms to operate the CT into the Metaverse [Lee et al. 2021].

4.2. WHY DO WE NEED A CRYPTO-TWIN

The main advantages that smart contracts and blockchain bring into the Digital Twin concept are the increased cybersecurity and resilience of the DT, the existence of transparent and reliable collective governance, which at the scale of DT aggregates at the level of cities is increasingly desirable, but also the

interplay of crypto economics in terms of the financial incentives, resilient automation and guaranteed execution of digital operations. While the concept of the Crypto-Twin is new, one can envisage the idea that Crypto-Twins can be used, in tandem with their physical twin, to create autonomous infrastructures, i.e. buildings and spaces that act autonomously as systems to serve their purpose. While this might be normally reserved for specialist infrastructures that need increased cybersecurity and autonomy, for example, a nuclear power plant, one can envisage the creation of CT aggregates enabling, at the level of cities or provinces, circular economies. A Crypto twin can allow a more improved integration with a circular economy via the use of tokens on smart contract and the deployment of crypto-economics frameworks for its operations.

4.3. THE PROPOSED CRYPTO-TWIN STRUCTURE

The framework encapsulating the Crypto-Twin contains four main components, the frontend interface, the smart contract infrastructure, the decentralized Data repository (realized on the Interplanetary Filesystem) and a simulation engine that allows us to simulate various future scenarios. In tandem, one has the physical infrastructure, i.e. the building in our case, including all energy and control systems. One might discuss whether the agents/actors and the IoT infrastructure are a part of the physical or the digital twin, but most probably, they remain a bridge between the two. (Figure 3)

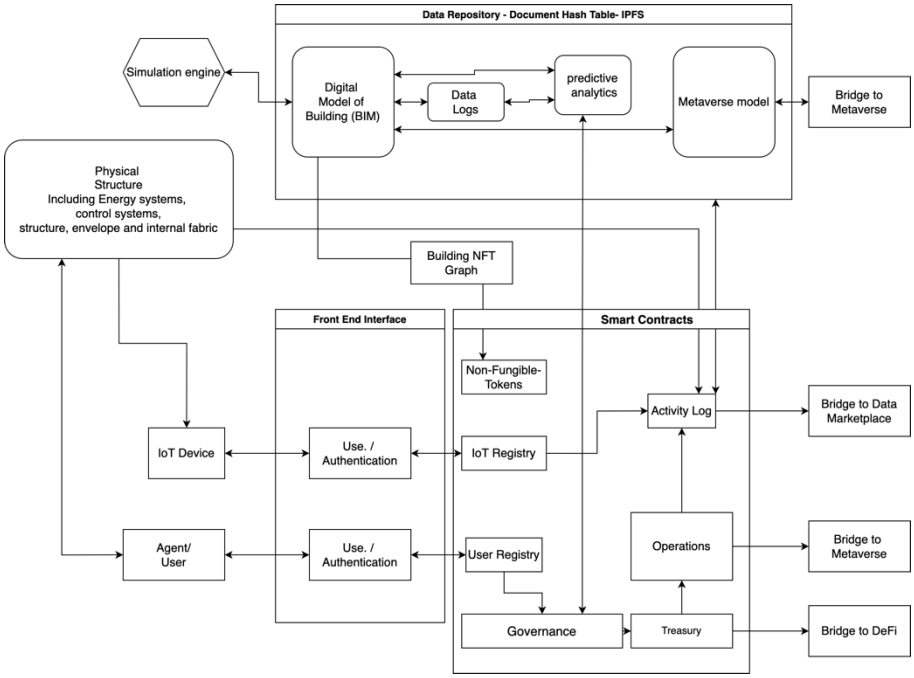

Figure 3. Crypto-Twin Framework Architecture, drawn by the First Author

The Smart contracts architecture (Figure 4) includes the following contracts: a governance smart contract, a user registry, a treasury contract and an operations SC. On top of these, an IoT registry that authenticates IoT devices inside the SC blockchain and an activity log complete the architecture. These of course, can be more elaborate depending on the complexity of the CT needed; however, we envision that these are required as a minimum infrastructure. The governance smart contract allows the decision-making within the SC/CT environment, regulates the updates, and acts as the key contract that structures and affects how operations SC and the treasury will react: furthermore, it encapsulates how, in the end, the physical construct is governed. The treasury contract exists so that operations on the blockchain can be paid by the CT itself but also for funding any other operation for the CT and the physical construct, for example, changing window glass panels in a maintenance scenario.

The log contract, the operations SC and the treasury all have bridges, i.e. connecting scripts to the metaverse. For example, the treasury can compound interest by lending funds for a particular amount of time, or borrow funds automatically via Decentralised Finance mechanisms. The activity log regulates or makes available performance data of the DT to a decentralised marketplace for buildings, where data can be exploited in aggregation: for example, all of the buildings' CTs of a city could contribute their data in a CT

aggregate market, in a framework that reinforces the decentralised data marketplaces concepts by Bucher and Hall [2022] .
Note that to be able to address the representation of the building to the smart contract level, we use tokenization and a topology structure [Dounas et al 2021]. This allows us to create a knowledge graph of the building, where each building component is a non-fungible token, i.e. a unique digital entity that can be manipulated via the smart contracts.

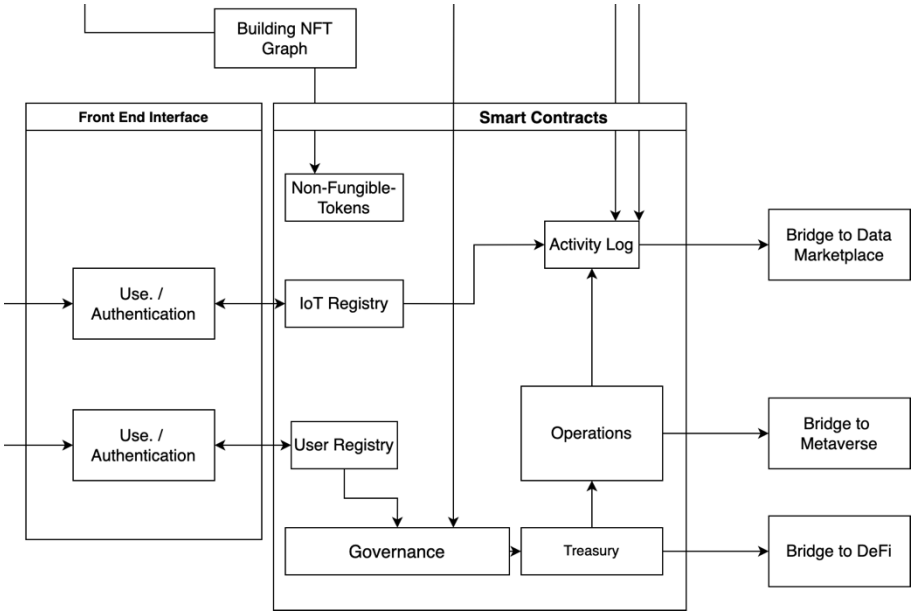

Figure 4. Crypto-Twin Smart Contract Architecture, drawn by the First Author

The main data that are not frequently updated are stored in a decentralised storage system created on the Interplanetary Filesystem (figure 5). In the case of sensitive data, those can be further encrypted, or placed behind cryptographic gateways. In that sense, the decentralized IPFS has meaning for increased resilience of the physical infrastructure hosting the data. However, this part can be replicated with various more centralised computing solutions that allow for redundancy of physical and digital infrastructure, for example, serverless architectures on a cloud. Nonetheless the important architecture here is the existence of a Building Information Model that is used as the infrastructure model twin of the physical building, its connection with a simulation and/or visualization engine that visualizes various scenarios, and of course, a data registry that contains the changes to the model. To be able to create bridges to a metaverse, a second building model is used, using geometry and modelling techniques most appropriate for the metaverse used, as BIM

are very heavy and detailed in information compared to what is required in most metaverses [Decentraland, 2022]

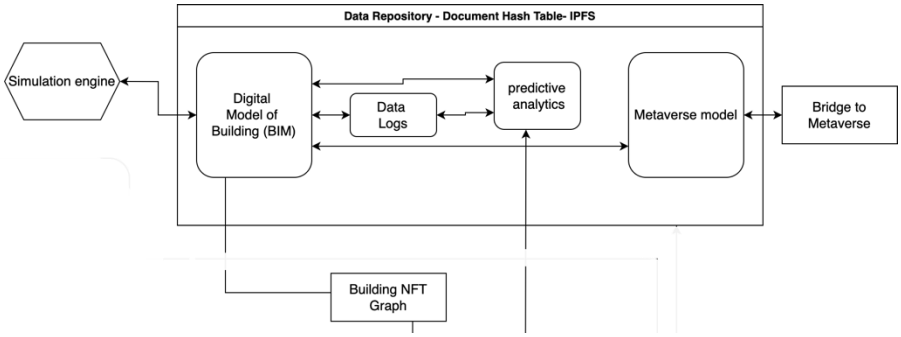

Figure5. Crypto-Twin Decentralised Storage Architecture, drawn by the First Author

5. Discussion

The CT architecture was created by using best practices from the literature [Hunhevicz et al 2021., Li et al. 2021, Wang et al 2022., Dounas et al 2020,2021] while simultaneously creating a flexible framework that can be scaled accordingly to needs. The methods with which the framework was created follows design science research patterns, where we propose innovative artefacts to solve a problem in industry or society. In particular we employed our knowledge of the environment in which digital twins might operate in the AEc industry, fused with the knowledge base of blockchain and DT applications to design the framework and smart contract architecture. We have yet to develop a fully working prototype, as to test fully we would also need the physical artefact as well. Still, we are in the early stages of developing the SCs and the bridges of integration Further to the authors' experience with structuring SC architectures, the concepts of decentralized autonomous organizations have been used towards making the CT a key component of decentralized autonomous spaces or infrastructures. CTs carry the constraints and overhead of the technology used to implement them, i.e. blockchain and smart contracts. Additionally, certain connections with technologies that are under current development might prove problematic or not yet mature for complete integration, for example, bridges with decentralized finance or marketplaces.

6. Conclusion and Further development

The Crypto-Twin SC architecture and framework can readily be used in a range of cases, from traditional uses of digital twins, where we need enhanced cybersecurity, to fully decentralised, i.e. operating on-Chain Autonomous organisations that include physical infrastructure in some shape or form, such as the Decentralised Autonomous Space [Wang et al, 2022]. In particular these formulations of DAOs, where humans, computing agents, and physical infrastructure co-exist in an autonomous organisation, challenge the orthodoxy in which we approach issues of common pool resources, governance, ownership and co-authorship and of course design of architecture. One can certainly imagine the lifecycle of a building design - where we start with a design CT prototype that is shaped to respond to crypto-economic incentives, for example to reduce carbon impact or waste, to a CT instance that inherits and evolves the crypto-economics of the prototype, to a CT aggregate of a city, where the CTs autonomously exchange information and funds to optimise collective benefits for a city.

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DAY 2 - PARALLEL SESSION 5

TOPIC 4 - VIRTUAL ENVIRONMENTS AND EMERGING REALITIES

SIMULATING HUMAN SENSES TO IMPROVE THERMAL COMFORT

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Abstract. Between the synergies of environmental perception and technological advancement evolves the parallel world of the metaverse. Evolutionary virtuality intends to aid humanity in envisioning the threatened future of cities under environmental risks through tailored features. Traditionally, the sense of sight – which is the focus of virtual reality – has dominated the architectural practice. However, architects and urban designers have begun incorporating other senses into their work over the recent decade. The expanding understanding of the multimodal nature of the human mind that has evolved from cognitive neuroscience research has received little attention so far in the architecture field. This paper investigates the role of synthesized sensory experiences – such as visual, auditory, olfactory, gustatory, and thermal sensations – in designing revolutionary settings that aim to improve people's interactions with their surrounding environments. A 15-minute experiment of an immersive experience in an office setting using virtual reality headsets is utilized to explore the role of multimodal sensory integration towards tolerance to the thermal environment. The findings revealed significant potential in using multiple senses – especially gustatory – to design thermally comfortable spaces. It is hoped that architectural design practice would progressively include our developing understanding of human senses and how they interact. This holistic approach ought to lead to the development of multisensory-inclusive workspaces that promote rather than hinder our social, cognitive, and emotional development.

Keywords: *Multisensory; Thermal Perception; Virtual Reality.*

ملخص. بين تآزر الإدراك البيئي والتقدم التكنولوجي يتطور العالم الموازي للميتافيرس. تهدف الافتراضية التطورية إلى مساعدة البشرية في تصور مستقبل مهدد للمدن من المخاطر البيئية من خلال معاييرهم المفصلة. سيطرت حاسة البصر – والتي هي محور الواقع

الافتراضي - على الممارسة المعمارية. وعلى الرغم من ذلك، في العقود الأخيرة، بدأ المعماريون والمصممون في دمج الحواس الأخرى في أعمالهم. وعلى الرغم من تطور أبحاث علم الأعصاب الإدراكي، لم يحظ الفهم الموسع للطبيعة متعددة الوسائط للعقل البشري باهتمام كبير في الآونة الاخيرة. لذلك يتناول موضوع البحث استكشاف تأثير الحواس الفردية - مثل البصر، السمع، الشم، التذوق بالإضافة الى الإحساس الحراري - في تصميم بيئات جديدة تؤدي الي تفاعلات صحية بين الأفراد ومحيطهم. يعرض البحث نتائج تجربة استخدام الواقع الافتراضي متعدد الحواس في بيئة مكتبية على تحسين الإدراك الحسي الحراري. أثبتت نتائج التجربة فعالية تعدد الحواس على الراحة الحرارية للأفراد في الفراغات وتشجيع استخدامها في التصميم. ولذلك نأمل أن تتضمن ممارسات التصميم المعماري للحواس البشرية وكيفية تفاعلها سوياً تطوراً ملحوظاً. حيث يؤدي هذا النهج إلى تطوير فراغات مكتبية ذات تصميم متعدد حواس ليعزز تطورنا الاجتماعي والمعرفي والعاطفي بدلاً من إعاقته.

الكلمات المفتاحية: *تعددية الحواس، الإدراك الحسي الحراري، الواقع الافتراضي.*

1. Introduction

Human beings are mostly considered visually dominant creatures (Hutmacher, 2019; Levin, 1993; Posner, Nissen, & Klein, 1976). Therefore, we strongly prefer visual thinking, reasoning, and imagination. Architects have traditionally been no different in this regard, designing mainly for the sense of sight (Bille & Sørensen, 2018; Rybczynski, 2001; Williams, 1980), as Pallasma (1996) noted in his work *The eyes of the skin: Architecture and the senses*. He also stated that our time's architecture is evolving into retinal art for the eyes. Architecture as a whole has devolved into a printed picture art, fixed by the camera's rushed eye. In addition, Le Corbusier (1991, p. 83) – the famous Swiss architect – took it even further, writing, "I exist in life only if I can see." Canadian designer Bruce Mau (2018) also commented on the current predicament that we let only two senses dominate our designs: sound and sight.

