SOAS University of London
United Kingdom

The Arab Society for Computer Aided Architectural Design (ASCAAD)
8th ASCAAD Conference 2016

PARAMETRICISM VS. MATERIALISM

Evolution of Digital Technologies for Development

Editors:
Aghlab Al-Attili
Anastasia Karandinou
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Imperial House Publishers
27 Old Gloucester Street, London, WC1N 3AX, UK
The Arab Society for Computer Aided Architectural Design (ASCAAD)
Proceedings of the 8th ASCAAD Conference 2016
First published 2016
Printed in the United Kingdom
ISBN: 978-0-9955691-0-2

Published by: Imperial House Publishers (IHP)

ASCAAD Declaration:

Articles edited in this volume were refereed by members of the International Scientific Review Committee in a process that involve detailed reading of the papers, reporting of comments to authors and modifications of manuscripts by authors. The re-evaluation of resubmitted articles was done by the scientific committee members to ensure quality of content.

يشرفني الترحيب بجميع القراء المتابعين لكتاب فعاليات المؤتمر العالمي الثامن (الجمعية العربية للتصميم المعماري بمساعدة الحاسب الآلي(ASCAAD)

يتناول المؤتمر عدداً من القضايا الحساسة في عصر التكنولوجيا الرقمية، كما يناقش مسائل معقدة متعلقة بعملية حساب التصميم الرقمي و تحليل التصميم المبني على الأداء و طريقة صنع المادة و نمذجة معلومات البناء و تصميم الحدود والصنع بالآلات وغيرها. وأرجو أن يكون جميع الزملاء والمقدمين للمؤتمر والحضور مصدر إلهام للجميع, وأن يعم المؤتمر بالفائدة والخبرة المرجوة على الجميع.

إنه لشرف لنا أن نستضيف المؤتمر العالمي السابع (للجميعة العربية للتصميم المعماري بمساعدة الحاسب الآلي (ASCAAD) في كلية الدراسات الشرقية و الأفريقية في جامعة لندن كما أود تقديم الشكر للجميع على دعمهم و جهودهم, مع شكر خاص لفريق الجامعي الذي لعب دورا هاما في كل من اللجنة العلمية و اللجنة التنظيمية للمؤتمر.

الدكتور أغلب العتيلي

رئيس الجمعية العربية للتصميم العربية للتصميم المعماري بمساعدة الحاسب الآلي

It is my privilege to welcome all readers of the proceedings book of the 8th ASCAAD International Conference.

The conference addresses a number of critical issues in the age of digitalization, and discuses complex matters related to digital design computation process, performance-based design analysis, the way of object-making, BIM and parametric design, machining and more. I hope that you will find your colleagues, presenters and attendees inspirational; and I hope you gain the expertise and thorough knowledge that you're looking for.

It is an honour to host the ASCAAD Conference at Effat University and I'd like thank everyone for their support and dedication, and a special thank you to the Effat team who played a major role in the scientific and organizing committee.

Dr. Aghlab Al-Attili

President of ASCAAD

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Foreword

RIGOROUS CREATIVITY

Ubiquity, Parametrics, Tectonics

WASSIM JABI
Welsh School of Architecture, Cardiff University, Cardoff, UK
jabiw@cardiff.ac.uk

Architects frequently understand and experience design and creativity as a personal and lonely activity. However, there is, increasingly, a need to collaborate with others in the design and construction of buildings. Digital technology is intricately intertwined with the creative and social aspects of the emerging practice world. A prime example is the use of digital fabrication technology and building information models to directly transfer information among architects, contractors, fabricators and consultants. At the same time, the discipline and practice of creative design is increasingly seen as a valuable cognitive skill, to be emulated, tapped, and understood by other disciplines in various settings. Fields outside of architecture and governmental granting agencies have shown strong interest in understanding, rationalizing and importing the creative design process that architects engage in. The obstacle, however, has been that architects and designers are rarely able to explain their processes in a manner understood by others. The advent of digital tools and social computing further complicates the issues of how designers design with such tools and how designers design with others (Lawson, 2005). Our aim should be to define a discipline of collaborative digital design with clear conceptual frameworks, methodologies, and epistemologies. The goal is two-fold: 1) to formulate a discipline of digital design based on sound theoretical and pragmatic underpinnings, and 2) to elucidate the processes of digital design so that we can better communicate them to other disciplines and thus engage more effectively in interdisciplinary research.

A discipline of digital design requires further definition and refinement; this can be achieved through a focus on a three themes consisting of: 1) Ubiquity, 2) Parametrics, and 3) Tectonics. In simpler terms, a discipline of digital design should concern itself with *people*, *rules*, and *things*.

Ubiquity

The first foundation, *ubiquity*, refers to the fact that digital information is rapidly becoming embedded in our daily lives. It enables collaborative interactions. Collaboration starts with simple casual interactions such as asking a question. It develops further within an organization through intra-disciplinary work – such as a team of architects and designers working together on a project. For larger and more complex projects, we often witness inter-disciplinary collaborative and coordinative processes among individuals with various backgrounds and training. Especially in the field of architecture and urban design, we also witness the users of and stake holders in these projects get involved in what is usually called participatory design. Ron Wakkary, for example, has emphasized this aspect in his research by using the term *everyday designers* (Wakkary, 2005). He argues that all of us contain innate design abilities that allow us to participate collaboratively in the formation of a project that affects our daily lives. Ubiquity enables synchronous and asynchronous collaboration. It can take place in the same location (co- located) or at different locations (dispersed) – aided by real-time communication technologies and persistent databases. The physical, ergonomic, and social settings of collaborative work have a direct relationship to the type of work being done. Lastly, in a collaborative process, it is useful to analyse the individuals/players involved, the tasks they perform, and the artefacts they produce and study.

Parametrics

The second foundation, *parametrics*, concerns itself with the rules governing the design process. "Parametric design is a process based on algorithmic thinking that enables the expression of parameters and rules that, together, define, encode and clarify the relationship between design intent and design response" (Jabi, 2013). Starting from George Stiny's *Shape Grammars* research (Stiny & Gips, 1972) and evolving through the newly found interest in parametric design (Woodbury *et al*, 2010) and generative algorithmic processes, parametrics is increasingly becoming not only a method, but a design philosophy (Schumacher, 2009), but more interestingly as a way of thinking (Oxman & Gu, 2015). A parametric understanding of the design problem has opened the possibility of investigating the deeper conceptual as well as tectonic structures of our proposals and has offered users and clients a realm of possibilities rather than a dictated solution. The field of parametrics has also allowed us to re-visit and discover the geometries of previously built works and more rigorously understand their design and construction rules (Jabi & Potamianos, 2007).

Tectonics

The third foundation of digital design, *tectonics*, is concerned with the relationship of *process* to *product*. It advocates the view that architecture will always be embedded in its tradition of attention to material, assemblage, and detail (i.e. the tradition of *making*). The term *digital tectonics* (Leach *et al*, 2004) expands this traditional notion into the current digital environment; thus making an argument that, while perhaps earlier computer-based work has ignored the architectural tradition of making, digital tools and technologies are not incompatible with a concern for materiality and craft. Indeed, they facilitate a powerful reformulation of design processes through parametrically constrained digital fabrication models and bring their own poetics to the equation. Architects have started using parametric and digital fabrication technologies to exert precise control over their design intentions through investigations that intersect the boundaries of algorithms, form, performance, material, and technique. A digital fabrication model can be used to more effectively investigate the impact and sequencing of production and assembly in the field and can communicate the above boundaries directly to others. A precise digital fabrication model can be transferred and translated digitally thus avoiding interpretation errors as it frees us of the need for representational annotation.

Several interwoven theoretical approaches must be employed to fully explain this research agenda and expand our understanding of digital design. In a vibrant research programme, one would expect to witness the following streams of concerns. Dialogs among those pursuing them and a collaborative atmosphere would further ensure that a discipline of digital design is formulated in a rigorous and collective manner:

- A humanistic approach (a concern for technology’s role in and effect on human praxis)
- An algorithmic/rule-based approach (parametrics, generative, novel software systems)
- A social/collaborative approach (HCI, ubiquitous computing, CSCW)
- An artefact-based approach (digital fabrication, digital/analogue, digital tectonics, building performance analysis)
- An academic/pedagogical approach (studio culture, inter-disciplinary design studios)

- A practice-oriented approach (building information modelling, workflow strategies, liability, legal and practice issues).

In summary, we should aim to discover a rigorous set of guidelines and a framework for the issues involved in the formulation of a discipline of digital design. It is hoped that this framework will encourage us all to be more explicit in our discussions and descriptions of digital design. This agenda can be pursued by using the three themes identified above that study individuals and how they work together with the aid of ubiquitous collaborative technologies, the rules and parameters they invent and apply in their design processes, and the tectonic artefacts they design, produce, and share. The maturity of this research agenda will enable us to better communicate *what we do* and engage in more meaningful interdisciplinary research.

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Section I

GENERATIVE & PARAMETRIC DESIGN & MODELLING

HUMANISING THE COMPUTATIONAL DESIGN PROCESS

Integrating Parametric Models with Qualitative Dimensions

AMER AL-JOKHADAR AND WASSIM JABI
Welsh School of Architecture, Cardiff University, United Kingdom
Al-JokhadarA@cardiff.ac.uk | jabiw@cardiff.ac.uk

Abstract. Parametric design is a computational-based approach used for understanding the logic and the language embedded in the design process algorithmically and mathematically. Currently, the main focus of computational models, such as shape grammar and space syntax, is primarily limited to formal and spatial requirements of the design problem. Yet, qualitative factors, such as social, cultural and contextual aspects, are also important dimensions in solving architectural design problems. In this paper, an overview of the advantages and implications of the current methods is presented. It also puts forward a 'structured analytical system' that combines the formal and geometric properties of the design, with descriptions that reflect the spatial, social and environmental patterns. This syntactic-discursive model is applied for encoding vernacular courtyard houses in the hot-arid regions of the Middle East and North Africa, and utilising the potentials of these cases in reflecting the lifestyle and the cultural values of the society, such as privacy, human-spatial behaviour, the social life inside the house, the hierarchy of spaces, the segregation and seclusion of family members from visitors and the orientation of spaces. The output of this analytical phase prepares the groundwork for the development of socio-spatial grammar for contemporary tall residential buildings that gives the designer the ability to reveal logical spatial topologies based on socio-environmental restrictions, and to produce alternatives that have an identity while also respecting the context, place and needs of users.

1. Introduction and Research Context

Computational design is about manipulating ideas, concepts and processes in clearly defined steps and instructions that are routinely made by computer (Terzidis 2009). This precise procedure offers to conceive operations, ideas and solutions not easily predictable. In the field of architecture, parametric design is an interactive computational-based approach, used for understanding the logic and the language embedded in the design process algorithmically and mathematically (Paper and Technion 2015; Woodbury 2010; Jabi 2013). It offers the designer control of the conversion of properties of objects and inputs into solutions and different alternatives accordingly with the minimum time needed; by defining, encoding and clarifying relationships between objects that are associated with specific rules and parameters (Jabi 2013; Fernandes 2013).

Currently, the main focus of computational models is primarily limited to building performance, optimisation, and the functional requirements of the design problem. Yet, qualitative factors, such as social, cultural and contextual aspects are also important dimensions in solving architectural design problems. The aim of this research is to combine all of these dimensions through applying a model of analysis on vernacular courtyard houses in the hot-arid regions of the Middle East and North Africa (MENA region) as a case. Different studies in the field of vernacular architecture show that these precedents are good examples of a socially cohesive and healthy environment, and have various features that reflect the lifestyle, local context, climate and cultural values of the society. Such elements include the courtyard, hierarchy of public/private spaces, different degrees of openness and enclosures, patterns of movement and geometric properties of spaces, which have the potential for achieving sustainability (see Figures 1 and 2).

Figure 1. Courtyard houses in Damascus, Syria (www.pinterest.com)

Figure 2. courtyard house in Tunis (redrawn by authors after Ragette 2003)

2. Reviewing Analytical and Generative Design Systems

Architects are trying to transform all design requirements into forms and spaces through adopting processes and series of goal-oriented steps. However, a successful design means that it has an identity where all components are in harmony with the context and requirements of the modern and future time (Mehrpoya et al. 2015). This issue requires designers to understand and analyse two sets of relationships between components. The first set addresses space-form languages, which includes lexical (geometrical) and syntactical levels. Different methods, such as shape grammar and space syntax, consider the morphology and the internal structure of the overall form and its components. The second set considers semantic and semiotic levels that are related to the meanings, symbols and values of elements and treatments. However, the syntactical level is also related to the second aspect which addresses the social life of users.

2.1 SPACE-FORM LANGUAGES

One of the useful tools for generating designs is to convert ideas into abstracted forms. Space syntax approach, developed by Hillier and Hanson in 1984, is used to understand spatial topologies and social relations implicit in the architectural setting through representing spaces by circles (nodes), and relationships within the overall configuration by lines. However, studies focusing on how such an approach might be used to generate or inspire new designs are limited (Lee et al. 2013). On the other hand, shape grammar, developed by George Stiny and James Gips in 1972, is based on the use of typological analysis methods by formulating spatial relationships, parameters, rules and restrictions. Moreover, it is a systematic process for generating new alternatives that depend on the use of shapes rather than symbolic computations. To control the process of form generation and the production of distinguished solutions, George Stiny (1980) introduced labels – such as letters, symbols or points – associated with shapes, to reduce symmetries. Moreover, Stiny specified parameters in terms of equations, constraints and transformations – such as translation, rotation, reflection or scale – which could be applied on shapes to increase the number of solutions and the flexibility in design.

However, there are some limitations for designers when applying such a formal approach. Shape grammars do not show the social, cultural and environmental aspects of the composition as they do not address the semantic and semiotic levels of the layout (Colakoglu 2000). Moreover, some of the design possibilities that are produced after applying shape grammar have no architectural meaning or relevance (Eilouti and Al-Jokhadar 2007). To cope with such limitations, scholars suggest different tools combined with shape grammars, such as descriptions, expressions and textual information.

2.2 DESCRIPTION AND DISCURSIVE GRAMMARS

Usually, details of design elements are provided in text and descriptions. To address this issue, George Sting (1985) proposed the concept of adding description functions, such as numbers, strings, lists, operators and parameters, to the shape rules to generate relevant solutions. Rudi Stouffs (2015) defined three schemes for descriptions. The first scheme, which is called ‘reflections’, reveals the spatial vocabularies that form the design and combination of elements. For instance, description rules have been included in the shape grammar of the *Yingzao Fashi* architectural style constructed by Andrew Li (2001: 30) for one of the spaces as the following: “*6-rafter building, centrally divided, 1-rafter beam in front and back, with 5 columns*”. The second scheme, ‘expressions’, used to describe some properties such as volume, cost or manufacturing plan.

‘Design brief’ is the third scheme that defines the user input data at the rule application; or the site data, such as functional zones and their adjacency relations; or conditional specifications, such as the enumeration of ‘true’ and ‘false’ that allows a function or rule label to be constrained beyond a single value (Eloy and Duarte 2011). José Duarte (2005) applied this scheme in the grammar of the ‘Siza's Malagueira housing program guidelines’, through organizing descriptions into three groups: (a) *contextual, typological and morphological features*, which include plot size, urban context, solar orientation, number of bedrooms, type of house, number of floors and existence of balconies; (b) *function and aesthetic qualities*, such as dwelling capacity, room capacity, articulations, distances between spaces and proportions; and (c) *construction cost*, through specifying areas, materials and thickness of walls.

Another attempt has been implemented by Teresa Heitor, José Duarte and Rafaela Pinto (2003). They were concerned with how two different computational approaches to design: shape grammars (large set of design solutions) and space syntax (that consider the context), could be combined into a single framework for formulating, evaluating, and generating designs. They utilised the spaces syntax to determine whether the applied formal and spatial principles are in the language and the contents of the grammar, by measuring three parameters: (a) depth, which is the topological distance of one space to all other; (b) control value, which reflect the relationship between spaces and immediate neighbours; and (c) contiguity that express the number of connections to adjacent spaces (Heitor et al. 2003).

3. A 'Syntactic-Discursive' Model for Encoding Traditional Courtyard Houses as a Trace of Social and Environmental Qualities

Integrating the embedded qualitative criteria of the architectural design problem with formal and spatial requirements remains a challenge in the computational process due to the difficulty of converting the abstracted issues into basic parameters that can be algorithmically represented. Therefore, feeding the parametric model with qualitative/quantitative data needs additional tools of analysis. This study adopts 'typology' as an instrumental tool of analysis, associated with different formal, syntactical, analytical and generative methods, such as space syntax, shape grammar, and descriptive grammars. The developed 'syntactic-discursive' model has been implemented on different vernacular houses from the Middle East and North Africa, as an attempt to define similarities and explore relationships between social, spatial and environmental dimensions.

The model depends on combining the syntactical analysis with three aspects of design: (a) geometric characteristics (e.g. shapes, areas, proportions); (b) social indicators (e.g. relationships, users, privacy, patterns of movement); and (c) environmental treatments (e.g. orientation, type of enclosures). These aspects are presented in five categories (see Figure 3):

1. *As-built plan*: showing the different patterns of movement and distances between the centre of the courtyard and the centre of each space.
2. *Visual analysis diagram:* showing the spatial organisation of spaces with visual connections between public and private domains.
3. *Space syntax analysis*: showing spatial relationships between spaces, courtyard and entrance, through measuring:
4. *Connectivity (NCn)*, which represents the number of immediate neighbours that are directly connected to each space.
5. *Integration value (i)*, which describes the average depth of space to all other spaces. The highest value indicates the maximum integration.
6. *Control value (CV),* which measures the degree to which space controls access to its immediate neighbours taking into account the number of alternative connections that each of these neighbours has.