Visual dominance can be explained or accounted for at least neuro-scientifically (Hutmacher, 2019; Meijer, Veseli, Calafiore, & Noppeney, 2019). After all, it turns out that processing what we see takes up significantly more of our brains than dealing with information from our other senses (Gallace, Ngo, Sulaitis, & Spence, 2012). According to Felleman and Van Essen (1991), visual information is processed by more than half of the cortex. Others believe the figure is closer to one-third (Eberhard, 2007, p. 49; Palmer, 1999, p. 24). This figure contrasts with the fact that around 12% of the cortex is dedicated to touching, 3% to hearing, and less than 1% to the chemical senses of smell and taste (Spence, 2020). It is worth noting, however, that the denigration of humans' sense of smell, which may be found, for example, in older publications on advertising (Lucas & Britt, 1950), turns out to be founded on dubious foundations. According to McGann (2017) in Science, the dismissal of olfaction dates back to the 1880s, when early French neuroanatomist Paul Broca wanted to make more space in the frontal sections of the brain (i.e., the frontal lobes)

for free will. In order to accomplish so, he appears to have had to shrink the olfactory cortex correspondingly. Zimmerman (1989), for example, arrived at a similar hierarchy, albeit with somewhat different weightings for each of the five basic senses. Zimmermann calculated a channel capacity of 10^7 bits/s for vision, 10^6 bits/s for touch, 10^5 bits/s for hearing and olfaction, and 10^3 bits/s for taste (gustation).

Morton Heilig, the creator of the Sensorama – the world's first multisensory virtual reality equipment (Heilig, 1962) – envisioned the hierarchy of attentional capture by each of the senses when writing about the multisensory future of cinema in an article initially published in 1955. Nonetheless, while observers from various disciplines appear to concur on vision's current supremacy, one cannot help but ask what has been lost due to the visual dominance seen everywhere in architecture. Even with the rise of virtual reality, the utilization of its benefits focused on its visual immersion. Chinazzo et al. (2017) used virtual reality to control the virtual conditions to understand the effect of short exposure to colored light on thermal perception. Salamone et al. (2020) evaluated the effect of visual stimuli on thermal comfort using VR techniques. They concluded that the light color has to be considered when predicting the thermal perception of individuals, which is highly due to the focus on visual immersion in VR. While visual hegemony is a phenomenon that can be found in almost every part of our everyday lives (Levin, 1993), the fact that it is so widespread does not mean that its supremacy should not be questioned (Dunn, 2017; Hutmacher, 2019). "Spaces, places, and buildings are clearly encountered as multimodal lived experiences," writes Finnish theorist Pallasmaa (2011, p. 595). We monitor our surroundings with our ears, skin, nose, and tongue rather than registering architecture solely as visual representations. "Architecture is the art of reconciliation between ourselves and the world, and this mediation takes place through the senses," he writes elsewhere (Pallasmaa, 1996, p. 50).

After some studies found cross-effects between multiple comfort domains (i.e., thermal, visual, acoustic, and air quality), the approach to analyzing human comfort has shifted to a multi-domain paradigm (Schweiker et al., 2020). Balcer et al. (2014) proved the effect of multisensory on thermal perception when they explored the integration between the temperature and color of an object, primarily when a conflict arises. According to their findings, participants judged cold temperature feelings as warmer when presented with a visual red color signal and warm temperature sensations cooler when presented with a visual blue color cue. The hue heat-hypothesis (HHH) (Bennett & Rey, 1972), which proposes that colors influence people's subjective thermal experience, is another example of the interplay between visual and thermal domains.

Moreover, climate change has emerged as a significant area of study in the natural and medical sciences, as well as more recently in the social and political sciences, as a result of the well-documented phenomenon of global

warming (Marx et al., 2021). The scientific community has made significant contributions to our understanding of the earth's climate system, including a variety of data and estimates on the future climate as well as information on the implications and dangers of predicted global warming (IPCC 2014; NCA4 2018). In recent decades, climate change has also grown in importance as a political, economic, and environmental concern, as well as a prominent topic of discussion in both public and political discourse.
Due to the heat rise risks we are facing because of climate change, and since the effect of other senses on thermal comfort has not been studied in the workspaces to the best of our knowledge, this paper aims to assess the influence of multisensory experience on the human's thermal perception and comfort level, utilizing the latest-available VR technology: Oculus Quest 2. The significance of this research lies in understanding the influence of other sensory experiences to improve the thermal acceptance of the surrounding environments to cope with heat rise, and hence, design resilient office buildings.

2. Methodology

2.1. PARTICIPANTS

Participants were recruited from an office space with a targeted age between 23 and 45. A summary of the subjects' main demographic and anthropometric characteristics is listed in Table 1. The experiment was voluntary, and participants were informed that they could withdraw their participation without giving a reason, per the European General Data Protection Regulation's principles and guidelines (GDPR). Prior to participating, the participants were given a printed information letter and asked to sign a consent form. It includes information on data security procedures as well as a generic questionnaire and assessment information. It did not, however, educate the subjects about specific changes in environmental variables, such as temperature changes or the introduction of scents.

TABLE 1. Demographic and anthropometric characteristics of participants.

Gender	Number	Age Range (Mean)	Height Range in cm (Mean)	Weight in kg (Mean)
Male	1	29 (29)	186 (186)	90 (90)
Female	5	24 – 40 (31)	156 – 167 (163.4)	50 – 70 (59.60)
Total	6	24 – 40 (30.67)	156 – 186 (167.17)	50 – 90 (64.67)

2.2. THE PHYSICAL AND VIRTUAL SET-UP

The experiment was carried out during the month of June 2022 in controlled chambers within a typical office space in Cairo, Egypt. Participants moved between two chambers during the whole experiment. The first chamber was only used to calibrate their thermal sensation by spending 30 minutes seated while doing their work on a PC. The second chamber, the experimental room, is where the immersive sensory testing was conducted using VR Oculus Quest 2 headsets. This chamber is used for lunch/coffee breaks: an exemplar of a lounge in a typical office environment. The space with dimensions of 5.40 x 4.20 x 2.35 m in height (Fig. 1) is lit by office panel lighting and natural lighting from a northeast-facing window with a window-to-wall ratio of 0.25.

Figure 1. Experimental Room (Camber 2): used to conduct the immersive experience.

A split HVAC system kept the first and second rooms at 22 °C and 32 °C, respectively. The air temperature for the first chamber set-point air temperature (Ta) of 22.0 ± 1.0 ◦C was defined in accordance with the

average HVAC set temperature in the tested office. Relative humidity (RH) was kept at 45 %, and wind speed (V) was almost 0 m/s during the whole experiment. The second chamber Ta was set to 32 ºC, RH was 55 %, V 0 m/s, which exceeds the rate of air temperature changes described in ASHRAE 55. A Testo 410-2 hand-held tool was used to measure and maintain the thermal environments per experiment values.
The three-dimensional virtual model was a built-in template on oculus homes called Retrowave Estate developed by Alphasia_CM (Figure 2). The model consisted of both outdoor and indoor spaces in its essence, which is the case with most office buildings. The violet and black colors were dominant in the outdoor spaces, and black with cyan strips for the indoor ones. The model could be used to demonstrate office environments in the future of the metaverse, where scenes are not constrained by physical boundaries such as that in the real world. The environment included a multilevel skeleton structure open to the surrounding views.

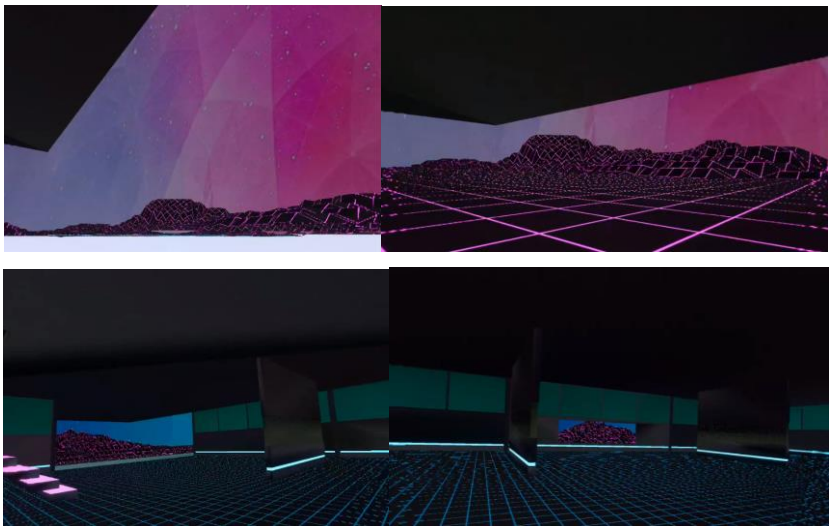

Figure 2. Virtual Set-Up: the immersive visual environment (visual stimulus).

2.3. EXPERIMENT

The experiment lasted 10 minutes to maintain heat dissipation from the VR headset (Wang et al., 2018). The influence of the induced sensory stimuli was recorded three times during the experiment. 1) When they entered the experiment chamber before wearing the VR headset where the thermal environment was the only stimulus. 2) After two minutes from wearing the headset. The visual stimulus was added to the previous thermal

stimulus. 3) After inducing all stimuli; olfactory, gustatory, and auditory (Figure 3). Votes for rating all the five senses included in the experiment were collected in the following format.

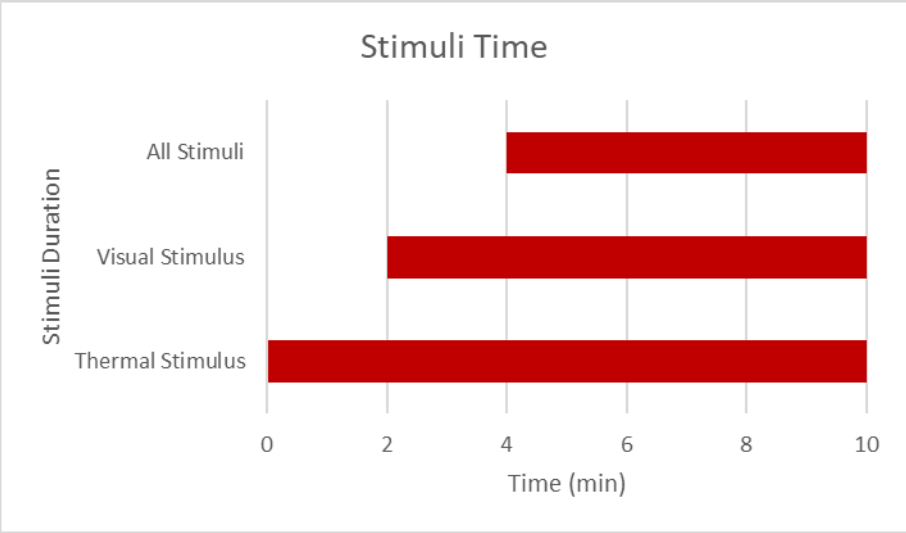

Figure 3. Stimuli Introduction Time and Duration.

Each participant was experimented individually, following identical procedures. Each person spent 30 minutes seated while working on a PC in the first chamber under the thermal conditions stated earlier. The participant then moved to the experiment room, which was 10 ºC warmer in terms of air temperature. Thermal sensation votes (TSV) and thermal comfort votes (TCV) were collected. We used a Likert-type scoring method from the participants to rate these two votes. The thermal sensation votes (TSV) used a 7-scale ASHRAE standard (1- Cold 2- Cool 3- Slightly Cool 4- Neutral 5- Slightly Warm 6- Warm 7- Hot). Thermal comfort votes (TCV), on the other hand, ranged from 1 to 5 (1- Extremely Uncomfortable 2- Uncomfortable 3- Neutral 4- Comfortable 5- Extremely Comfortable). The participants wore VR headsets, which introduced the 3D visual environment demonstrated earlier, and were free to explore and navigate using two hand-held controllers. The gustatory stimulus was introduced through a cold orange juice drink, which is known to regulate perceived thermal comfort. The auditory stimulus used *Miserere, Allegri* music, which has proven to mitigate stress response (Thoma et al., 2013). The olfactory stimulus was introduced through Citrus and Lavender scents, also known for reducing stress and helping meditation during aromatherapy (Cauchi, 2021). It is worth mentioning that the former three stimuli were introduced simultaneously. The experiment procedures are further illustrated in Figure

4. Records of the TSV and TCV were collected each time. Enough time was given for each participant to explore the immersive environment before ending the experiment. After removing the VR headsets, participants were asked to explain their overall experience and preferences and identify the most effective stimulus.

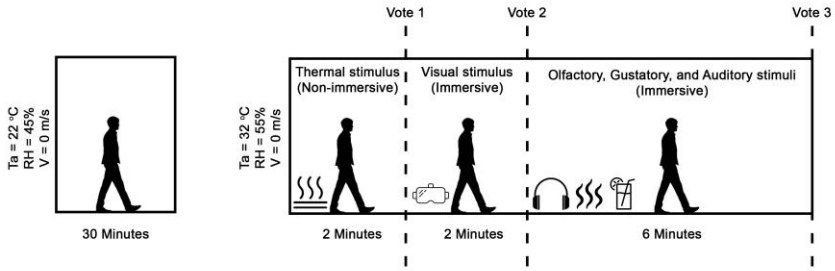

Figure 4. Experiment Procedures.

The participants' olfactory, gustatory, and auditory sensory votes used a five-step Likert-type scale to rate their intensity, where ‘1’ was insignificant and ‘5’ was very intense. The goal was to verify the influence of an integrated sensory experience to improve thermal comfort and increase people's tolerance to heat.

3. Results

The thermal sensation votes were used to identify the participants' thermal perception of their thermal environment. First, we tested the results' normality for thermal sensation (TS) and thermal comfort (TC) using the Shapiro–Wilk test. The results are shown in Table 2.

TABLE 2. Shapiro-Wilk test results to show the distribution of the different votes

		TS (Thermal Stimulus)	TS (Visual Stimulus)	TS (All Stimuli)	TC (Thermal Stimulus)	TC (Visual Stimulus)	TC (All Stimuli)
Shapiro-Wilk	P value	0.240	0.0104**	0.047**	0.005***	0.494	0.005***

**p < 0.05, ***p < 0.01

Most distributions show a significant departure from normality as the p-value is less than 0.05, so we concluded that the distributions are not normal. Second, we analyzed the thermal sensation and thermal comfort during the

three stages indicated in the methodology using the Mann-Whitney U Test to see if there were considerable variations between the three sets of results (Tables 3 and 4).