Depth and hierarchy of spaces: each space is represented by its actual shape rather than symbolic nodes, and arranged to show the hierarchy of spaces (public, semi-public, semi-private, private, and intimate); orientation (West (W), East (E), North (N), South (S), North-East (NE), North-West (NW), South-East (SE), and South-West (SW)); type of enclosure (covered, open, semi-open), shared surfaces between adjacent spaces; the entry access of each space; and the actual distance between the centre of spaces and the centre of adjacent rooms.

Spatial and geometric relationships: showing the proportions of each space (X:Y); percentage of space area from the overall area of the house (%All); proportions related to the courtyard (1:C); actual distance (D1) in metres from the main entrance (N1) to the centre of the space; actual distance (D2) from the centre of the courtyard (N2) to the centre of the space; and the dominant users of each space (male, female, or both).

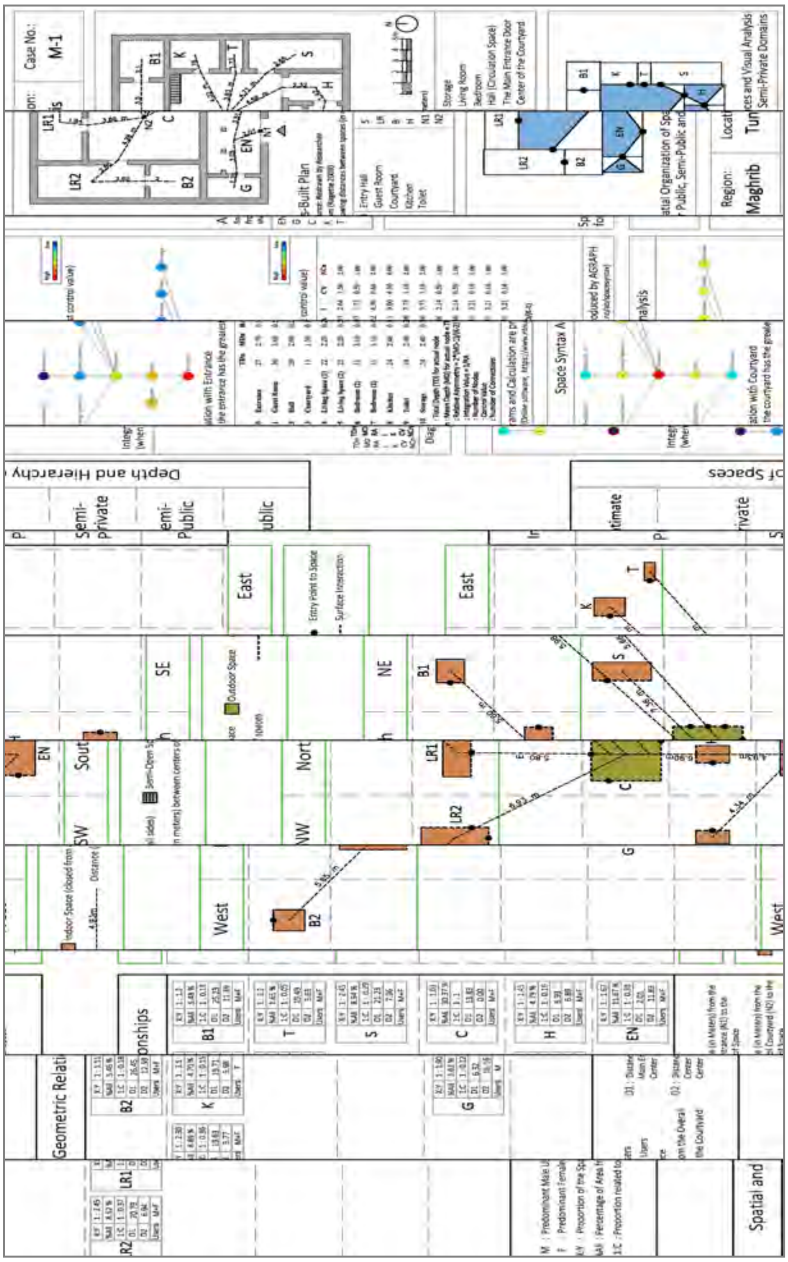

Figure 3. A syntactic-discursive model for analysing a vernacular courtyard house in Tunis (Authors)

4. Results and Discussion

Based on the syntactical-discursive model of analysis, it is obvious that the human-spatial behaviour, the social life inside the house, the hierarchy of spaces, and the segregation and seclusion of family members from visitors are regulated by a series of syntactic elements. After applying the analysis on a vernacular courtyard house in Tunis, different qualities are observed.

- Most spaces follow the geometric patterns of the courtyard with a symmetrical layout arrangement.
- The space syntax analysis shows that the courtyard, which is a semi-private space, has both the greatest control value (CV = 4.50) and the greatest integration value (i = 9.00), which means that other spaces, mostly private zones, are controlled and accessed through the central space of the house, where most of the daily functions are located. This arrangement provides a protected and suitable area for family gatherings.
- The hall (H), which is a semi-public circulation space, connects the entrance with the main courtyard. It is a mediator between the inside of the house and the outside world. However, the bent entrance passageway preserves the visual privacy of the family.
- Guest reception room is a shallow space used for male visitors, and it has the lowest integration value (i = 1.73), as it is situated off the courtyard and next to the entry hall. There is no visual connection between this space and the semi-private and private domains, so the privacy of the family members could be achieved.
- All private spaces face the courtyard, and have approximately the same distance between the centre of the courtyard and the entry point of that space. This depth, which ranges between 5.65 and 7.30 meters, provides a suitable distance for the residents to live in a comfortable atmosphere. All intimate spaces (bedrooms) should be accessed through private spaces to give more privacy.

The results of analysis are translated into 39 variables to define social, spatial and environmental descriptions and constraints (see Table 1) that are used for constructing the grammar for vernacular courtyard houses in the study area (see Figure 4). This type of grammar and model of analysis differs from shape grammar and space syntax method in many aspects. In terms of components, all geometric properties, proportions, functions, and type of enclosure are defined. Moreover, spaces are arranged according to the public-private hierarchal system and the solar orientation. In terms of relationships, the actual distances between spaces, the pattern of movement, and the physical-facial (wall-to-wall) relations are associated with rules. Finally, aspects related to the social dimension, such as visual privacy, interaction and the dominant users of each space are specified.

TABLE 1: Variable Descriptions (Spatial, Social and Environmental Parameters)

Features	Variables		
Morphology	v1	Type of house < detached, attached from one/two/three sides >	
	v2	Number of floors < number >	
Overall Geometry	v3	Overall Layout	Shape < square, rectangle, irregular >
	v4		Total width < m >
	v5		Total length < m >
	v6		Area < m^2 >
Spatial Description	v7	Name of interior spaces < name (space ID) >	
	v8	Number of courtyards < number >	
	v9	Main courtyard location < centre, front, back, side edge >	
	v10	Type of outdoor spaces < balcony, terrace, courtyard, gallery, iwan >	
	v11	Area of outdoor spaces < m^2 >	
	v12	Percentage of outdoor spaces from the overall < % >	
	v13	Total number of rooms < number >	
	v14	Number of living spaces < number >	
	v15	Number of bedrooms < number >	
	v16	Staircase < true, false >	
Geometric Properties for Each Space	v17	Room layout	Shape < square, rectangle, irregular >
	v18		Width < m >
	v19		Length < m >
	v20		Height < m >
	v21		Area < m^2 >
	v22	Proportion of the space < space ID: X:Y >	
	v23	Percentage of area from overall < space ID: % All >	
	v24	Proportion related to courtyard < space ID: 1:C >	
	v25	Distance from the entrance to the centre of the spaces < space ID: D1=m >	
	v26	Distance from the centre of the main courtyard to the centre of the spaces < space ID: D2=m >	
Spatial Topologies	v27	Relation with adjacent spaces < space ID: adjacent spaces, Orientation>	
	v28	Changes in levels between spaces < number of steps, spaces ID (1), (2) >	
	v29	Changes in levels between outside and the entrance hall < no. of steps >	
Social Qualities	v30	Predominance users < space ID: male, female, male/female >	
	v31	Type of space < space ID: intimate, private, semi-private/public, public >	
	v32	Spaces that have direct visual connection with the courtyard < space ID >	
	v33	Spaces that have direct visual connection with entrance < space ID >	
	v34 v35	Integration with the entrance and with the courtyard < sort spaces from the lowest integration value to the highest integration value >	
	v36	Hierarchy of spaces < true, false >	
Environmental Considerations	v37	Orientation < space ID: N, S, E, W, NE, NW, SE, SW >	
	v38	Thickness of exterior walls < thickness cm >	
	v39	Thickness of interior walls < thickness cm >	

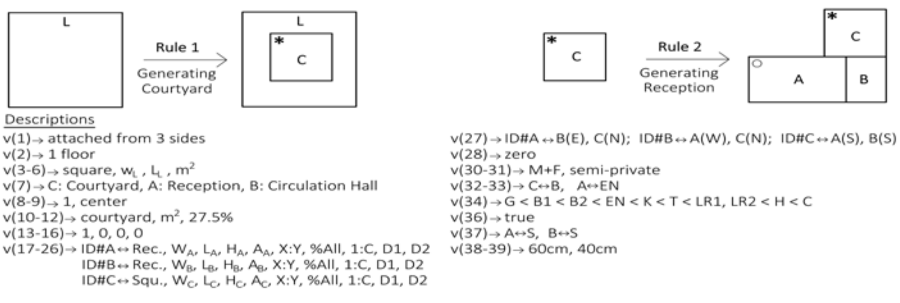

Figure 4. Rules associated descriptions for generating courtyard and reception

5. Conclusion

Shape grammars and space syntax methods are useful tools for exploring formal and spatial relationships. Yet, these approaches do not show the social, environmental and semantic levels of the composition. The use of syntactic-discursive analysis for encoding historical cases and the needs of users gives the designer the ability to reveal logical spatial topologies based on socio-environmental restrictions that control the overall configuration of solutions. The model combines descriptions with shape grammars and syntactic relationships to define the geometric properties of spaces that are associated with its qualitative dimensions. In the next stages of this ongoing research, this analytical phase for traditional houses in the hot-arid regions of the Middle East and North Africa prepares the ground for the development of socio-spatial grammar for generating parametric solutions for contemporary tall residential buildings that encourage social interaction between families, while respecting their needs, lifestyles and context.

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ALGORITHMIC THINKING IN DESIGN AND CONSTRUCTION

Working with parametric models

A. PETEINARELIS AND S. YIANNOUDES
Technical University of Crete, Chania, Greece
ng5ten@yahoo.com | soc.yiannoudes@gmail.com

Abstract. This paper examines the parametric model in algorithmic design processes, using the outcome of an educational digital design and fabrication course as a case study. In its long history, algorithmic design as a form-finding method, allowed designers to manage complex non-standard associative geometries, suggesting a shift from the digital representation of form, to its systematic representation into a parametric model through code. Rather than a style or a tool, the parametric model is best defined in mathematical terms; in practice it incorporates the organizational logic of the form and the topological associations of its parts, so that a change in its constitutive parameters will invoke a concerted update of the entire model, and, iteratively, formal and structural variations. In a series of design experiments that took place at the School of Architecture of the Technical University of Crete in the spring of 2015, we used parametric models represented into visual code, from the initial conceptual stage to fabrication. From the experience and outcome of this course, we deduced that, compared to other digital formation methods, parametric models allow the designer to constantly interact with the model through the code, producing discreet variations without losing control of the design intentions, by "searching" into a wide range (albeit finite) of virtual results. This suggested a shift in culturally embedded patterns of modernist design thinking.

1. Introduction: Parametric Design

Although the term "parametric design" can be traced in many recent publications on digital design (Woodbury, 2010; Jabi, 2013), the term "parametric architecture" was coined for the first time in the 1940's by Luigi Moretti, who, in his writings, pointed to the study of architectural systems by "defining the relationships between the dimensions dependent upon the various parameters", to produce variations of the form of buildings (Bucci & Mulazzani, 2000). In line with Moretti and since buildings and cities have always taken shape according to changing parameters, either environmental, cultural, constructional or functional, we could easily argue that architecture and design have always been parametric (Aish & Woodbury, 2005; Gerber, 2007; Hudson, 2010). However, Patrik Schumacher, a few years ago, introduced the term "Parametricism", to refer to a "new great style" and suggest the advent of a new paradigm in architecture after modernism (post-modernism and deconstruction being only transitional stages), along the lines of a new research program (as defined by Lakatos in the philosophy of science), with certain methodological and stylistic rules (Schumacher, 2008; 2010). Of-course, Schumacher's view, who, in our opinion, mostly showcases the architectural style of his practice Zaha Hadid Architects (ZHA), is very prone to criticism, because several emblematic buildings of modernism, like Villa Savoye, can and have been parametrically modelled. But as we will show, rather than an architectural style, parametric design is concerned with the management of the relations between the parameters that define a geometric structure in the design process, and the best definition for what we will refer to as "parametric model" comes from mathematics.

1.1. THE PARAMETRIC MODEL

In his doctoral dissertation Daniel Davis, instead of "parametricism" or parametric design, talks about "parametric models" based on the definition of the parametric equation in mathematics. Parametric, in mathematics, is a set of quantities expressed as an explicit function of a number of parameters, such as the formulas that describe the catenary curve: $x(a,t)=t$ $y(a,t)=a \cosh(t/a)$. Hence, "A parametric model is set of equations that express a geometric model as explicit functions of a number of parameters" (Davis, 2013). This mathematical definition of the parametric catenary curve, characterizes the inverted suspension models with strings and birdshot weights used by Antoni Gaudí to automatically simulate -by analogue means- the route of the forces and thus the multiple variations of the form of his Colònia Güell chapel, according to the set of outcomes that derived from the parameters (string length, anchor point location, birdshot weight). Similar analogue methods for parametric calculations were later expounded by Frei Otto at the Institute for Lightweight Structures (ILS), who used several experimental form-finding and optimization techniques, as documented in the ILS publications. These methods are currently revisited by contemporary practices that make use of parametric and algorithmic design, while Otto's legacy has recently been further investigated (Peteinarelis, 2015; Fiorakis, 2016).

Davis will conclude that "…a parametric model is unique, not because it has parameters (all design, by definition, has parameters), not because it changes (other design representations change), not because it is a tool or a style of architecture, a parametric model is unique not for what it does but rather for how it was created. A parametric model is created by a designer explicitly stating *how* outcomes derive from a set of parameters" (Davis, 2013). Thus, the use of parametric models in digital design, allows designers to describe the geometry of their model (either orthogonal or curvy) with flexibility, and create dependencies between the components of the model, using specific rules and constraints. Designers can use current parametric modelling software like Revit to manage complex and associative geometries, i.e. they can associate dimensions and parameters with the geometry, so that a change of a part, a rule or a constraint that describes it, will affect and update the entire model.

To create parametric models, designers use algorithmic editors that usually incorporate visual programming languages (like Grasshopper/Rhino3d, Max/MSP or Revit/Dynamo), to overcome the constraints of the interface, and to design directly, managing not the form (with the design tools provided by common software packages), but the code that generates the form. In this way the designer can formulate the associations of the parts of the parametric model into code, so that a change in the parameters that describe it, will cause a coordinated overall update – thus observing the variations of the generated results. This allows freedom and flexibility to deconstruct the problem and thus represent it with precision and control, into code (Burry, 2011). Understanding the parametric model in the form of code in the context of algorithmic design is the rationale of the postgraduate course discussed next.

2. From Code to Fabrication

The postgraduate course "Advanced Digital Tools in Design and Construction" runs at the school of Architecture at the Technical University of Crete. Central to the course is the concept of code and its representation for the creation of parametric models. In the spring of 2015 we examined form-finding techniques with algorithmic thinking, emphasizing the unified use of the digital model, from the initial abstract diagram (body-plan) to fabrication, according to the properties of the materials used and the capacities of digital prototyping machines.

Apart from the historical precedent and the theoretical aspects of parametric design, we reviewed several current practices in parametric and algorithm design, more or less experimental, to gain insights from their design approach for our design course process. For example, Lisa Iwamoto and Craig Scott designed a structural skin parametrically correlated to changes in building stress and strain for their Jelly Fish House (2005-06), and Tom Wiscombe (Emergent Architecture in Los Angeles) used the patterns of dragonfly wings to model the variably patterned structural envelope of his Paris Courthouse project (2006). Most importantly however, Archim Menges and his team in the Institute for Computational Design at Stuttgart, proposed a design methodology, on the basis of biomimetic principles as well as Manuel DeLanda's neo-materialist thinking, foregrounding the properties of the construction materials as morphogenetic information, simulated in the computational process, from concept to robotic fabrication. The ICD/ITKE Research Pavilion 2010 is a characteristic achievement of the team's method.

Drawing on these biomimetic attitudes that start from the structural characteristics of form, in our design course we asked students to analyze a natural form of their choice, determining its geometric and qualitative characteristics, in order to describe, using diagrams, the rules that express, and the code that organizes its structural complexity. The aim was to finally restructure these diagrams into a new code, a genotype that would incorporate the basic design choices for novel form-finding, in particular, for the design of a utilitarian object – namely a lighting fixture. Students would choose the structural characteristics that would be parameterized, and then transfer this new code into the environment of graphical algorithm editor Grasshopper3D for Rhino. They would thus be able to form a parametric model of the object that they would design and build.

We used two qualitatively different prototyping methods, which affected both the form and the fabrication instructions incorporated in the parametric model. The first method was 3D printing, which builds complex geometric forms by successive layers of plastic (additive manufacturing). The second method was subtractive manufacturing, using CNC milling machines and Laser cutters, which entailed taking account of the constraints, tolerances and specific characteristics of the materials and machines used. When the code was completed, the students 3d printed some of their results, namely the family of forms that emerged from their parametric model, and then they selected one of them as a model for further digital processing and 1:1 fabrication, experimenting with different construction materials.