TABLE 3. Mann-Whitney U Test Results for Thermal Sensation

		TS (Thermal Stimulus)	TS (Visual Stimulus)	TS (All Stimuli)
TS (Thermal Stimulus)	U-value	-		
	P-value			
TS (Visual Stimulus)	U-value	9	-	
	P-value	0.17384		
TS (All Stimuli)	U-value	11.5	4.5	-
	P-value	0.33706	0.03752**	

** $p < 0.05$

TABLE 4. Mann-Whitney U Test Results for Thermal Comfort

		TC (Thermal Stimulus)	TC (Visual Stimulus)	TC (All Stimuli)
TC (Thermal Stimulus)	U-value	-		
	P-value			
TC (Visual Stimulus)	U-value	12	-	
	P-value	0.37886		
TC (All Stimuli)	U-value	8	7	-
	P-value	0.12852	0.09296*	

*$p < 0.10$

As the p-value comparing different thermal comfort and sensation votes is only less than 0.10 when comparing visual stimulus to all stimuli, it is concluded that the results show no significant difference between the different data sets except between the ‘visual stimulus’ and the ‘all stimuli’ in both the thermal sensation and thermal comfort. However, the boxplots (Figures 5 and 6) show considerable variations between the three sets.

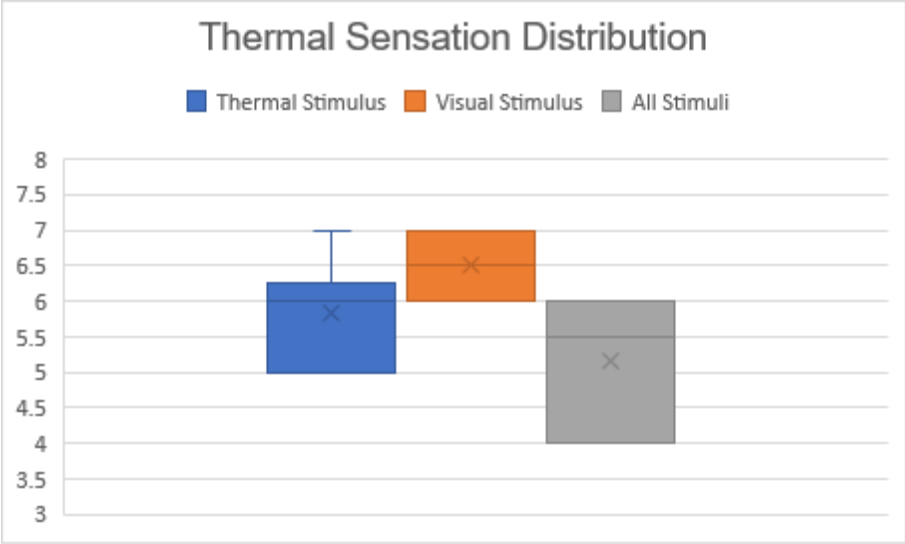

Figure 5. Boxplot for Thermal Sensation.

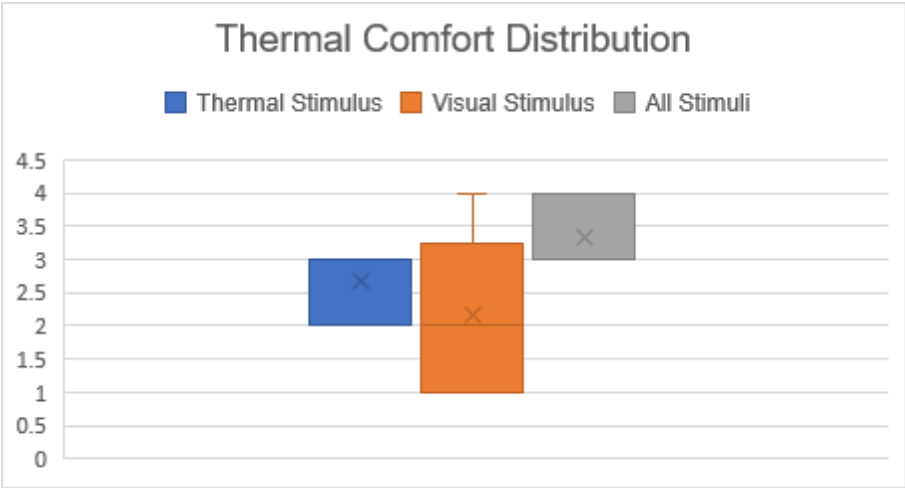

Figure 6. Boxplot for Thermal Comfort.

For both thermal sensation and thermal comfort, the mean value got worse from the first set (thermal stimulus) to the second one (visual stimulus). This observation does not necessarily mean the visual stimulus negatively affects those parameters because the heat accumulation during the first two minutes can result in the same outcome. The results only mean that the visual stimulus cannot withstand the accumulation of heat on its own. Later, after the integration of other sensory, 'all stimuli' parameter, a considerable, positive impact on TSV and TCV were recorded. For the

thermal perception, the ‘all stimuli’ showed an improvement in the thermal sensation – towards comfort levels – with a mean value of 5.167 compared to 5.833 and 6.5 for ‘thermal stimulus’ and ‘visual stimulus,’ respectively. It also showed an improvement in the thermal comfort level with a mean value of 3.333, compared to 2.667 and 2.167 for ‘thermal stimulus’ and ‘visual stimulus,’ respectively. It is also worth mentioning that after introducing the multisensory stimuli, the participants rated the intensity of the gustatory sense the highest, with an average of 4.333 out of 5, followed by the auditory sense with an average of 4.167. Surprisingly the visual sense scored the lowest along with the olfactory sense with an average of 3.5.

4. Discussion

The findings validate the influence of the multisensory stimuli on improving the individuals' thermal sensation, which was not observed through the visual stimulus alone as the mean of the comfort vote increased and the thermal sensation vote decreased, which are both preferable in the experiment context. We suspect that the reduced influence of the visual stimulus compared to the other stimuli on the thermal tolerance could be due to the expectations of the subjects moving into the immersive space during the first transition. The psychological factor –the expectations in this context – strongly influences the thermal sensation vote, which is reflected in the numbers stated above. The introduction of all stimuli during the immersive stage of the experiment had amplified effects. However, further experiments are needed to verify these findings in which other stimuli are introduced prior to the visual stimulus. All the votes recorded revealed improved thermal comfort levels with higher tolerance to the warmer conditions of the space when all senses were induced. After removing their VR headsets and during their post-experiment interview, participants ensured such findings. The intensity of each sense was recorded by the participants and ranked accordingly. The Gustatory was ranked first, followed by the auditory. The visual and olfactory were tied for the lowest ranking.
The results validated the influence of *Miserere, Allegri* music to mitigate stress response (Thoma et al., 2013) and improve the thermal tolerance of individuals. Other types of music could be tested further in future work. In addition, the evaluation of the lavender versus citrus scents revealed that lavender is better in elevating comfort and improving thermal sensation. The effects of lavender in reducing stress have been proved by Cauchi (2021), which further confirms our findings.

The technological advancements allowed us to utilize virtual reality environments to control the sense of sight without compromising the control

of the other senses, which opens up the possibility of investigating different environmental conditions in different settings and understanding the effect of each on our thermal sensation and thermal comfort. Many studies concluded that humans spend an average of 87% of their time indoors (Diffey, 2010). This figure has potentially increased in the last couple of years due to the COVID-19 pandemic and the emergence of remote or hybrid work models. This phenomenon leads to improving and integrating virtual reality settings in workspaces. It is hoped that the findings of this research encourage professionals to design and develop spaces for such emerging models using multisensory stimuli as their main driving force for better accommodation of comfort in mitigating the heat rise of cities. As the results provide first insights into the effect of the multisensory experiences, future investigations into this matter are encouraged.

5. Conclusion and Future Recommendations

This study acts as a proof-of-concept for the effect of multisensory stimuli on thermal sensation and thermal comfort to mitigate heat rise risks due to climate change. In order for architects to develop an understanding of those effects, it is imperative for future study designs to address different types for each stimulus, similar to our test for citrus versus lavender scents. Cross-referencing different variations of the different senses shall allow future studies to reach more insightful results.

Our statistical methods for testing the normality of the results and variance significance using Shapiro-Wilk and Mann-Whitney U tests, respectively, are designed for a small sample of data and nonparametric sets. However, in future studies, with the increase in participants number, we recommend using the Kolmogorov-Smirnov test for normality, and if it yielded a normal distribution of results, the use of the T-test would be recommended instead of Mann-Whitney. Finally, in addition to the statistical approach, we recommend intensive investigation of the gustatory sense since it showed the greatest potential in improving thermal comfort, and participants rated its intensity the highest.

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AUGMENTED MASONRY DESIGN

A design method using Augmented Reality (AR) for customized bricklaying design algorithms

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Abstract. The *Augmented Masonry Design* project presents experimental research about developing and applying Augmented Reality (AR) technology for customized design algorithms, exploring a real-time, interactive, and spatial-free design method for the early architectural design stage. We aim to resolve the current 2D-based design limitations and provide architects with a 3D-4D immersive perception in AR for a practical and easy-to-use design method. Furthermore, with reference to the Covid-19 pandemic, we propose that this method could break through site accessibility and constraints by breaking the barriers of physical space. Towards this aim, we apply the *Augmented Masonry Design* into two prototypes: a) user interface (UI) immersive design, in which interactive inputs will communicate with design algorithms in AR through the inputs from the screen-based UI on mobile devices (e.g., smartphones and tablets); b) intuitive interaction immersive design, in which interactive inputs will be translated to design algorithms directly in AR through hand gestures on head-mounted devices (HMD) (e.g., *Microsoft HoloLens*). Our Findings highlight the advantages of immersive design in the initial stage of architectural drafts, which gives designers better spatial understanding and design creativity, as well as the challenges arising from the limitations of current AR devices and the lack of real physical simulation in the design system.

Keywords: *Augmented Reality (AR), Immersive Design, Customized Algorithms, Masonry Design*

ملخص. يقدم مشروع تصميم البناء المعزز بحثًا تجريبيًا حول تطوير وتطبيق تقنية الواقع المعزز لخوارزميات التصميم المكيفة، واستكشاف طريقة تصميم آنية وتفاعلية وخالية من المكانية لمرحلة التصميم المعماري المبكر. نهدف إلى حل قيود التصميم الحالية ثنائية الأبعاد وتزويد المعماريين بإدراك ثلاثي الأبعاد ورباعي الأبعاد في الواقع المعزز لطريقة تصميم

عملية وسهلة الاستخدام. علاوة على ذلك، وبالإشارة إلى جائحة كورونا، نقترح أن هذه الطريقة يمكن أن تخترق إمكانية الوصول إلى الموقع والقيود عن طريق كسر حواجز المساحة المادية. لتحقيق هذا الهدف، نطبق تصميم البناء المعزز في نموذجين أوليين: أ) تصميم غامر لواجهة المستخدم، حيث تتواصل المدخلات التفاعلية مع خوارزميات التصميم في الواقع المعزز من خلال المدخلات من واجهة المستخدم القائمة على الشاشة على الأجهزة المحمولة (على سبيل المثال ، الهواتف الذكية والأجهزة اللوحية) ؛ ب) تصميم غامر تفاعلي بديهي، يتم فيه ترجمة المدخلات التفاعلية إلى خوارزميات التصميم مباشرة في الواقع المعزز من خلال إيماءات اليد على الأجهزة المثبتة على الرأس على سبيل المثال ميكروسوفت هولولنز. وتسلط نتائجنا الضوء على مزايا التصميم الغامر في المرحلة الأولية من المسودات المعمارية، مما يمنح المصممين فهمًا مكانيًا أفضل وإبداعًا في التصميم، فضلاً عن التحديات الناشئة عن قيود أجهزة الواقع المعزز الحالية وعدم وجود محاكاة فعلية حقيقية في نظام التصميم .

الكلمات المفتاحية: *الواقع المعزز، التصميم الغامر، الخوارزميات المكيفة، تصميم البناء .*

1. Introduction

In 1950, the rise of CAD transformed architectural design from hand-drawing design to the stage of computer-drawing design. Since then, architects gradually removed the shackles of pen, paper and board in the design method, and presented their creations through computer graphics (Lo et al., 2020). In the past twenty years, computers have evolved to provide a large number of different design tools covering the area of architectural design editing and analysis (Schneider and Petzold, 2009). Nevertheless, the traditional screen-based visualization method used for design and analysis lacks the actual scale of the architecture, and limits how well the architects understand the space through a computer, as drawings are done outside the building site without testing the design concept onsite, hence there might be differences between the design and final construction (Nguyen et al., 2014).

The last decade has witnessed the explosion of new technologies, and their impacts have dramatically changed architectural design methods (Huang et al., 2018). For instance, AR technology, with the characteristic of overlapping the holograms on the actual physical world and connecting interactions between human and digital data in real-time, is at the forefront of the immersive methods applied in the architecture and engineering field for spatial experiment, interaction, visualization, and immersing users in an augmented world to enhance collaboration between designers, digital outcomes, and physical space (Sampaio and Henriques, 2008). Greg Lynn is one of the first architects to use AR in the architectural design process. He places holographic versions of digital models in existing environments and manipulates them concerning the context for design outcomes visualization. Although the architectural modelling method has fundamentally changed in its history, the AR tools currently integrated with the corresponding design

methods are mainly limited to only enhanced visualization. Very few projects attempt to solve the challenge of modelling in an immersive environment, which requires a new input method to eliminate the traditional mouse-keyboard combination (Coppens et al., 2018). Moreover, relying on 2D equipment for 3D operations is ineffective, because it does not provide the exact dimension of freedom and senses. So architects began to use new technology to explore immersive design methods and eliminate screen-based 2D restrictions in the early design stage (Song et al., 2021).

This paper proposes a novel design method, verified by design experiments, using AR for customized design algorithms by combining the unique characteristics and functions of AR to find out how AR immersive technology is changing and evolving the conventional design methods in architecture.

2. Research Methodology

The *Augmented Masonry Design* research project proposes an AR-assisted immersive design method consisting of two phases: a) UI immersive design, in which interactive inputs will communicate with design algorithms in AR through the inputs from the screen-based UI on mobile devices (e.g., smartphones and tablets); b) intuitive interaction immersive design, in which interactive inputs will be translated to design algorithms directly in AR through hand gestures or ArUco marker recognition on head-mounted devices (HMD) (e.g., *Microsoft HoloLens 1*). The task of this research is to use AR immersive technology to develop customized algorithms for the early architectural design stage of masonry structures. The reason for choosing brick structures is because bricks are the basic building unit for many architectural structures and meet the requirements of parametric design and AR interaction, which can conveniently and intuitively validate whether the proposed AR-assisted immersive design method is feasible.