Iro Skouloudi, who designed the project "Pinecone", studied the mathematical rules that define the geometry and structure of pinecones, using them as input for the parametric model that described its geometry. Through her research she found that the position of the petals on the pinecone coincides with the intersection points of clockwise and anticlockwise spirals, the amount of which corresponds to two successive Fibonacci Sequence numbers. Thus, the number of the petals and the sunlight intrusion is optimized. Moreover, the opening and closing of the petals (their angle to the central axis of the pinecone) depends on humidity. These observations were then transferred to the parametric model of the restructured version of the pinecone (fig. 1).

Figure 1. Parametric model of the reconfigured pinecone and 3d-printed family of forms.

Figure 2. 1:1 scale model.

The model started with a surface defined by intersecting spirals. The intersections of these spirals were the positions of the supports of the petals, which were adjusted to always be vertical to the plane that was tangent to the clockwise spiral at the intersection point. The size of the petals was correlated to the z axis, which was defined by the vertical axes between the intersection points. By controlling and modifying the initial overall form, and the position, orientation, and shape of the petals through the parametric model, the student could flexibly create and print different variations of the outcome (fig. 1). In the next stage, the student modified the parametric model, in order to introduce the manufacturing parameters of two versions of the object as it was implemented in 1:1 scale by plywood (fig. 2).

The next project by Alicia Markianaki, started from an examination of butterfly flaps, in order to determine the shared branching rules of their ribs. The student found that the edge that is attached on the body of the insect is always smaller than the external one, that there is successive bisection of the ribs along the flap, and that the cross-sections of the ribs become larger towards the base of the flap. The student created a parametric model in the form of code, introducing these rules, which could control the general shape, the bisection sequence, and the changing cross-sections of the ribs. The model generated a family of forms, which were 3d-printed in small scale (fig. 3). Subsequently the student explored fabrication methods, using plaster and clay casted in CNC-milled wood mold (fig. 4), to build one the variations on a 1:1 scale.

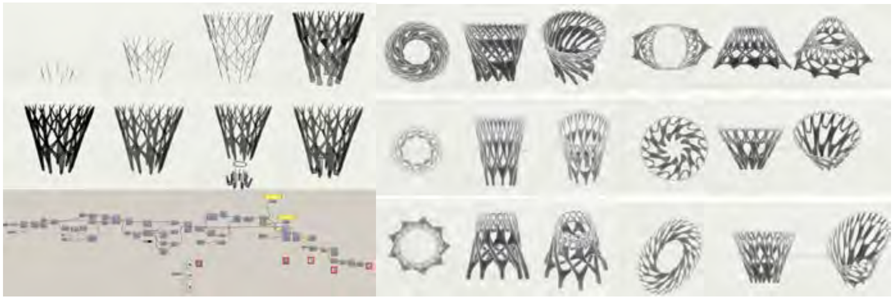

Figure 3. Parametric model and family of forms.

Figure 4. Wooden mold and clay models

Giorgos Spyridakis's project point of departure were the draperies of speleothems and the processes that generate them, namely successive layers of water and calcite. Using Kangaroo physics engine plugin for Grasshopper, the student could dynamically simulate this process using wind force, and freeze the derived form on a moment he preferred. After the initial 3d printing session of his model, the student studied potential fabrication techniques (contouring the model and building it by stacking wooden boards, cast using rammed earth etc.). He chose to fabricate it using polyester and polyurethane mold (fig. 5).

Figure 5. Kangaroo model of surface, 3d printed model and natural formations

In our view, the contribution of the course is that it helped us understand the possibilities of digital tools and parametric models, and enhanced students' skills to manage complex geometries from the stage of the concept to final fabrication.

3. Parametric Models in the context of Digital Design

The last 20-25 years, computer-aided design and manufacturing has allowed designers to draw, manage, and construct geometrically complex buildings and structures, which often led to a "neo-expressionist" or "post-organic" architectural vocabulary based on curvilinear forms. This "topological tendency" in architecture (Di Christina, 2001), can be traced in the practices and discourse of architects like Peter Eisenman, Frank Gehry, Greg Lynn, Foreign Office Architects (FOA), UNStudio, Sanford Kwinter, Stan Allen, and Peter Saunders, and in numerous publications of Architectural Design (AD) magazine. Rivka Oxman attempted to categorize the outcome of many years of digital design practice into a number of design models, drawing on Donald Schon's design theory and his concept of "reflection in action", to examine the relation between the designer and the object of design in each design model (Oxman, 2006). Digital design processes use a dynamic environment of topological deformations, morphogenetic force fields, and generative form-finding processes. Such design practices seem to point to a shift from the concept of form and its representation, to the concept of formation, i.e. the mechanism, the performative process of form generation (aka emergence). This shift, from a representational to a performative approach to digital design, seems to be an emergent characteristic phenomenon of digital design, and defines the concept of formation as a flow of events and open potentials, in which the form is only a moment of effectuating the virtual, in Deleuzean terms, the diagrammatic machine that generates the form.

4. Conclusion

Design using parametric models, as studied in the course we discussed, presents significant differences in relation to other digital design models, as discussed by Oxman. First, it manifests the systematic representation, not of form, but of the code that describes it. Second, by contrast to algorithmic design models that automate form-finding, such as the evolutionary design models that use genetic algorithms, and the grammatical transformative models, that use mathematical expressions for the generation of shapes through transformational rules, the parametric model gives designers the capacity to constantly interact with the model (adjusting parameters or even the topological relations that define it through the visual code). Third, designers are able to parametrically control the initial design intentions to generate discreet variations of the model (family of forms), “searching” within a wide range (albeit finite) of virtual results.

Finally, digital techniques bring forth a new framework for design thinking. Contemporary experimental and built parametric design projects, such as those by Foster & Partners, Zaha Hadid Architects, NOX, NBBJ, and Ball Nogues Studio, demonstrate an attempt to reconfigure foundational concepts of modernist architecture and design, by replacing cultural patterns of the “first machine age”, characterized by normative processes of standardization and repetition, with alternative ways of thinking embedded in the so-called “digital culture” (Gere, 2008), characterized by the discreet, the flexible and the differentiated, rooted in Deleuzean philosophy, and the sciences of complexity.

Acknowledgements

We would like to thank the students of the postgraduate course “Space, Design and Built Environment” of the School of Architecture Technical University of Crete, Iro Skouloudi, Alisia Markianaki, and Giorgos Spyridakis for giving permission to publish their work in this paper.

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MATERIALITY IN ITS MINIMUM

Minimum Material Consumption through Design with Mathematics

ZUBIN KHABAZI AND MICHAEL BUDIG
Singapore University of Technology and Design
Zubin@morphogenesism.com | Michael_budig@sutd.edu.sg

Abstract. Contemporary practice of architecture has extensively utilized computation in its processes, which has brought lots of potentials like explicit integration of mathematics with design. This helped designers in different ways, ranging from modeling complex forms to simulating material behavior. Through presenting two experimental projects, this paper discusses how mathematical form-finding and math-driven form generation techniques could help to achieve not only complex designs, but also products which are optimized in their material use. This is a study to use mathematical functions in favor of mass reduction, as a sustainable design approach.

1. Introduction

The global inquiry for better building performance, less material waste, or less building energy consumption is prominent, ethical and vital, yet achieving a sustainable building is not a linear, straightforward task. It seems that in an ongoing progression of research, there could arise specific design approaches that incorporate some of the agendas/goals of sustainable design. This paper will address two experimental projects. Both are aiming to achieve minimum material consumption through the use of design processes driven by mathematical functions. It discusses how computational design platforms and digital fabrication technologies helped to use math-driven generative design approaches to reach this agenda. This will be presented after a brief overview of the historical background and will be further discussed and evaluated in a broader context.

1. Architecture and Mathematics

1.1. A HISTORICAL OVERVIEW

Architecture and mathematics have had strong relations throughout history, but this relation has solidified in buildings through different manners and meanings. Antoine Picon mentions that this relation was intense and ambiguous, sometimes as the foundation of the whole discipline and sometimes as a tool (Picon, 2011). Math as a tool, especially in geometry, has helped the discipline for the realization of projects. Geometry plays an important role, not only in the process of design and construction, but also in the communication and representation of architecture (Pottmann, 2007). Ivins believed that "*great advances in geometry, would be followed up directly by the development of art/architecture*" (Ivins, 1964). But for some time before the 18th century, another side of this relationship, which gave a metaphysical power to it, was about meaning and conception. It was mostly envisioned in the 'proportion' of buildings, as something sacred and celestial (Picon, 2011). This mythical power would be more sensible if defined in its cultural context. It has been declared by philosophers like Jacques Bènigne Bossuet in the 17th century as a conception that "*God had created the world by establishing the principles of order and proportion*" (Bossuet, 1722). Following this idea that geometry and proportions are initiated by God and it is an architect's duty to reflect it in buildings, they experienced "*the exhilaration of empowerment*" (Picon, 2011).

From the late 18th century and by introduction of calculus, the relation of architecture and mathematics has changed. Application of calculus introduced areas like material strength which were different from proportions in dealing with design problems (Picon, 2011). Calculus provided rigid boundaries which were setting limitations, not as flexible as designing with proportions. This is what later progressed into engineering principles, where civil engineering started to get its independence from architecture. From the 18th century onwards, mathematics played a foundation role in the scientific studies of structures and material behavior, and the relation of architecture and mathematics has expanded and intensified through scientific areas (structure, material, building mechanics, building performance, etc.). This has been changed even more extravagantly while facing the new age of computational design.

1.2. MATHEMATICS AS THE GENERATOR OF ARCHITECTURAL FORM

Contemporary architecture benefits from mathematics in different ways. The first areas are subfields like advanced and computational geometry, where with the promotion of Non-Euclidean, Fractal, Procedural or Parametric geometries through computer tools, it is mathematics that helps architects to have access to unimaginable spaces (Shelden and Witt, 2011). The second area is simulation of material/environmentalal behavior using mathematical rules, to have more understanding of the physical behavior of design products. The third is the inherent mathematical rules that are used in the structure of algorithms in computational architecture. The fourth is actually a continuation of the third where design processes directly use mathematical functions in their form generation. In this method, instead of hidden functions in a software black box, explicit mathematical formulae and functions would help to develop design schemes.

2. Mathematics in Design Practice

2.1. DIGITAL 'KARBANDI'

'Karbandi' domes are structures of traditional Iranian architecture in Islamic periods (Figure 1). They could be described as ribbed vaulted domes, which are comprised of intersecting arches. The space between these intersecting arches fills with brickwork, usually in a decorative manner that produces the intricacy of the dome. Different types of geometrical configurations have been developed to cover various spatial/planning situations. Unfortunately, like so many other traditional techniques, Karbandi did not find any application in modern construction. There are various cultural, historical and style-related reasons behind this, but one cannot deny their engineering and technical difficulties in contemporary construction.

Figure 1. 'Timche Malek', Isfahan, Karbandi dome (Photo: Hossein Panjehpoor)

The main question at the heart of this design-research project was to study the technical difficulties of the realization of Karbandi construction and to see how new digital media could facilitate its construction with new material strategies. Studies showed that there are mainly two barriers in front of the task: the first relates to the complexity of formal and decorative patterns of the elements and the second problem is the engineering difficulties of masonry; by its nature it cannot be easily integrated into modern construction systems. Traditional masonry is heavy and complex, and without any adaptation to accommodate modern construction methods, progress cannot be made.

The Digital Karbandi project is a re-interpretation of the technique, with the aim of redesigning it with lightweight materials for realization through digital fabrication. The process comprised of understanding geometrical features of the dome to be regenerated in a parametric design space. The traditional Karbandi usually gets its shape through division of a circle in plan, connecting division points in a certain order through diagonals to subdivide internal space into tiles and then projecting the resulted tiles onto the dome's surface to make arches and brickwork patches. Utilization of computational design platforms made it simple to follow the same rule, but also use more complex logics of subdivision, driven by math logics. Although the original surface of the dome was a symmetric revolved surface, the final output of the digital process did not feature a regular geometry, but rather half of a deformed ellipsoid. Therefore the projected tiles on the surface were become unique and differentiated (Figure 2).

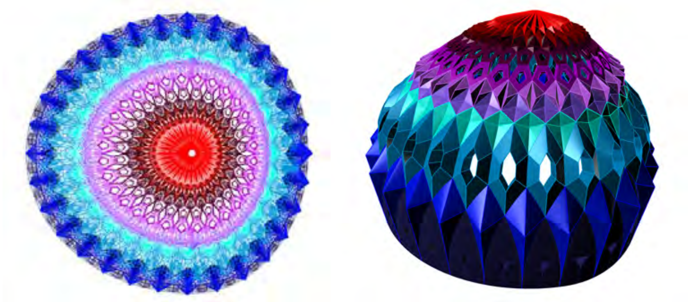

Figure 2. Subdivision of the surface and generation of dome elements with cellular solids

Projected tiles are the base boundaries to be filled with pyramid-type brickworks in its original Karbandi, but here they have been substituted with various cellular solids in the skin of the dome. The idea was to use them because they made up of adjacent flat faces, with empty internal spaces, which was important for fabrication strategies as well as their weight. Operation of surface subdivision technique, tiling, multi-faceted point extrusion, symmetry, deformation and morphing, helped to figure out new combinations of solids, which have never existed as Karbandi elements before. In the end, the design was finalized with pure geometry-math operations in an algorithm to fill the dome's surface.

Departing from a traditional masonry structure towards a lightweight digitally fabricated product was the initial idea of construction, which happened by using cellular solids made with sheet materials. The output of this digital design process was a non centrally-symmetric mock-up, made by lightweight, pre-fab elements (Figure 3). It helped to reproduce the Karbandi, with new language of design and compatible with contemporary construction technologies.

Figure 3. Digital Karbandi; final mock-up made with flat but folded pieces

2.2. CRAFT PAVILION

The aim and scope of this project was to design and fabricate a pavilion (Figure 4) with fiber composite materials. While the use of thin fiber composite surfaces could be promising for lightweight construction, its design should follow the same logic to arrive at an ultra lightweight output. Searching for various ideas of working with surface geometries, here minimal surfaces showed benefits for the aim of this project.

Mathematical minimal surfaces feature minimum surface area in the boundary condition that they are stretching inside (Nitsche, 1989). This means that they inherently occupy less area, which implies less material use conceptually. But they also feature a mathematical property which is zero Mean Curvature across the whole surface (Nitsche, 1989). This property denotes that there is no active energy inside the surface and if any flow of forces exists inside, then there is a state of equilibrium between them.

Figure 4. Courtyard of the Vartan historical house with Craft Pavilion

In this design experiment, mathematical minimal surfaces were modeled with their parametric equation in R3 space. Such equations could be used directly inside the parametric platforms for modeling purposes. Here, Gyroid as a subclass of Periodic Minimal Surfaces has been chosen. A Gyroid could be modeled in R3 space using this math function:

$$\mathrm{Cos}(x)\mathrm{Sin}(y) + \mathrm{Cos}(y)\mathrm{Sin}(z) + \mathrm{Cos}(z)\mathrm{Sin}(x) = 0 \quad (1)$$

With proper range of data as (x,y,z), software could generate points of the Gyroid surface, P(x,y,z). It is possible to manipulate various parameters of the equation and its input data to achieve a non-regular minimal surface as the design output (Figure 5).

Figure 5. Internal sections of the pavilion, made by non-regular Gyroid minimal surfaces

As before, the design was simply a double-curved surface. To be able to make it using fiber composites, the strategy of fabric forming was chosen, meaning that the whole surface would ne subdivided into smaller parts, each converted into a formwork, and a fabric attached to it. This fabric would get the shape of the surface and provide a flexible formwork to apply the fiberglass and resin (Khabazi, 2015). The thickness of fiberglass was around 5 mm, which made it a very thin and lightweight construction. Assembly of the pieces resulted in a mathematically designed pavilion made by ultra-thin, lightweight fiberglass (Figure 6).

Figure 6. Craft Pavilion made with thin layer of fiber composite

3. Discussion: Materiality in its Minimum

3.1. OPTIMIZATION

Both of the presented projects in this paper use certain methodology to reduce material consumption. There are similar approaches in ‘optimization tools’, which are trying to reduce mass while they also using mathematics.

For further evaluations of the methodology of the work, it should be seen in this context. It should be noted that optimization is a broad subject and there are various targets in design problems to be optimized and minimizing mass is just one of them. This is only an overview of those techniques that relate to the subject of this study for further discussions.

Simulation. At first, 3D modeling tools were only capable of modeling forms, and embedding materials was for rendering and visualization purposes only (bitmap images). Later on, modeling tools were integrated with simulation of physical behavior of materials. This helped to make a model which was more aware of physical realities. Simulation by itself does not reduce or optimize material use in a project but it can provide this opportunity to analyze behavior of design elements and at some points, reduce the mass within a certain tolerance. These changes in mass were based on trial and error.

Structural Optimization / Shell Optimization (SO). This technique tries to find the optimum solution for a given design problem with the aim of reducing the total mass/volume of a structure while also reducing the total stress. This is one of the main approaches to reducing material use with the application of mathematical operations. It usually has multiple parameters involved in its process, sometimes with contradictory ones to be solved (Razvan and Grama, 2014). Although developed for structures only, it is still a very crucial strategy to reduce the amount of valuable materials (like steel) in buildings.

Topology Optimization (TO). TO is a subfield and a general type of structural optimization. It seeks to find the optimum material distribution of a structure under certain load/support condition (Bendsoe and Sigmund, 2013). TO is a tool for the initial stages of the design to help to find the better material distribution which should be further completed with other shape/size strategies (Razvan and Grama, 2014). Although this technique has been designed for structural problems, it is applicable to any generic design problem (including architecture), which needs material distribution. It would iteratively reduce the material from the design space to reach a state of optimum material distribution. It should be noted that the output of this process might be a region or accumulation of voxels which might not necessarily meet the manufacturing constraints such as milling or casting direction or material continuity (Razvan and Grama, 2014). Usually further refinement and post-production should be applied to the output.