The employed immersive design workflow (Figure 1) is driven by an instant connection between 3D-modelling software (*Rhinoceros 7*), parametric design environment (*Grasshopper*) and AR holographic immersion plugin (*Fologram*). *Fologram* is a third-party API developed by architects for architects, which could extract human gestures, screen taps, device location and mark information, and the *Fologram* App UI provides a bridge to interact and modify the related parameter sliders in parametric design from *Grasshopper* through AR. The *Fologram* plugin works with its integrated graphical algorithm editor *Grasshopper*, which are ubiquitous tools in architectural design, and can easily be integrated into established immersive design workflows.

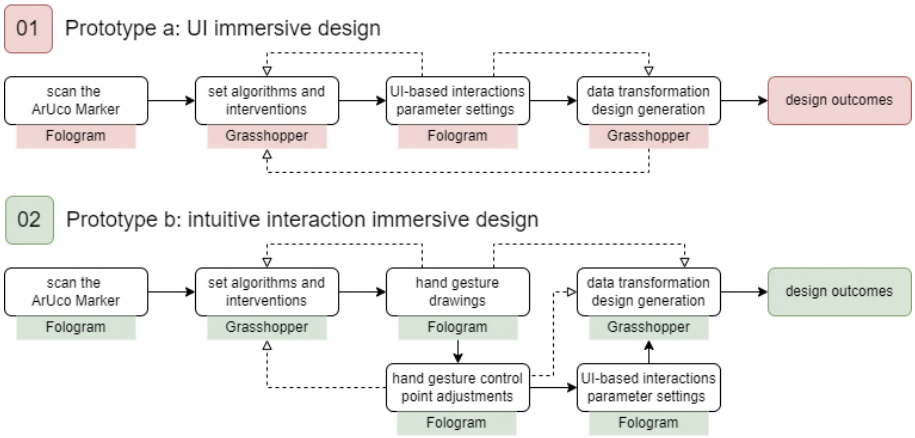

Figure 1. The flowchart of *Augmented Masonry Design* research. It describes each key step of the AR-assisted immersive design method using the UI immersive design prototype (in red) and the intuitive immersive design prototype (in green). The related plugin and software are shown below in each step.

In the *Augmented Masonry Design* workflow, the hardware includes a handheld device – *iPhone 11*, and an HMD – *Microsoft HoloLens 1*. We also use a laptop for back-end running and debugging. These devices are connected to a WIFI router in the same IP address network environment for transforming the data from different stages, and live streaming comments on design software and plugins to visualize and output response ports. We will test our workflow by conducting two design experiments with the UI and gesture-based design input method respectively in order to apply the workflow on different AR devices and different levels of immersion. These two different experiments can verify the feasibility and limitations of immersive design multi-dimensionally.

3. Experiments and Findings

3.1. PROTOTYPE A: UI IMMERSIVE DESIGN

For the UI immersive design tool, we applied an AR UI that can extract the basic unit and parameter setting from the corresponding design algorithms in design software (*Rhinoceros 7 and Grasshopper*). This tool enables designers to achieve onsite real-time designs and visualization modifications through UI-based interactions from screens, such as parameter settings, data adjustments, and marker recognition in AR. The design algorithms have already been pre-set from our design library, representing different brick-based structures. Architects can also customize the design algorithms and

interventions according to their needs and extract interactive parameters in our open platform AR UI through *Grasshopper*.

For example, we use the design of a brick column to validate the UI immersive design tool. First, the geometric concept of the design coordinate was based on an ArUco marker, that can be placed on-site on the floor as the centre point or the reference point of the brick column. After scanning the marker through the smart AR device (*iPhone 11* for this prototype experiment), the design coordinate will be picked up from physical to virtual in *Grasshopper*. Second, the adjustable values, as well as parametric definitions, will be incorporated in the *Grasshopper* according to users' design algorithms. These values include brick size, the number of bricks per layer, brick angle, proportions, column rotation of each layer, column pattern, as well as the height of the column, etc. Designers can add or modify parameters for their customized algorithms and interventions. Third, the designers can build their own AR brick columns with AR UI by developing and adjusting the related parameters through device screen inputs and modifying the structure outcomes onsite as holograms (Figure 2). Last, the outcomes will be recorded in *Grasshopper*. Multi-designer or remote users can scan the same ArUco maker to access the design outcomes, as well as share and modify the design in an instant design environment, providing a remote design strategy.

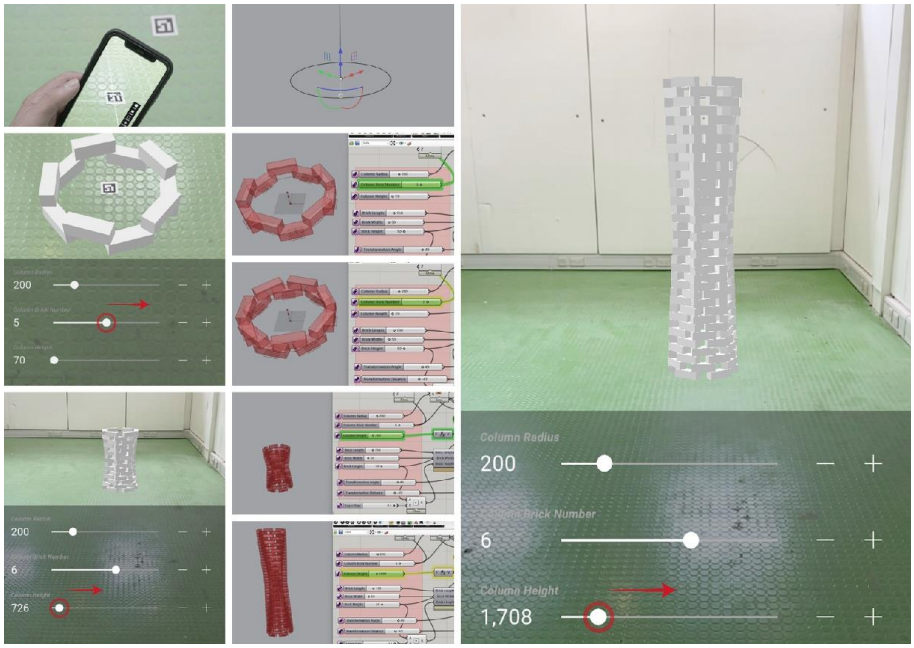

Figure 2. The process screenshots of UI immersive design for designing a brick column from the *Fologram* App on *iPhone 11*. The designer can scan the ArUco marker to define the

design coordinate. After setting the design algorithms, the designers can interact with the parameter sliders from AR UI, such as brick size, number of bricks per layer, column radius, column height, etc., and preview the outcome in real-time onsite as holograms in AR.

In summary, the UI immersive design tool does fulfil our pre-determined assumptions. We successfully designed various columns with different algorithms in our UI. Through the parameter adjustment of the screen UI and the real-time onsite preview of the holographic model, the designer can better experience the sense of space and scale. Our tool provides an appropriate and intuitive experience for design feedback and modification. Ubiquitous mobile devices such as smartphones and tablets can be used as AR UI tools, which will make UI immersive design easier to be popularized and accessible. However, the UI immersive design tool has some limitations as well. For example, the UI-based design method constrains the possibility of design algorithms by only adjusting the limited parameter sliders. For some complex or curved surface designs, the UI-based physical recognition method can not provide input methods other than the basic ArUco maker for the coordinate design points, which are generated with linear directions as columns. Moreover, interacting with a small screen naturally lacks a more integrated experience. Designers need to hold the smart devices by hand and experience sensory holograms through the screen, which is not an intuitive immersive experience. The screen-based holographic visualizations will cause tolerance in information transmission and spatial glance.

3.2. PROTOTYPE B: INTUITIVE INTERACTION IMMERSIVE DESIGN

For the intuitive immersive design tool, we employed methods of gesture recognition, path tracking, and ArUco markers tracking to transform intuitive human movements and hand gesture interactions into design algorithms. The basic parametric design logic has been pre-determined in our database. The key parameters such as spline curves and Nurb surfaces, which determine the shape of design outcomes, will be input intuitively through the designers' gesture tracking and recognition in the AR environment. Designers can develop and customize the parametric design logic and the critical interactive parameters according to algorithms through *Grasshopper*.

For example, we use the design of a brick wall to validate the intuitive immersive design tool. First, the geometric concept was based on an ArUco marker, that can be placed on-site on the floor as the centre or reference point of the brick wall. After scanning the marker through the HMD (*HoloLens 1* for this prototype experiment), the design coordinate will be picked up from physical to virtual in *Grasshopper*. Second, the designer can use the 'tap and hold' hand gesture in *HoloLens* to draw the virtual spline

curve of the brick wall next to the centre point in AR. The spline curve will be displayed as holograms onsite with several control points on it for the user to modify and adjust the shape. Third, in parallel, the spline surface will be generated and extruded directly along the spline curve with AR holographic grid control points for the interactive adjustments. After the spline curve is determined, the brick holograms will fill the surface automatically. Designers can adjust the numbers of bricks, the angle of bricks, the brick structure density, etc., by using the same method in prototype a, or even set interference points for more customized algorithms. Last, the outcomes will be recorded in *Grasshopper*, which also supports multi-designer outcome sharing and remote collaborative design functions (Figure 3).

In summary, the intuitive immersive design tool indeed achieved different brick wall designs with corresponding algorithms. This approach gives users a deeper immersion in that the users' hands are liberated and the virtual model changes from a screen-based AR experience to a head-mounted one. Moreover, the variety of design outcomes is broadened due to gesture recognition and other more flexible parameter inputs and interactions through AR. However, the intuitive immersive design still has some limitations. For example, the *HoloLens 1* and similar HMD devices are still quite expensive and therefore not available to generic users. Due to the extensive calculation of interactive information transmitted in this prototype, there are delays between gestures and results in the entire real-time design process. Therefore, optimizing the parameters involved will improve the user experience and system fluency. Moreover, the gesture-based manually entered lines are full of freedom, which causes the outcome surface to be unsmooth or challenging to control. Therefore, optimization functions such as limitations for gesture inputs, rebuild smoothness, and Z-axis alignments should be added to optimize the spline curves for better final outcomes.

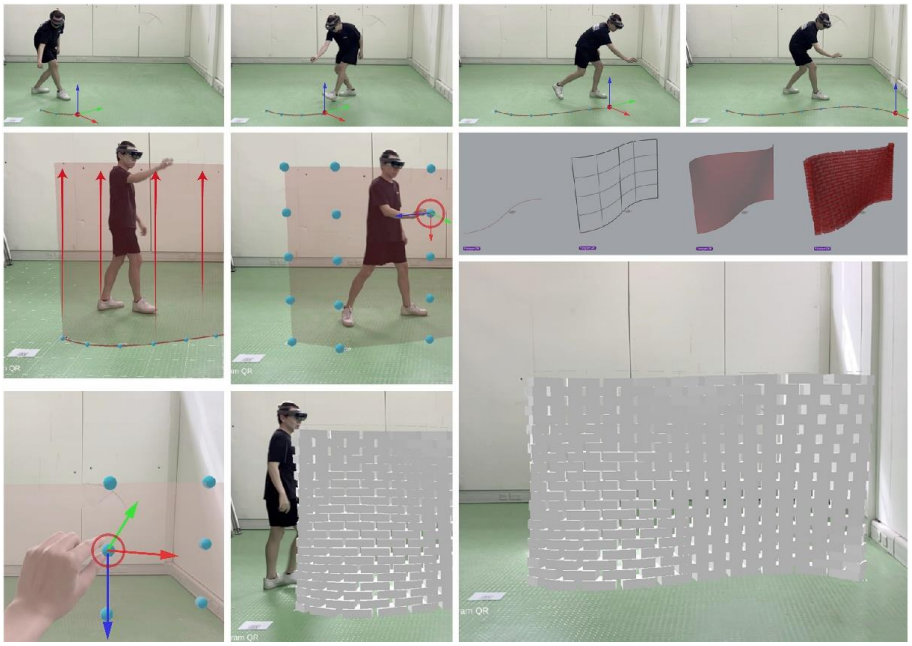

Figure 3. The process screenshots of intuitive interaction immersive design for designing a brick wall structure from *Fologram App* on *HoloLens 1*. The designer can scan the ArUco marker to define the design coordinate. After setting the design algorithms, the designer can use hand gestures to draw and point out the spline curve. After modifying the spline curve, the corresponding spline surface will be generated with grid control points. The designer can interact with the surface in AR. After the surface is determined, the bricks will be generated in real-time onsite as holograms.

4. Conclusion and Discussion

The *Augmented Masonry Design* research developed and verified an AR-assisted immersive design method that successfully applies the customized design algorithms in the AR environment, exploring a real-time, interactive, and spatial-free design method in the early architectural design stage for brick structures (Figure 4). Closely practising the AR-assisted design process as well as analyzing the outcomes, it can be concluded that the proposed immersive design method does fulfil our pre-determined assumptions and offers a new way to modify design drafts and preview onsite locations through AR in real time. The employment of AR technology provided the illusion of actual spatial objects. It aided real-time evaluation and instant modification of design proposals in the early stage. Additionally, architects are able to preview their digital designs out of the sketch or computer screen, as well as interact and communicate with the related onsite physical

environment. This onsite design and preview functions break the conventional 2D-based design method, providing designers with a 3D-4D immersive perception in AR for more practical design. Moreover, the application of AR technology in the early architectural design stage enables the users to improve their cognition and understanding of space, triggers reflections and remodelling of the architectural design process, and cultivates their design creativity and outcome variety. Our AR-assisted design method gives architects more freedom, as well as its remote collaboration and multi-designer outcome-sharing functions break through the constraints of conventional 2D-based design media.

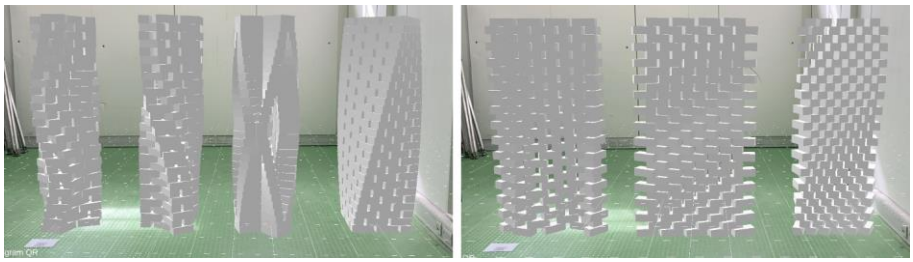

Figure 4. The screenshots of the *Augmented Masonry Design* research outcomes from the *Fologram App* on *iPhone 11*. Designers used different immersive design algorithms and interventions to create multi-variety brick-based structures, including brick columns (left) and brick walls (right).

However, there are limitations and space for further improvement. The current immersive design method is only suitable for simple parametric design, and there are apparent restrictions on the amount and functions of interactive parameter settings. The AR-assisted design process and related verifications are only carried out in initial discrete structures such as brick-based structures. Whether this workflow is suitable for other more complex architectural scale designs remains to be verified by future experiments. Moreover, the sensors of AR devices are affected by the surrounding light condition. If too much or too little UV light occurs in the natural environment, for instance, the holographic model sometimes has difficulties locking a model in a specific place. Consequently, the holograms always drift by the surrounding environment's interferences. Sometimes, it is necessary to restart the device and re-scan a QR code to correct the location. In further research, extra sensors, such as *Kinect*, are needed for helping to scan the onsite design environment and the design base precisely to reduce the unstable disadvantages of current AR. Additionally, this immersive design method lacks a physical simulation and a feedback system to make the design results easier to build for the future construction stage.

Finally, our *Augmented Masonry Design* project provides designers with direct design input and interaction methods besides pen and traditional mouse-keyboard combination through AR. We will systematically develop this AR-assisted immersive design method to test and apply it for more different architectural structure forms or materials in the early architectural design stage. Promote this immersive design method with convenient manipulation such as UI-based or intuitive gesture-based for architects, get their feedback and opinions after use, and improve the method to make the whole process smooth and reasonable for initial architectural design.

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MINDFUL SPACE IN SENTENCES

A Dataset of Virtual Emotions for Natural Language Classification

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Abstract. Spatial emotions have played a critical role in visual-spatial environmental assessment, which can be assessed using bio-sensors and language description. However, information on virtual spatial emotion assessment with objective emotion labels and natural language processing (NLP) is insufficient in literature. Thus, designers' ability to assess spatial design quantitatively and cost effectively is limited before the design is finalized. This research measures the emotions expressed using electroencephalograms (EEGs) and descriptions in virtual reality (VR) spaces with different parameters. First, 26 subjects experienced 10 designed virtual spaces with a VR headset (Quest 2 device) corresponding to the different space parameters of shape, height, width, and length. Simultaneously, the EEG measured the emotions of the subjects using four electrodes and the five brain waves. Second, two labels – calm and active – were produced using EEGs to describe these virtual reality spaces. Last, this labeled emotion dataset compared the differences among the virtual spaces, human feelings, and the language description of the participants in the VR spatial experience. Experimental results show that the parameter changes of VR spaces can arouse significant fluctuations in the five brain waves. The EEG brain wave signals, in turn, can label the virtual rooms with calm and active emotions. Specifically, in terms of VR spaces and emotions, the experiments find that more relative spatial height results in less active emotions, while round spaces arouse calmness in the human brain waves. Moreover, the precise connection among VR spaces, brain waves in

emotion, and languages still needs further research. This research attempts to offer a useful emotion measurement tool in virtual architectural design and description using EEGs. This research identifies potentials for future applications combining physiological metrics and AI methods, i.e., machine learning for synthetic design generation and evaluation.

Keywords: *Virtual reality (VR), Spatial Perception, Spatial assessment, Electroencephalogram (EEG), Natural Language Processing (NLP)*

ملخص. لقد طالما لعبت العواطف المكانية دورًا مهمًا في التقييم البيئي البصري المكاني، والذي يمكن تقييمه باستخدام أجهزة الاستشعار الحيوية ووصف اللغة. ومع ذلك، فإن المعلومات المتعلقة بتقييم المشاعر المكانية الافتراضية مع تسميات العاطفة الموضوعية وتقنيات معالجة اللغة الطبيعية غير كافية في الأدبيات ذات الصلة. وبالتالي ، فإن قدرة المصممين على تقييم التصميم المكاني من الناحية الكمية وفعالية التكلفة محدودة قبل الانتهاء من التصميم. يقيس هذا البحث المشاعر التي يتم التعبير عنها باستخدام مخطط كهربية الدماغ (EEGs) وتوصيفات في مساحات الواقع الافتراضي طبقا لمجموعة مختلفة من المعايير. أولاً اختبر ٢٦ شخصًا ١٠ مساحات افتراضية مصممة باستخدام سماعة الرأس الافتراضية (جهاز Quest 2) تتوافق مع مجموعة من متغيرات الفراغ مثل الشكل والارتفاع والعرض والطول. في الوقت ذاته، تم قياس عواطف المستخدمين باستخدام أربعة أقطاب كهربائية وموجات الدماغ الخمسة عن طريق مخطط كهربية الدماغ (EEG). ثانيًا، تم إنتاج ملصقين - هادئ ونشط - باستخدام تخطيط كهربية الدماغ لوصف فراغات الواقع الافتراضي تلك. أخيرًا، تمت مقارنة الاختلافات بين الفراغات الافتراضية والمشاعر الإنسانية والوصف اللغوي للمشاركين في التجربة المكانية للواقع الافتراضي عن طريق مجموعات بيانات المشاعر. تظهر النتائج التجريبية أن التغير فى المتغيرات لفراغات الواقع الافتراضي يمكن أن تثير تقلبات كبيرة في موجات الدماغ الخمس. يمكن لإشارات موجة الدماغ EEG ، بدورها تسمية الغرف الافتراضية بمشاعر هادئة ونشطة. على وجه التحديد، فيما يتعلق بفراغات الواقع الافتراضي والعواطف، وجدت التجارب أن الارتفاع المكاني النسبي يؤدي إلى عواطف أقل نشاطًا، بينما تثير الفراغات المستديرة الهدوء في موجات الدماغ البشري. علاوة على ذلك، لا يزال الاتصال الدقيق بين فراغات الواقع الافتراضي وموجات الدماغ في العاطفة واللغات بحاجة إلى مزيد من البحث. يحاول هذا البحث تقديم أداة مفيدة لقياس المشاعر في التصميم والوصف المعماري الافتراضي باستخدام مخطط كهربية الدماغ. يحدد هذا البحث إمكانات التطبيقات المستقبلية التي تجمع بين المقاييس الفسيولوجية وطرق الذكاء الاصطناعي، أي التعلم الآلي لتوليد التصميم التركيبي وتقييمه.

الكلمات المفتاحية: *الواقع الافتراضى، الإدراك الفراغى، التقييم الفراغى، مخطط كهربية الدماغ، تقنيات معالجة اللغة الطبيعية.*

1. Introduction

Design evaluation in the real-world costs much before the design is finalized. Moreover, it’s expensive to incorporate user feedback with sentiments and description post-design due to the individual differences. Quantifying and explaining user experience are important to detect patterns to make generalizations in design assessment.

The immersive experience of virtual reality (VR) offers a new way to measure the impact of pure visual experiences (El Beheiry et al., 2019) with lower cost before the design is finalized. Researchers can simulate intricate real-life spaces in VR to investigate the emotion feedback that subjects experience inside the spatial settings. Although there are many VR and electroencephalograms (EEGs) studies (Shemesh et al., 2021; Suhaimi et al., 2020), their spaces lack the elements of everyday architectural spaces, such as windows and doors (Shemesh et al., 2017), and the language interpretation of the spaces by the participating experimenters (Hu et al., 2019). Our study hypothesizes that we can quantify people's descriptions and explanations of spaces by analyzing their sentences with emotional labels.

The immersive spaces in this research consist of 10 rooms with variable design parameters of shape, height, width, and length to stimulate emotional experiences of spaces that the users experience during everyday life. In the experimental study, 26 participants describe the virtual spaces of different parameters and explain their reactions in sentences to create a spatial dataset. The dataset is built in 3 dimensions of spatial parameters, sentences, and emotional labels to assess the spatial emotions in everyday language. Our study aims to assess how design parameters influence linguistic and emotional responses to virtual spaces. Our dataset assists architects' decision-making processes in facilitating more accessible and accurate labeling of description and emotion reactions to spaces.

2. Related Work

Virtual reality (VR) technology has been used as an architectural assessment tool to assist in decision-making for unbuilt spaces, as well as psychological, educational and recreational design tools. Measurements of architectural spaces in VR involve measuring quantitative spatial parameters and qualitative spatial features. Quantitative spatial measures are mostly related to size, proportion, scale, and distance perceptions (Shemesh et al., 2021), while qualitative features are the environmental aspects of spaces, such as openness and closeness (Ergan et al., 2018b, 2018a). Assessments of architectural spaces in VR involve the feedback from user physiological data and language explanation, such as descriptions and questionnaires.

In the assessment of VR spaces, non-architects find it difficult to explain their exact feelings about the visual space. For example, non-architects will describe a space with some sentences, like "it is a space for me to study calmly in," rather than a more straightforward word, like "tranquil" or "unaroused." To quantify emotional reactions from participants in VR spaces, researchers build body biosensor systems, including

electroencephalogram (EEG), galvanic skin response (GSR), heart rate in photoplethysmogram (PPG) and eye tracking, to measure and assess basic emotions in VR spatial experiences (Ergan et al., 2018a). Among all the biosensors, EEGs play a role in measuring the emotion of brain waves to measure cognitive emotion and assess architectural design with descriptions (Diemer et al., 2015). In this research, the emotional states of calmness and activeness are measured with EEGs corresponding to the descriptions during the spatial experiences.

Natural language processing (NLP) has been recognized as a critical language tool for statistical analysis and assessment of designed spaces. However, everyday descriptions of the experience with natural language, such as the text sentences from Twitter, seldom result from only visual-spatial experiences. These sentences describe the spaces merged with other elements, such as the temperature, social interactions, and senses. Architecture researchers have difficulty distinguishing whether the experiences in a sentence come from space or from other elements of everyday life, such as food and weather. Existing emotion classifiers do not provide effective guidance to architects in practical applications (Mohammad et al., 2018). Thus, the architecture researchers' ability to evaluate spaces using language is limited. This research aims to build a dataset of natural language mapping from visual-spatial sentence descriptions to visual-spatial emotion labels.

3. Methodology

This section introduces the parameters of VR models, the apparatus and the psychophysiological Indices of biosensors (EEG devices), overview of participants, experiment procedures and data analyzing methodology (Figure 1). The methods aim to match the sentence descriptions with the corresponding emotion and spatial parameters using EEG and VR models.

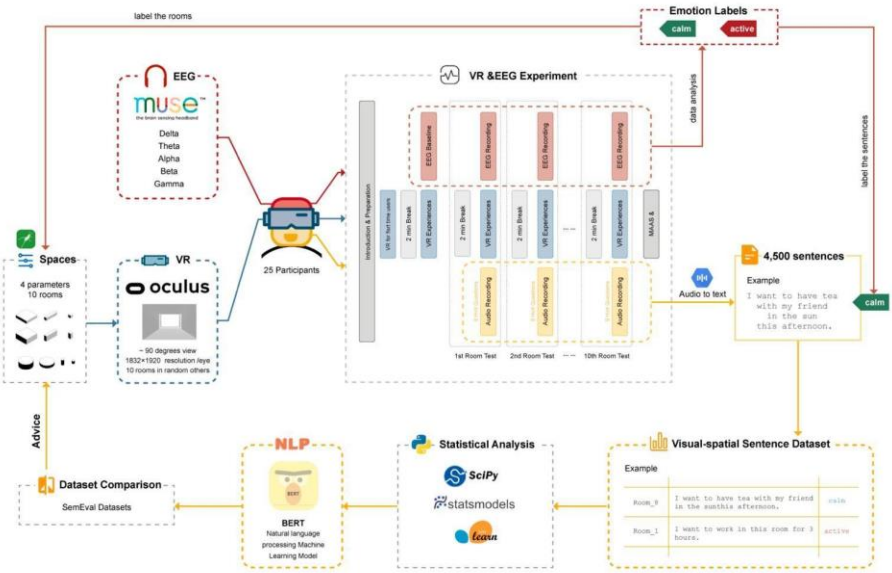


Figure 1. A diagram showing the pipeline of the methodology using EEGs, VR and NLP

3.1. ARCHITECTURAL SPACES AND VR DEVICES

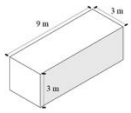
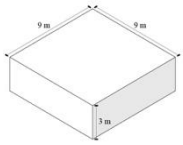
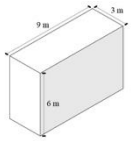
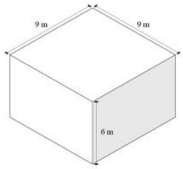
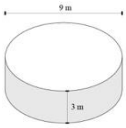
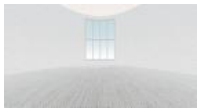
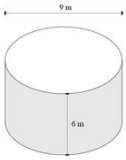
Researchers rendered 10 3D room models in Unity for the VR headset experiences. The parameters of the virtual rooms (Table 1) are the shapes of the rooms (rectangle, and round in diameter of 3 m or 9 m), and the sizes (height in 3 m or 6 m, width in 3 m or 9 m, and length in 3 m or 9 m) of the rooms. Other virtual spatial parameters, such as color, light and the size proportion of the window (0.5 m, 0.5 m, 0.5 m, 0), remain the same. Many of these prototyped rooms are shaped in design strategies as potential spaces for new study, work, and recreation. All of them can play an important role providing calming space for mindfulness.

The participants were also equipped with a wearable VR device – Oculus Quest 2. The Quest 2 offers a VR experience with the field of view in 90 degrees and per eye resolution of 1832×1920. The researchers set up the 10 room models in Quest 2 for VR testing. All these space models are then recognized as calm (mindful) or active (anxious) spaces using electroencephalogram (EEG) devices with a spontaneous effect on human brain waves in five brainwaves: alpha, beta, gamma, theta, and delta.

TABLE 1. The parameters of the 10 VR rooms

Room No.	Shape	Height	Length	Width	Room Settings	Immersive View

MINDFUL SPACE IN SENTENCES

1	Rectangle	3 m	3 m	3 m		
2	Rectangle	3 m	3 m	9 m		
3	Rectangle	3 m	9 m	9 m		
4	Rectangle	6 m	3 m	3 m		
5	Rectangle	6 m	3 m	9 m		
6	Rectangle	6 m	9 m	9 m		
7	Round	3 m	3 m			
8	Round	3 m	9 m			
9	Round	6 m	3 m			
10	Round	6 m	9 m			

3.2. BIOSENSORS

Viewing the VR rooms, the participants were also equipped with a Muse headset – a wearable brain sensing headband. The device is fully portable and can be paired with any tablet or smartphone and operated with the Muse application (Mind Monitor) to record the EEG data. The sensors are placed on the frontal lobes of subjects to detect the five brain waves (Table 2) – delta (1-4 Hz), theta (4-8 Hz), alpha (7.5-13 Hz), beta (13-30 Hz) and gamma (30-44 Hz). The EEG device tracks and records the five brain wave patterns in 4 electrodes of signal collected from frontal areas (TP9, AF7, AF8 and TP10 electrodes). Brain waves data from Muse 2 are absolute band powers, based on the logarithm of the Power Spectral Density (PSD) of the EEG data for each channel. When analyzing the EEG data, we compared the data of five types of oscillations.