3.2. MATHEMATICAL DESIGN VS. OPTIMIZATION

Optimization is a crucial concept that helps to reduce mass/volume of building elements and structures to an optimum value. But it should be noted that such tools mostly work with pre-existing design objects, or in the case of TO, pre-defined situations with blobby outputs. The objective of the projects presented in this paper is also to reduce the mass, however the process starts from the initial ideas of design, rather than optimization of the result. Here the aim was to initiate design with inherent potential of minimized material use. An analogy of the methodology could be drawn here between this approach and physical form-finding in architecture.

Studies on physical form-finding was the main focus of the work of Frie Otto and this methodology was applied to the design of lightweight structures. He tried to find the state of equilibrium of forms under certain forces to get the most optimized models in the early stages of design (Schanz, 1995). Here with similar methodology, mathematical laws substituted physical ones, which are actually the basic rules of such physical phenomena. These math operations are mostly concentrated on surface functions as the representative of the thinnest physical elements that could be built in architecture. The first project (Karbandi) used mathematical-geometrical rules of subdivision and cellular solids in order to convert massive elements of a masonry structure into empty solids, which were lightweight and made by sheet materials. The second project (CRAFT pavilion) utilized mathematics to generate forms directly through math functions of minimal surfaces. In both scenarios, the design was concentrated on the generation of surfaces, which could provide minimum energy, maximum stability and minimum material use. Understanding mathematical surfaces and their behavior in the physical world helped to develop an environmental-oriented design methodology.

Conclusion

It is just recently that a new quest for mathematics as a generator of design started to take shape. Cecil Balmond remarks of his endeavors in design and engineering: “I found answers in early Greek mathematics. […] I also looked into the modern instabilities of mathematics where uncertainty principles and fractional geometries were opening new words. Chaos theory produced impossibly beautiful structures; could such animation be brought to building science, a loose or traveling geometry giving shape and form?” (Balmond et al., 2007). Thanks to computers, the integration of mathematics and design actually happened even faster than what was assumed (Terzidis, 2006).

Driving a design with mathematical functions to result in minimum material use as a sustainable design strategy, is an interesting subject of investigation. The negotiation of design parameters and physical matters through math functions, would insist on a shift of emphasis towards a generative approach in the imagination and realization of buildings, more aware of environmental concerns. Such methodology has the potential to produce a new language of design that follows a contemporary formal repertoire and at the same time benefits from certain futuristic goals for the built environment. That is why Mark Burry highlights this contradiction in today's design endeavor, where instead of specificity, it tries to be generic to tackle more comprehensive problems: "[there is a] need for rapid and universal quantum reduction in consumption and environmental degradation. The mathematics-design nexus in its newly pluralist and agile manifestation is ubiquitous in this mission" (Burry and Burry, 2010).

Acknowledgements

The realization of Karbandi project was part of a workshop by morphogenesism and the CRAFT project was a pavilion built as an educational program co-directed with Mehran Davari (Tehrancraft.com). Further studies and evaluations of the techniques are part of the work of authors at Singapore University of Technology and Design.

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ALGORITHMIC CLUSTERING OF SPATIAL ENTITITES

Clustering of 64 single rooms using the Self-Organizing Map algorithm.

PERIKLIS KYRIAKIDIS
Independent scholar/Architect, Zurich, Switzerland
periklis.kyriakidis@gmail.com

Abstract. Grouping spatial entities according to any kind of parameters has always been important both for practical and for theoretical purposes in architecture. For a long time, classification according to traditional reference systems was considered the only method to fulfil this purpose. However, in recent years, information technology has led to the hybridization and spread of design outputs, challenging the limits of applicability of these traditional reference systems and making it meaningless to refer to classification. This paper suggests the method of clustering spatial entities using user-defined reference systems. The method is demonstrated with a case study where 64 single rooms are clustered according to user-defined parameters with the use of the Self-Organizing Map. This method gives the power to the user to define and determine reference systems for the clustering of architectural projects according to their needs.

1. Introduction: Clustering Instead of Classification

Classification of a number of spatial entities is performed in relation to a traditional reference system. Classification in architecture has been based on historical, technical, geographical, aesthetic, functional, social, political or other parameters that are regarded as traditional reference systems. For example, according to a history-time based traditional reference system the Notre-Dame Cathedral in Paris belongs to gothic architecture, the Palazzo Rucellai of Leon Battista Alberti in Rome belongs to the Renaissance and the Villa Savoye of Le Corbusier in the outskirts of Paris belongs to modernism.

Nowadays, the introduction of information technology has driven a shift in the practice and theory of architecture. During a lecture on the foundations of digital architecture Peter Eisenman[1] deferred to the notion of multiplicity in an attempt to explain the epistemological implications of the introduction of information technology in architectural practice and theory. Multiplicity is linked with possibilities for form variation, optimization of construction, the global networking of any kind of architectural data and eventually leads to the proliferation of hybrid architectural vocabularies and to the creation of insurmountable loads of data. The results are characterised by the blending of once discretised architectural attributes. They defy old schools of thought and test the limitations of classification according to traditional reference systems.

Another view on the impact of multiplicity in architecture came during the 14th Biennale of Architecture in Venice "Fundamentals" (2014), which was curated by Rem Koolhaas. In reaction to the emergence of millions of variants of architectural parts in the last decades, Koolhaas suggested that architects are in need of finding the common denominator among them. Therefore, the central exhibition of the Biennale, which was called "Elements", featured the 15 fundamental elements of architecture, which, according to Koolhaas (2014), are "used by any architect, anywhere, anytime: the floor, the wall, the ceiling, the roof, the door, the window, the façade, the balcony, the corridor, the fireplace, the toilet, the stair, the escalator, the elevator, the ramp…". Koolhaas explicitly negated the difference and complexity of all these elements and deferred to the traditional reference system of typology in order to classify them.

Classification has been a very efficient and successful method to address the subject of grouping of spatial entities until now. However, in the contemporary context which is characterized by the emergence of numerous hybrid design vocabularies it no longer qualifies as the appropriate process for this purpose. Traditional reference systems cannot interpret the hybrid designs that overflow reality. A recent example of a vast collection of data was the results of the first stage of the design competition concerning the Guggenheim museum in the Finnish capital of Helsinki in 2014. Entries from all around the world amounted to 1715 and composed a database that can no longer be treated in analogue terms. In the website[2] of the competition statistics concerning the geographical origin of these proposals can be found, but the problem remains. Hence, the need for a new method of classification of architectural entities becomes apparent. One that is capable of dealing with the multiplicity of the current architectural theory and practice and simultaneously of considering different traditional reference systems without flattering them, while being applied on big data.

Clustering a number of spatial entities using a user-defined reference system is proven to be a valuable alternative of the traditional classification, which tackles the modern needs of architecture. This reference system makes use of a combination of attributes of traditional reference systems and therefore can be adapted to the needs of the user in each particular case.

Similar research has been conducted using the Principal Components Analysis algorithm. This statistical procedure uses an orthogonal transformation to convert entities of possibly correlated variables into a group of values of linearly uncorrelated variables called principal components. As Vahid Moosavi[3] has shown, however, this procedure assumes a universal traditional reference system towards which all of the entities are projected and related.

This paper suggests that clustering using a Self-Organizing Map algorithm can be adopted as an alternative method for the grouping of spatial entities, as it operates regardless of any traditional reference systems and only based on a user-defined reference system. The use of this method has already shown promising results when used at the level of the plot. This paper goes one step further presenting the results of the application of the same method in the level of rooms.

2. Method and Application: Self Organizing Map Algorithm

The use of the Self Organizing Map (SOM) algorithm is suggested as an unsupervised process to cluster spatial entities. The SOM algorithm was created by Teuvo Kohonen in the 80s. The algorithm is based on the neural network methodology which enables the representation of multidimensional data in much lower dimensional spaces and their clustering according to user-defined numerical parameters without supervision. This means that no predefined output or traditional reference system influences the clustering process, but, on the contrary, the output depends only on the user-defined parameters.

An application of the SOM is featured in the work of Benjamin Dillenburger[4]. The SOM was used for the rearrangement of the plots of Zurich's city centre, making it possible to have clusters of plots with similar properties important for the user.

For the case study presented in this paper the same algorithm was used, but on another scale. The clustering potential of the SOM was examined in a set of 64 single rooms shown in Figure 1, which were arbitrarily chosen. These 64 rooms were clustered according to a set of seven user-defined parameters, i.e. area, outline length and numbers of corners, staircases, windows, doors and fireplaces of each room.