TABLE 2. The five brainwaves' absolute frequency ranges read from the Muse headset

Name	Frequency Range	Description in emotion
Delta	1–4 Hz	Usually indicating the unconscious mind and occurs in deep sleep
Theta	4–8 Hz	Usually indicating the subconscious mind and occurs in sleeping and dreaming
Alpha	7.5–13 Hz	Usually indicating a relaxed mental state yet aware and are correlated with brain activation
Beta	13–30 Hz	Usually indicating active mind state and occurs during intense focused mental activity
Gamma	30–44 Hz	Usually associated with intense brain activity

3.3. COMMENTS FROM THE PARTICIPANTS

Individuals differ in terms of baseline anxieties and arousal levels in reacting to the VR room experiences. The Mindful Attention Awareness Scale (MAAS) can measure mindfulness as an attribute that varies between people (Brown and Ryan, 2003). Thus, MAAS measures the diversity of attention to and awareness of present events and experiences in the VR spaces. The questionnaire includes questions related to the elements of VR spaces and the experience.

The question settings of the questionnaire are 5 gradients – almost always, very frequently, something frequently, something infrequently, very infrequently, and almost never, while people cognize and feel the spaces

hardly by these numerical values. Moreover, the questionnaire questions are difficult to cover all the spatial cognition and emotional feedback of the participants. To collect more feedback in the experiments, participants expressed their spontaneous spatial feelings through their language. Researchers used audio to record participants' comments on the spaces and questions (Table 3). After converting the audio to text, researchers conduct a natural language processing analysis of the sentences combined with emotion from EEGs.

TABLE 3. The questions for each participant during the VR test for each room

	Feeling Sentences
Question 1	How would you describe the space in more than two sentences?
Question 2	How would you describe your feelings of the space in more than two sentences?
	Behavioral Intention Sentences
Question 3	What would you like to do in this room right now?
Question 4	What would you like to do in this room for the following 3 hours?
Question 5	What would you like to do in this room with your best friends?
	Spatial Intention Sentences
Question 6	If this room was part of your house, then, which room of your house do you think this room would be and why?
Question 7	If this room was a public room, what kind of function do you think the room would have?
Question 8	If you could name this room, what name or title would you want to choose and why?
Question 9	The previous subject described the room as “a prison”; what do you think about that?

3.4. EXPERIMENT SETUP

The participants consisted of n = 26 people (16 women, 10 men; mean age = 27, SE = 7.65). They were architecture or non-architecture students and volunteers from higher education institutes, such as MIT and Harvard. 6 of them do not have VR experience before and 20 of them have VR experiences before our test.

The experiment was designed to be independently executed by each of the participants, and each session was recorded individually (Table 4). They were also provided with a VR headset (Oculus Quest 2), Muse headset to measure brain waves, a chair to sit on, and a quiet area to stay for 30 minutes (Figure 2). All participants underwent a short training and a short sample session with the apparatus. They were instructed by the researchers on how

to perform the experiment—describe their views or feelings of the VR rooms in sentences following the questions (Table 3) designed to elicit appropriate responses. After this, participants experienced the rooms in a random order, describing their feelings in audio-recorded sentences.

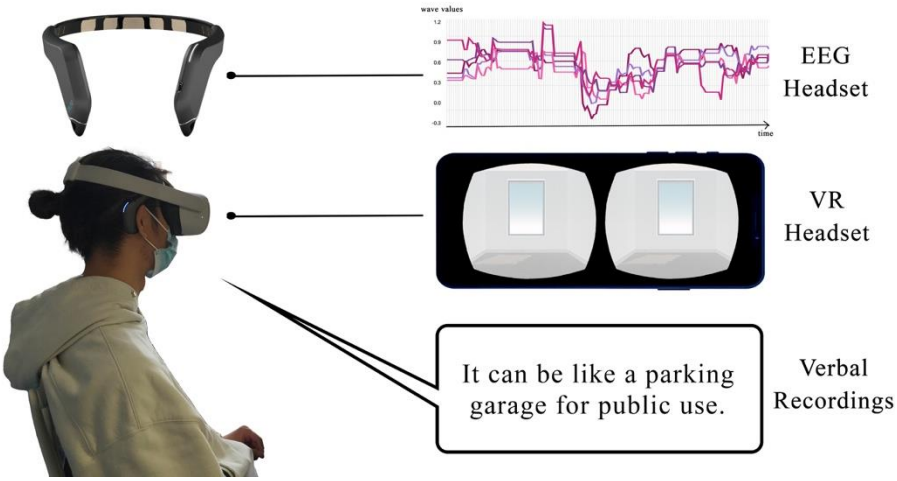


Figure 2. Example of participants' experiments with EEG headset, VR headset, and Verbal recordings

In the VR experiment, connectivity with the Muse headset had to be established with Bluetooth and checked for all four electrodes (TP9, AF7, AF8, TP10) each time. After the proper connection of smartphones with Muse, the baseline phase of the experiment—the relaxation phase—was established. During this time, participants were asked to close their eyes and relax for 30 seconds while their EEG data were recorded by Muse (the baseline phase, was later on subtracted from the signal). Next, during the 60 minutes' sitting, participants looked at the VR rooms without unnecessary movement. Viewing the VR rooms, the participants answered the questions asked by the researchers. Complete recording of sentences at 10 room views (plus the break time of 2 min each for interval) took between 45 and 60 min. The participants filled out the questionnaires after doing the VR experiment.

TABLE 4. Research design and the phases of the procedures

	Preparation for VR Research
Phase 1	10 VR rooms designed by researchers (Section 3.1); Random choice of rooms' orders and questions for participants to answer (Table 3).

Phase 2	**Introduction for Participants** Introduction to research goals and equipment — instructions for all 26 participants. Presentation of research VR headset including 10 rooms in random order. Test Bluetooth connection—smartphone to Muse EEG device. First-time VR users will have 1 min more to experience the VR headset to overcome the initial excitement of trying VR for the first time. Then, the participants had 30 seconds' rest before the VR Research and Audio Recordings.
Phase 3	**VR Experiments and Audio Recordings** The participants are seated in a room without sound or movement for the VR tests. During the VR spatial test, the participants wear the Muse Headset to record the EEG data simultaneously. The researchers ask the participants the questions (Table 3) on the topics of spatial feeling, behavior intention, and random sentences for each virtual room. The participants answer in sentences to describe each virtual room. The researchers audio-record the sentences to match the sentences and the emotions from EEG to build the dataset. The participants have a 2 min break in the transition of the two VR rooms to avoid emotional influences of the room transition.
Phase 4	**Individual Mindfulness Balanced Questionnaire** The Mindful Attention Awareness Scale questionnaires (Brown and Ryan, 2003) together with other VR experiences related questions measured the individual emotional differences.
Phase 5	**Data Curation** Data preparation as described in the "Statistical Analysis" section of this article.
Phase 6	**Data Analysis** Data analysis as described in the "Results" section of this article.
Phase 7	**Dataset Building and NLP** Dataset preparation and NLP training as described in the "NLP Classification Training" section of this article.

4. Results

Our dataset contains 1,402 sentences from participants' comments with 2 labels and 10 rooms (Table 5). We analyzed our dataset using electroencephalograms (EEGs), statistical tools and natural language processing (NLP) classification models. In this section, we showcase the

potential of using our dataset for data-driven analysis of spaces and emotions.

TABLE 5. Example of our dataset with1,402 sentences, 2 emotion labels and 10 rooms

Room ID	Sentences	Emotion label
6	This is very upright space, and I'm looking at this strike so weird.	1
6	It looks like terrace; I don't know how did you attach the texture.	0
3	It's a similar room, I would say, still upright, but seems like the window says is smaller, but it's still like large accordingly relative to the wall that I'm facing. So, I would say it's still like a very, like nice view room.	0
3	I think it's large, I would not say it's huge, but it's a size of like good. I like a small dance hall, but I see is quite low, like a dorm ceiling.	0
8	I feel like I'm in a barrel. So, I've already decided the nickname. Because it's cylinder and very tall. So make me like a can, and it's weird, because you are there any kind of flaw here, because like this is a curry wall and like the door, as well as the handrail, has some bug.	1
8	It has a curvy like window.	0

4.1. ANALYSIS FROM THE USERS' COMMENTS

In terms of the relationship between rooms and emotions, each room can arouse some participants' calm and active emotions. Therefore, it is difficult to label a room with emotion. Moreover, some rooms have distinct emotional features, such as room 1 (shape = rectangle, height = 3m, length = 3m, width = 3m), room 6 (shape = rectangle, height = 6m, length = 9m, width = 9m), and room 5 (shape = rectangle, height = 6m, length = 3m, width = 9m), and some do not have distinct emotional features (Figure 3).

Furthermore, Figure 3 illustrates that rooms have stark individual differences in emotional arousal. Participants may have generally more active emotions (e.g., Participant 9, 10, 15, and 26), or calmer emotions (e.g., Participants 7, 13, and 23) in the virtual reality (VR) environment. Such deviations may come from the deviation of individual spatial cognition and spatial perception, or the individual's different stress responses to VR space during the experiments. For example, Participant 25 said he was excited when speaking and wondering in the VR rooms.

In terms of the relationship between sentences and emotions, the emotional labels of sentences were strongly correlated with participant number and room height parameters. The significant differences in emotions among the participants also reflect the difference in the individual's emotions towards the room. However, for the higher spaces, most participants

exhibited calmer emotions (Table 6, -0.20** with significance in the relationship between height and active). Therefore, we expect further analysis between sentences and emotions.

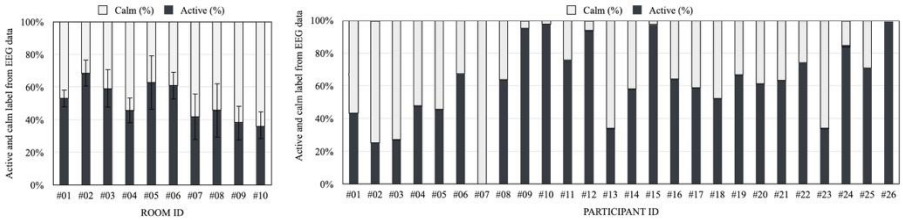


Figure 3. Calm and active distribution by Room ID and Participant ID

TABLE 6. Correlations between emotion labels of rooms and participant ID

	Participant_ID	Emotion_label
Participant_ID (gender/architects/)	1	**.303****
Room_ID	.051	-.035
Length	**-.101****	-.037
Width	-.009	.076
Height	-.038	**-.020****
Emotion_label	**.303****	1

4.2. EEG RESULTS

In order to prepare the emotion label data from the EEGs, we carry out additional preprocessing and then statistical analyses using Python programming language (with the libraries SciPy, Statsmodels and Scikit_posthocs).

The EEG signal from the Muse 2 headset is recorded with the use of the Muse Monitor mobile app. The absolute signal undergoes a Fast Fourier Transform (FFT) algorithm in Muse to compute the power spectral density of each frequency range (for instance, alpha, i.e., 9-13 Hz) on each channel. Basically, the signal from each channel shows “how much” of each frequency exists in the interval of one second. The raw data are given on a log scale, in units of Bels, for further analysis.

At first, the signal is cleaned in terms of the number of non-informative elements and errors (e.g., missing data, non-numeric values, poor signal quality obtained from a particular electrode, eye blinks and jaw clenches annotation data, dropped samples, etc.). Then, we subtract the 30 s baseline (relaxation phase of the study) from the rest of the signal, for each room and for each participant separately. Subsequently, we average the absolute band

power of the five oscillations for each session in the VR as well as for each person, for later comparisons.

After the preprocessing of the absolute wave data and extraction of all 5 oscillation bands (using Formula 1), we conduct analysis of variance (ANOVA) with Sidak's correction for multiple comparisons, where the mean oscillation values for each location are the dependent variables, and the type of rooms and type of oscillation are independent variables.

$$\text{alpha}_{\text{absolute}} = (\text{alpha}_{\text{TP9}} + \text{alpha}_{\text{AF9}} + \text{alpha}_{\text{AF9}} + \text{alpha}_{\text{TP10}})/n - \text{alpha}_{\text{basseline}} \quad (1)$$

n = real active number of channels for each participant

The mean oscillation values (Formula 2), of each room assigns the emotion labels – calm (0) and active (1) – of the room for the virtual spaces and the sentences describing the rooms.

$$\bar{\alpha} = 1/25 \sum_{i=1}^{25} \alpha_i \quad (2)$$

The text sentences of each room transcribed from the audio are labeled with the room emotion data for further correlation analysis and NLP classification training. Basically, for each room (10 in total) in VR, 450 sentences from the subjects (26 in total) with 2 labels, calm and active from the EEGs. Correlation matrices are then be generated for all 5 oscillation bands and rating differences to uncover possible correlations between the emotions, sentences, and room parameters.

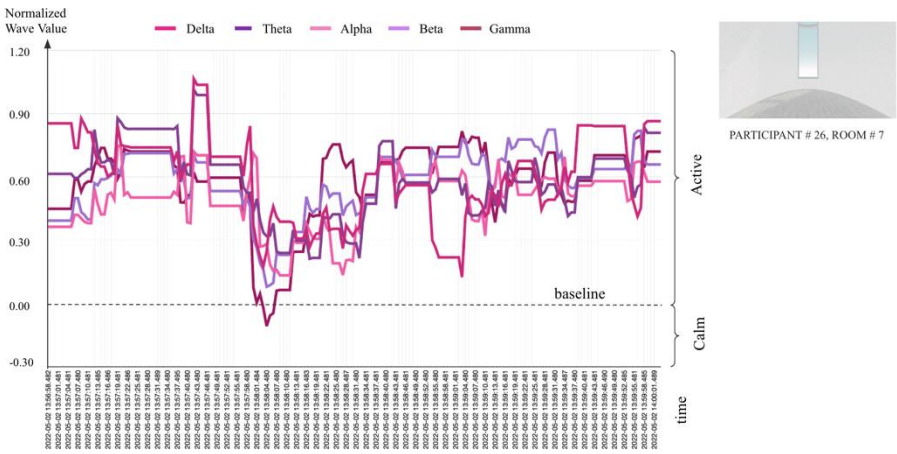


Figure 5 Example of emotion labeling

When participant experiencing the room number 7, we record his brain wave, and audio sentences stimulated by this room. We find that, he had an active emotion that above the 0 line – which is his baseline of brain wave. So, we label this sentence with active.

4.3. NLP CLASSIFICATION

Aside from quantitatively analyzing, our dataset can also be used to define natural language processing (NLP) tasks. Bidirectional Encoder Representations from Transformers (BERT) is a deep learning-based model for NLP which are pre-trained using a very large text corpus (Devlin et al., 2019). BERT is used for text classification training to compare the spatial emotions in virtual reality from our dataset and non-spatial emotions from the existing emotion dataset, such as SemEval2018Task1 (Mohammad et al., 2018), Ascertain (Subramanian et al., 2018) and Dreamer (Katsigiannis and Ramzan, 2017).

In this section, we introduce two novel tasks based on our dataset. In the first task, given a space's parameters of shape, length, width, and height, we predict whether the room will arouse a calm emotion or an active one. In the second task, given a sentence, we predict the emotions aroused by the spaces. Both these tasks are not only challenging from an NLP perspective, but also have potential applications. For example, models for predicting the emotions aroused by a space might be used in recommendation systems for architectural design. Also, a model trained to predict the emotions given comments using thousands of training examples might result in better design feedback for architects.

In task 1, since there are 10 rooms and 4 parameters, but there are only 1402 sentences, the mAP of the model is not high - only 0.3. For classification training with 10 labels, a larger training set should be required to learn the features.

In task 2, the model has an F1 score of 0.82 for the active label in the validation set while an F1 score of 0.37 for the calm label. This is due to the fact that the number of labels in the overall training set and validation set is about 50% less than that of the active (Figure 3), which makes the samples challenging to learn and validate. Therefore, in the results of classification learning, the machine tends to classify more sentences as active.

The results on the two classification tasks show that the discrete distribution of the training set over room parameters and the imbalanced distribution over sentiment labels lead to biased training results. The envisioned solutions include increasing the number of participants in sample collection to increase the dataset and balancing the number of two types of sentiment labels.

TABLE 7. Results of trained BERT model of Task 2

	precision	recall	f1-score	support
Calm	0.35	0.41	0.37	24
Active	0.69	1.00	0.82	54

accuracy			0.69	78
macro avg	0.35	0.50	0.41	78
weighted avg	0.48	0.69	0.57	78

4.4. DATASET COMPARISON

We compare our dataset with existing sentiment classification datasets in two aspects: psychological datasets and NLP emotion datasets.

Compared to other psychology datasets, our dataset is the first to use space as a medium for natural language and EEG. Existing datasets inspire emotions through images and quantify the data by measuring data to build datasets, such as Ascertain (Subramanian et al., 2018), Dreamer (Katsigiannis and Ramzan, 2017), and FER-2013. However, our dataset is a language corpus inspired by spaces and measured by EEG. Such datasets are difficult to analyze because language is ambiguous, and the mutual interpretation between emotion and language is also ambiguous. Also, the language of everyday life is not extreme and does not have a strong emotional consensus to provide further analysis.

Compared with other NLP sentiment classification datasets, on the one hand, our dataset provides different sentiment labels since EEG devices are better at accurately measuring the emotional state of calm and active. If complex emotional states, such as happiness, need to be measured, more complex measurement equipment is often required. Therefore, our dataset adopts different emotion labels from existing NLP emotion classification datasets in the use of emotion models. For example, SemEval2018Task1 (Mohammad et al., 2018) adopts emotion labels such as anger, fear, joy, or sadness, while we use calm and active. On the other hand, our dataset comes from precise linguistic descriptions of spaces, and other datasets, such as SemEval2018Task1 (Mohammad et al., 2018), have sentences from Twitter – a language corpus that describes elements of every aspect of life. Since spatial elements inspire the sentences in our dataset, our dataset is a more spatially relevant corpus.

TABLE 8. Results of trained BERT model of Task 2

Sentences	**Our dataset**	**SemEval-2018 Task 1: Affect in Tweets**
This space feels more relaxing, but with more sounds like the space for worshipping or for prayers.	calm	joy
I feel very energetic and I feel like dancing.	active	joy
I can’t stop. I finished - dejected. luckily no one is in the bathroom. So I go to a stall and wait until my pants are dry.	active	fear
Well stock finished & listed, living room moved	active	joy

around, new editing done & fitted in a visit to the in-laws. #productivityatitsfinest #happy

5. Discussion and Limitations

In settings of VR spaces, on the one hand, the parameters are more controllable than real-world spaces, and VR spaces are a cheaper experimental test tool than real-world constructions. On the other hand, VR spaces may not necessarily reflect real-world user experiences. Spatial elements in the real world are complex and changeable, and selecting the combination of complex architectural features is key to experimental testing. For example, some researchers have selected elements such as openness and closeness (Ergan et al., 2018a). The more choices of elements, the more complex the spatial composition and the longer the experiment.

Participants in this study experienced the space at a fixed point standing or sitting. However, in the real world, the experience of space is continuous, and people experience architectural spaces not statically, but with movements. As a next step, moving panorama video may be a good start for testing real-world spaces.

The study tested brainwave data from 26 participants in a VR space using a Muse 2 device with 4 electrodes. More expensive EEG equipment may be able to reflect more comprehensive brain wave data. For example, the 14-channel EEG device (Emotiv Epic) with O2 and P7 electrodes (Shemesh et al., 2017), is a particularly important signal point (citation) for spatial experience. In addition, in terms of body sensors to capture more bio data, other devices can be used, such as electromyography (EMG), galvanic skin response (GSR), heart rate in photoplethysmogram (PPG), and eye tracking. For instance, the user's gaze trajectories or other behaviors in VR spaces may also cause measurement biases in the data for emotions.

During the experiment, this study collected participants' data such as EEG and audio, while the participants were sitting or standing and speaking or listening. Certain factors, such as the sitting or standing state of the participants, should be controlled. Participant 25, for example, said that speaking in the VR space would arouse his excitement. Other factors, such as smell and white noise, and psychological cognitive factors including memory, will also cause certain experimental errors in the impact of spatial emotions.

In terms of NLP, we asked the participants particular questions for feedback on their emotional states. However, many kinds of questions might be asked and answered. Future research should include a spatial task with

guidelines, such as asking participants to wait, to stimulate specific feelings (stress or calm).

6. Conclusion

Our spatial dataset, the first publicly available spatial dataset for spatial research and design purposes, contains 1402 sentences and 2 labels – calm and active. Our analysis shows interesting trends and predicts two results: (i) the emotional reaction to a space based on spatial features and (ii) the emotion in brain waves corresponding to a sentence based on its contents. Our experiments show that certain properties of spaces, such as length, width, and height, are correlated with higher possibilities of calmness, reflected in EEG data. We offer a useful NLP emotion classification dataset for architectural design improvement using everyday sentences. More importantly, we hope that our dataset helps architects understand the virtual spatial emotions in everyday language to guide design. In terms of application, our model can generate emotional evaluations of spaces based on the user's verbal description and brainwave data. Our models can be used to evaluate machine-learned or human-generated designs in the age of AI.

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AUGMENTING LANDMARKS: EXTENDING "PLACES" IN THE HYBRID CITY

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Abstract. Several recent technological advancements are substantially altering how we interact with urban spaces. The existing physical space as we know it now encompasses a plethora of emerging realities into which we shift in and out, resulting in what is called Hybrid Spaces. Augmented Reality (AR) today gives way to forms of hybrid realities that are accessible through our handheld devices, and which allow us to engage with our physical reality in a new way. These devices allow us to access and view digital information that is saturating our urban spaces, and yet appear invisible to the naked eye. When this information is localized, it can be used to augment physical space with virtual overlays. These augmentations may become physically linked to the environment, establishing virtual landmarks that could only be accessed via these handheld or wearable digital portals through digital applications. This gives way to new forms of engaging in real-time with our socio-cultural daily activities. The literature shows that urban space is reimagined through augmented reality (AR) which plays a significant role in introducing new augmented "places" supporting our physical ones as hybrid realities. This paper, accordingly, investigates the notion of location-based AR experiences on landmarks in the urban space in accordance with our spatial memory, and how augmented reality through mobile devices, plays an important role as a gateway between our physical space and the virtual one. It also seeks to understand how these augmentations might insert and employ symbolic or personal meanings to the space, based on our different interpretations. In doing so, we conducted an integrative analytical review of the most recent literature, to study the forms of augmentations in multiple cities, and how they are used as

agents in our spatial experience. The paper then introduced a framework that could be used to assess users’ satisfaction and the design considerations of the AR spatial experience. Finally, the paper adopts a few recent AR practices to be assessed by the proposed framework.

Keywords: *Hybrid Space, Augmented Reality, Virtual, Landmarks, Mediating.*

ملخص. تعمل العديد من التطورات التكنولوجية الحديثة على تغيير كبير في كيفية تفاعلنا مع الفراغات الحضرية. يشمل الفراغ المادي الحالي كما نعرفه الآن عددًا كبيرًا من الحقائق الناشئة التي نتحول إليها ونخرج منها، مما يؤدي إلى ما يسمى بالفراغات الهجينة. ويفسح الواقع المعزز اليوم المجال لأشكال من العوالم الهجينة التي يمكن الوصول إليها من خلال أجهزتنا المحمولة، والتي تسمح لنا بالتفاعل مع واقعنا المادي بطريقة جديدة. تسمح لنا هذه الأجهزة بالوصول إلى المعلومات الرقمية التي تشبع فراغاتنا الحضرية وعرضها، ومع ذلك تبدو غير مرئية بالعين المجردة. عندما يتم ترجمة هذه المعلومات محليا، يمكن استخدامها لتعزيز الفراغ المادى باستخدام التراكبات الافتراضية. قد تصبح هذه التعزيزات مرتبطة ماديًا بالبيئة، مما يؤدي إلى إنشاء معالم افتراضية لا يمكن الوصول إليها إلا عبر هذه البوابات الرقمية المحمولة أو القابلة للارتداء من خلال التطبيقات الرقمية. ويفسح هذا المجال لأشكال جديدة من الانخراط بطريقة متزامنة مع أنشطتنا الاجتماعية والثقافية اليومية. تُظهر الأدبيات أن الفراغ الحضري يعاد تخيله من خلال الواقع المعزز الذي يلعب دورًا مهمًا في تقديم "أماكن" جديدة معززة تدعم أماكننا المادية باعتبارها عوالم هجينة. ووفقًا لذلك، تبحث هذه الورقة البحثية في فكرة تجارب الواقع المعزز القائمة على الموقع وتأثيرها على المعالم في الفراغ الحضري وفقًا لذاكرتنا المكانية، وكيف يلعب الواقع المعزز من خلال الأجهزة المحمولة دورًا مهمًا كبوابة بين فراغاتنا المادية والفراغ الافتراضي. كما يسعى إلى فهم كيف يمكن لهذه التعزيزات أن تُدخل وتوظف معاني رمزية أو شخصية في الفراغ، بناءً على تفسيراتنا المختلفة. وقد أجرينا فى هذا الإطار مراجعة تحليلية تكاملية لأحدث الأدبيات لدراسة أشكال التعزيزات في مدن عدة، وكيفية استخدامها كوكلاء في تجربتنا المكانية. وقد قدم البحث بعد ذلك إطارًا يمكن استخدامه لتقييم رضا المستخدمين واعتبارات التصميم للتجربة المكانية للواقع المعزز. ثم تخلص الورقة البحثية إلى تبنى بعض ممارسات الواقع المعزز الحديثة ليتم تقييمها من خلال الإطار المقترح.

الكلمات المفتاحية: *الفراغ الهجين، الواقع المعزز، الافتراضية، المعالم، الوساطة الرقمية.*

1. Introduction

Cities are full of imagery with various cultural connotations. These visuals are personal interpretations in one's imagination that help us become accustomed to unfamiliar spaces. Space is the boundary into which we commute and go about our everyday lives. Exploring new foreign spaces is seen as a difficult cognitive effort, particularly in metropolitan areas (Axon & Speake, 2012). We employ our cognitive processes to move from one location to another, yet technology enables new hybrid realities to emerge alongside our physical ones. Cities nowadays are not only rich in physical sights and landmarks, but also in digital information associated with specific

locales, resulting in the emergence of new emergent environments. A recent common form is the augmented space which hosts virtual overlays attached to the physical space multimedia in form(Manovich, 2006), only accessible through an electronic device.

Our handheld mobile devices now host plenty of applications that use augmented reality for navigation and gaming purposes. What’s more interesting is that some of these applications are location-based software, which means that it could only be used based on one’s location in an urban space. AR research and studies have long been concerned with the ramifications of such technology on user experience, as well as how to address the technological challenges confronting this kind of mediation to benefit us. Few studies, however, looked at AR as a design tool. This study represents the satisfaction and socio-cultural preferences of users in an AR-based environment, as well as the design considerations to make for an optimal spatial experience. This technology is being employed in many cities and metropolitan areas to improve users' mobility. This study aims to discover how these augmented landmarks affect our navigational aid and cognitive behavior. Also, to comprehend the nature of these augmentations' relationship to our built environments, as well as how they may insert symbolic or personal meanings into the space as we perceive it. A matter which raises very important questions: (A) would these augmentations after time, become constructed in our minds as mental images too? (B) How would these location-based augmentations affect our spatial memory? To answer these questions, this study will adopt several academic researches to form an integrative framework and use it to reflect on a few chosen private sector projects that use augmentations on existing landmarks.

2. Hybrid Spaces

It is challenging to commute in a city featuring digital and virtual overlays. Several researchers and authors sought to investigate the influence of such augmentations on our spatial experience in the built environment. (Qureshi et al., 2018) investigated how virtual, augmented, and mixed realities assist users to explore and enrich their experience of a city's rich history, phenomenology, and culture. Qureshi emphasized how technology, although "liberates" us, both restrict how we travel about the city. GPS is a typical case of how we follow specified directional routes that regulate our movement.

Due to its effectiveness and efficiency, GPS has lately become an important tool for mapping and surveying digital maps and has largely superseded other mapping methods. A feature that assists our understanding

of the surrounding urban fabric and the most prominent landmarks, yet users assisted with mobile map GPS systems and have access to technology find it more difficult to orient, perform cognitive tasks, and acquire spatial knowledge in urban spaces than non-assisted users. (Ishikawa et al., 2008), (Willis et al., 2009).

Mobile devices are utilized to imbue physical spaces with digital information attached to precise locations. Because of the built-in location-aware technology in these devices, users may interact with one another depending on their relative proximity by viewing each other's positions on a map that can be accessed from a mobile phone screen. A "Hybrid Space" connects people (nodes) with mobile devices that are always connected to the internet (paths) and other users. This is the space where nodes, or "people," are organized and networks, or "communications," are established (de Souza e Silva, 2006). If we have access to the internet, we may access public places as well as information about them.

Augmented Reality is used in too many forms in the urban space, one common form is the Augmented Reality Navigation Applications (ARNs). (Huang *et al*., 2012) examined the influence of different interfaces of ARNs on spatial knowledge acquisition. The findings showed that while AR navigation had no bearing on wayfinding, it had a negative impact on how well users acquired spatial information. However, a different study discovered that while being quite useful in knowledge-gathering, AR users tended to focus less on landmarks and displayed a lesser reaction in their visual behavior (Dong *et al*., 2021).

ARN apps, whether developed by individuals or authorities, may be useful tools that play an essential part in our knowledge-gathering and way-finding processes. Artists, historians, and urban planners, on the other hand, employ AR technology to augment the historical and socio-cultural perceptual experience of visitors to the city. Artwork frequently reflects these efforts to conserve cultural heritage. This demonstrates that augmented reality (AR) plays an important role in reshaping urban space and providing new augmented "places" as hybrid realities that enrich our physical ones.

3. Augmenting Spaces

(Manovich, 2006) investigated augmented spaces as paradigms that artists and architects should consider as 'substance' rather than simply an unseen space or 'vacuum.' He wanted to determine whether these virtual overlays are as significant to our spatial perception. He discussed how to add significant layers of data to a real physical location without altering the experience in order to overcome this issue and design it like we would in an

architectural dilemma. Manovich's Poetics of Augmented Space inspired the hypothesis that virtual augmentations might have a substantial influence on how current data space is physically structured.

He also explored how the augmentation of space influences the profession of architecture. The architect overcomes physical challenges and begins integrating virtual things into that space; the critical issue is how to merge layers of data with actual space. (Shafer, 2018) investigated the ontological nature of AR Points of Interest (POIs) temporally localized across the world, referring to them as "unseen hubs" in a constantly connected environment. Using qualitative arguments and contemporary AR activities, the research aims to frame these AR POIs as objective "wilderness" that may co-exist by artists without us being aware of their presence. For instance, a street painter who creates graffiti art on outdoor urban walls or fences may now employ augmentations of these artworks to only be visible through "digital media" on the streets without degrading the quality of the physical place.

In 2017, J. Jin investigated augmented spaces in more detail as fresh platforms for socio-cultural experiences (Jin, 2017). She suggested narratives in which we would employ AR technologies and “re-conceptualize” augmented space to create immersive engaging environments within physical spaces. These narratives are formed by three key elements. First, “bridging the physical and digital”, which is to combine the physical environment with the digital data, or in other words, combining the real with the virtual. Second, “mediating social and cultural changes”, that result in people using augmented spaces in more socially and collaboratively engaging ways. Third, “place-making” involves changing a space into a place by including actions and activities, meanings and interpretations, physical characteristics, the lived experiences of individuals and social groupings, and cultural aspects. (Kljun et al., 2018) his study encourages designers and artists to employ AR with the purpose of “user engagement”, he adopted several AR practices in artwork, tourism, and cultural projects. Users interacted more with the artworks in the mixed reality environment, which suggests that AR applications should be used more practically rather than merely for exploration.

In a case study, (Chan et al., 2021) adopted the three "emotional design" characteristics to investigate the influence of augmented space on the responsive recognition of human presence in urban space. The initial experience is "visceral," involving visual and sensory aspects incorporated into the design. The second level is "behavioral," which includes how we engage and interact with the environment, as well as whether the design meets the emotional needs of its users. The third level is "reflective," which entails engaging one's thoughts and consciousness to develop ideas for an

effective emotional response. Another study sought to determine whether or not visitors to historical sites would value the use of AR technology in enhancing 3D representations of textual information on top of actual artefacts using QR codes (Wakefield et al., 2019). The study also found that, while older people were more likely to agree on the value of AR, it was helpful and improved users' experiences across age groups. The study also suggests that investing in AR for historical landmarks is wise. The levels and aspects that must be addressed for a successful AR spatial experience are shown in Figure 1.

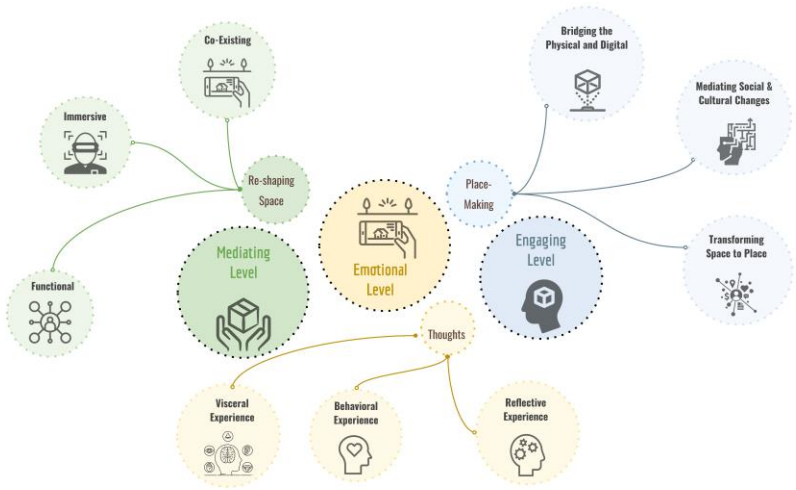

Figure 1. The framework of design considerations for a successful AR spatial experience. Source: (Authors)

4. Augmenting Landmarks

Designers, developers, and artists frequently face financial and commercial value challenges that prevent them from integrating AR technology into urban spaces and heritage landmarks. This is mostly because artifacts associated with device performance and development tools. Hence, AR could be a good aid for historical sites to revive tourism, as stated by Bec *et al.* (2021) “Tourism is an economic driver that could provide viable avenues to accomplish these aims.” In his research, he introduced the idea of “Second Chance Tourism”, which refers to techniques used in the digital preservation of tourist attractions and landmarks that require refurbishment or demolition. The study also promotes more research into how an idea like that might impact visitors’ experiences and satisfaction.

Furthermore, Andrade & Dias (2020) adopted the notion of cultural marketing by exploring the impact of an AR application on Portuguese landmarks. They introduced the concept of “Phygital Society” which refers to the blurring of online and offline experience in new technological innovations like AR.

They discovered that utilizing AR to innovate cultural heritage helped users with their spatial awareness and also added significantly to their awareness and familiarity.

The London-based Startup Company, Blippar, launched a recognition feature for well-known landmarks worldwide that are shown in figure 2 below. Users of this application point their smartphones towards landmarks and Blippar technology identifies them. What’s interesting about the software provided by Blippar unlike other applications, it uses “computer vision” to identify structures and not GPS or location-based information. Which gives the advantage to recognize a landmark just from a photo (Goode, 2018).

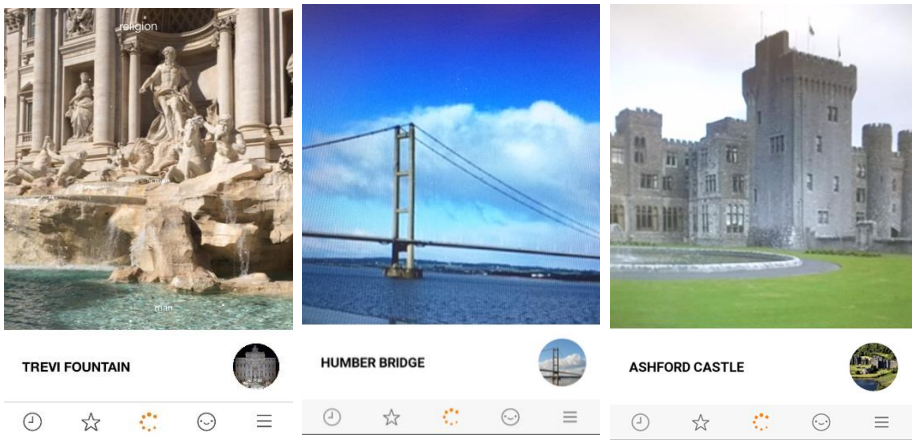

Figure 2. Blippar landmark recognition feature. Source: (Goode, 2018)

Snapchat, the giant social media application debuted the "Custom Landmarker Feature" in 2019. This feature uses their AR lens studios to augment virtual artistic representations above the real world as shown in figure 3 below, allowing “*creators to anchor Lenses to local places they care about – from statues to storefronts – to tell richer stories about their communities through AR.”* (*Snap AR*, 2019). This feature is a location-based experience that is supported by Snap AR lens studios' developers using the real-world digital infrastructure. Here, AR is used to “enhance and transform the world” as part of their entertainment, educational, and marketing strategies to allow artists to tie stories to local locations as a socio-cultural

experience. The "Local Lenses Feature" (*Snapchat “Local Lens”*, 2020) was recently developed to include community "snaps" and a point cloud depicting the geometry and surfaces of a 3D reconstructed map of a local urban block. A function that enables artists to interact with a collaborative persistent AR space layered on the real world as shown in figure 4.

Figure 3. Before and After AR snap at Buckingham Palace, London Source: (Snap AR, 2019)

Figure 4. Artists using Local Lens feature from Snap AR to graffiti paint facades of a local street. Source: (Snapchat “Local Lens” London, 2020)

The "Detonator" interactive gaming project allows players to interact with the socio-cultural and historical context of several historical landmark sites in London. On a designated physical pole at the site, the project overlays representational data on landmine locations around the globe during World War II. The game displays the number of landmines that are present in a specific nation and simulates explosions by projecting digital representations of them onto actual physical poles.

Figure 5. Detonator AR Social Game Source: (Detonator, 2012)

5. Discussion

Research and studies around AR have always been concerned with the implications of such technology on user’s experience, and how to develop the technical issues facing this form of mediation to benefit us. Few studies though discussed the AR practices as a mere design tool. This study signifies users’ satisfaction and socio-cultural preferences in an AR-based environment and the design considerations to undertake for an effective spatial experience. AR practices must take the user's sociocultural preferences into account. Three important design levels, namely; the mediating level, the emotional level, and the engaging level could be used to satisfy these preferences. These levels resemble three steps in achieving a successful AR spatial experience. The first step associated with the mediation level is to Re-shape Space, which entails a notion of co-existing through an immersive medium. The second step involves an engaging level, to Re-Place Space by mediating our socio-cultural preferences through the digital medium. The final step should enable a user to exert personal experiences to the design. To determine whether or not these levels are attained, the practices used above in this study are being put to the test.

The landmark identification feature of the Blippar application uses a digital database of previously scanned famous landmarks and offers users digital information on top of the actual landmark. As it offered helpful digital data that was localized on top of the physical world, it attained the co-existing and functioning components on the mediating level. Due to the virtual items' abstract character, it lacks an immersive aspect. This nature also prevented it from having any emotional impact. While on the engaging level, it did not mediate the social and cultural changes, although associated with historical and personal meanings.

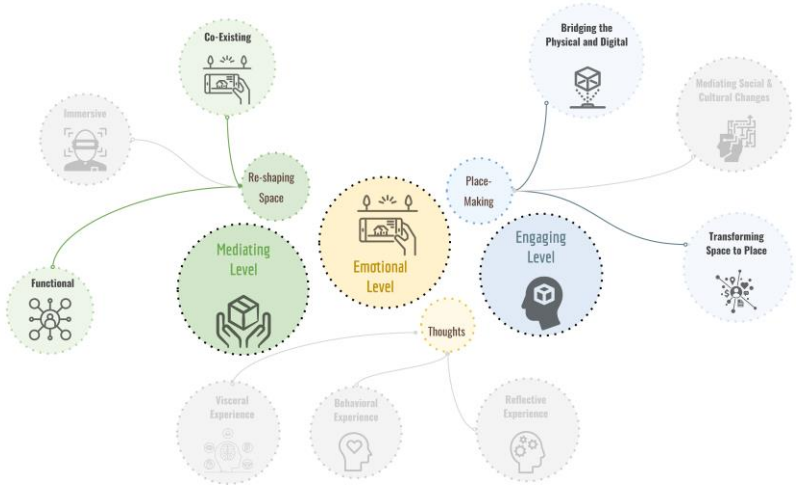

Figure 6. Blippar AR spatial experience. Source: (Authors)

While enabling users to create and collaborate on the AR experience, Snapchat also associated socio-cultural and personal perceptions. By delivering immersive, aesthetically pleasing, satisfying, and considerate virtual augmentations to the locals in the real world, it also accomplished the mediating and emotional levels.

Detonator, on the other hand, did not incorporate the experience's social, cultural, and personal connotations. Consequently, a designer's objective vision that augments the physical landmark is offered.

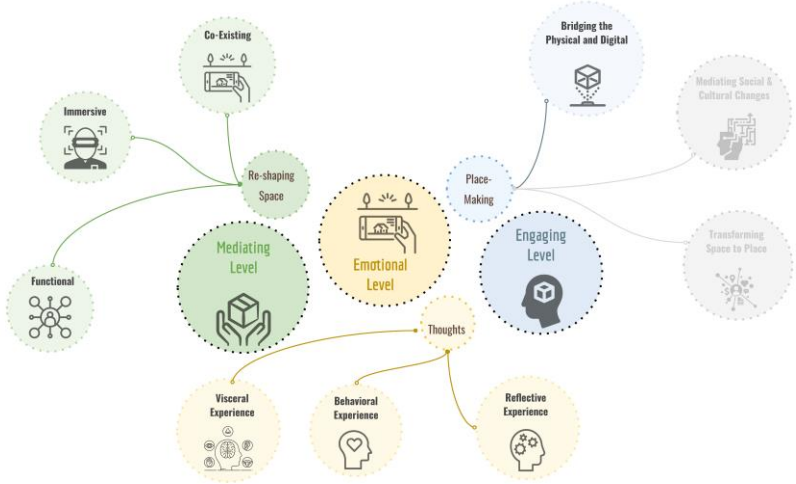

Figure 7. Detonator AR spatial experience. Source: (Authors)

6. Conclusion

In the modern era, urban space has begun to take on more distinct meanings. Adding new dimensions, producing overlapping features, or even permitting new forms of realities to coexist. This notion represents a significant milestone for technological interactions in our daily lives, supporting individuals in their navigation of urban spaces.

According to the literature discussed above, augmenting landmarks influences our navigational aids, and considerable studies indicated that it may even impair users' memory and spatial perception of the surrounding physical space. However, they still play an important role in our knowledge-gathering abilities and cognitive processes. This research sheds insight into how people interpret spatial experiences of augmented landmarks on a personal and collective level, particularly in built urban environments that are rich in digital information. Based on contemporary practices that utilize AR to reflect socio-cultural preferences for engagement, it is convenient to argue that AR enhances our spatial experience and encourages users to engage with personal meanings and interpretations augmented on top of the physical space.

Our mobile devices are potent mediums that connect us to hybrid coexisting realities, offering us beneficial experiences when being in the proper hands. The main issue for a number of researchers is the future of augmentation mediums in the Metaverse. Social media companies, as well as other private sector corporations, are constantly developing haptic products and headgear AR glasses to make the experience more tangible. It's only a matter of time before these products are marketed and used in cities. So it's critical to understand the nature of these gateways and the boundaries that will limit access to these coexisting realities, and the findings of this article are a start in that direction.

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