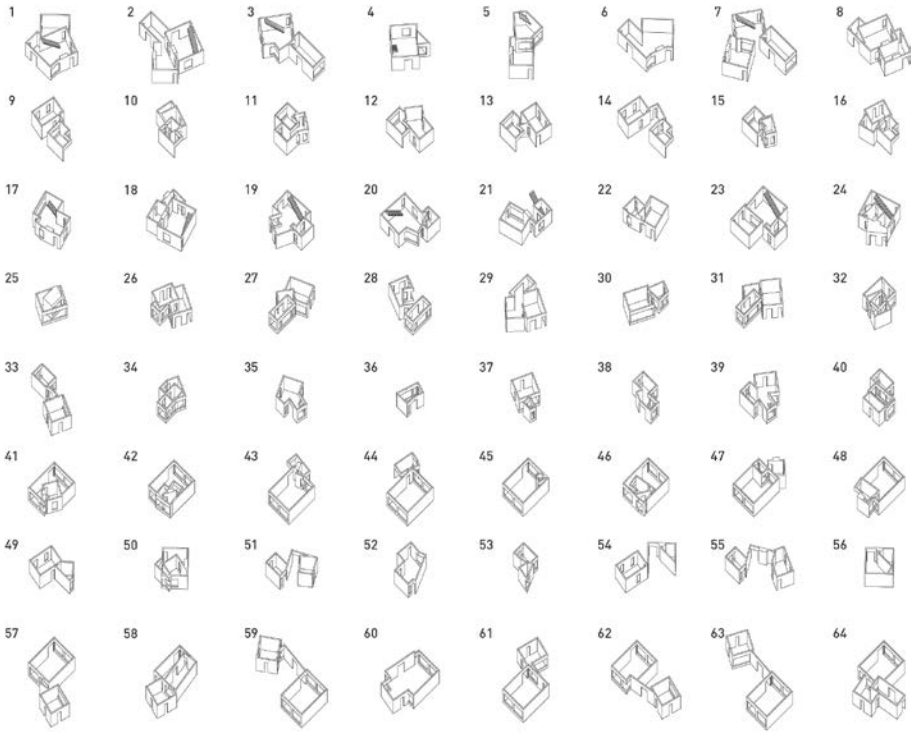

Figure 1. The set of 64 single rooms.

The artificial network was created from a 2D grid of 10 x 10 nodes. Each node had a set of seven parameters representing the parameters the rooms. Initially the value of these parameters was randomized for each node. The first step was to pick randomly one of the single rooms and check one by one all of the nodes in order to find the one whose parameters match the best to the values of the parameters of the room. The node that was selected through this process is called the Best Matching Unit (BMU). Depending on their distance to the BMU the other nodes started to adjust the values of their parameters so that they get close to the ones of the BMU. The process was repeated for all of the single rooms of the initial set until the end of the clustering.

3. Result Analysis and Future Work

The result was clusters of rooms according to the values of the seven user-defined parameters, represented on a map as illustrated in Figure 2.

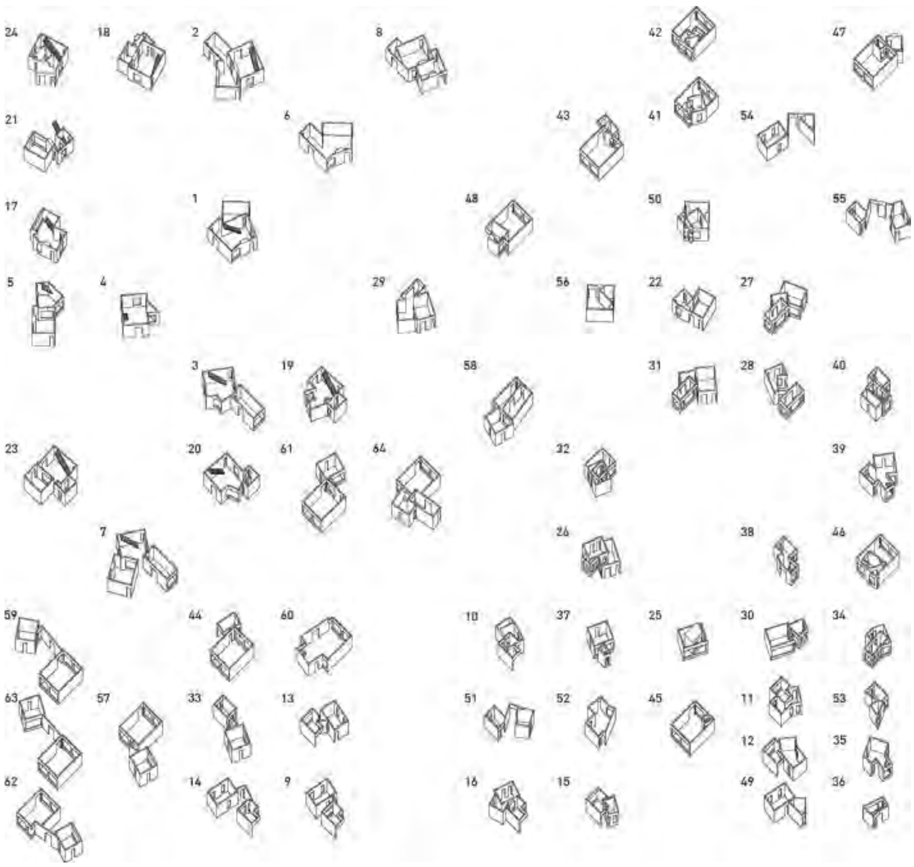

Figure 2. The clustered set of rooms.

During the execution of the algorithm the nodes of the SOM were trained in iterations and adapted themselves to the input.

As the SOM used to cluster the rooms without relating to any traditional reference system it is understood that different kinds of numerical parameters will result in different clusters of the same rooms. At the same time, the fact that the algorithm is absolutely set up by the user, who defines the input data and the values of parameters, induces a new idea of clustering in architecture. In an extended version any database of spatial entities can be clustered according to the specific purposes of the user. Therefore, the user has the possibility to both determine the sample spaces and define the parameters of the clustering process.

It is also crucial to refer to the limitations of the use of SOM. In this quantification process there is uncertainty related to the primacy of numbers when the symbolic dimensions of spaces are analysed. The user should also bear in mind that the quality of the results of the clustering process is sensitive to the input, i.e. sample spaces and numerical parameters. Those two critical points should be investigated in the future.

4. Conclusion

This paper presents the potentials of clustering using user-defined reference systems as an alternative to the classification method using traditional reference systems. The case study where single rooms were clustered according to user-defined parameters using SOM algorithm shows promising results for further implementation of the method in various scales of spatial entities. The results demonstrate how empowering these methods can be proven for the user and the potential for various applications. Future work includes the determination of the uncertainties related to the numerical expression of symbolic dimensions and the sensitivity of the method to the input parameters.

Acknowledgements

The work presented in this paper is part of the author’s Master thesis done for the Master of Advanced Studies in Architecture and Information directed by the Chair of CAAD (Professor Ludger Hovestadt) in the Federal Institute of Technology of Zurich (ETH Zurich).

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ARCHITECTURAL SPACE PLANNING USING PARAMETRIC MODELING

Egyptian National Housing Project

MOHAMED ELSAYED, OSAMA TOLBA, AHMED ELANTABLY
Arab Academy for Science, Technology, & Maritime Transport, Egypt
elsayed80@gmail.com | otolba@aast.edu | ahmed.antably@aast.edu|

Abstract. The Egyptian government resorts to prototype housing for low-income citizens to meet the growing demand of the housing market. The problem with the prototype is that it does not meet specific needs. Consequently, users make modifications to the prototype without professional intervention because of the high cost. This paper discusses an automatic multi-stories space planning tool that helps low-income citizens to modify their prototype housing provided by the government. Social, spatial and functional design aspects were set in the original design prototype by an architect. The proposed tool simulates spaces spatial locations in the original design by simulating the analogy of mechanical springs through an interactive simulation of a parametric model. The authors developed the used algorithm in the generative design tool *Grasshopper* and the live physics engine *Kangaroo*, both working within the *Rhino 3D environment*. The algorithm has two versions, one-floor level version and two floors version targeting the wealthier users. Results indicate that this tool integrates with the exploratory nature of the design process even for non-professional users. The authors designed a tool that will help the users to study the effect of the desired modifications against the originally provided prototype, it also makes it easier for users to express their requirements to a professional designer, conserving time and financial cost.

1. Introduction

The Egyptian government resorts to prototype housing to meet the growing demand of the housing market. In recent years, the government launched the National Housing Project (NHP) for the low-income citizens by providing small land plots and limited financial support for the users to build their homes through a provided prototype designs. The problem with the prototype is that it is inadequate for everyone's needs.

This paper discusses an automatic multi-stories space planning tool that helps low-income citizens to modify their prototype housing provided by the government. Social, spatial and functional design aspects were set in the original design prototype by an architect. The tool introduces an algorithm that simulates the analogy of mechanical springs through an interactive simulation of a parametric model. The role of spring forces is to solve proximity relations between spaces after users' modifications.

This paper is trying to explore some of the undiscovered areas regarding the validity of physically based space planning theories in multi-stories and exploring related design objectives through a design tool used by normal users.

2. Background

The problem of architectural space planning is a *wicked* problem (Rittel & Webber, 1973). The problem is concerned with the allocation of a set of space elements according to certain design criteria (Wong & Chan, 2009). Others describe such problem as an unsolved problem in computer science (NP) (Gero & Kazakov, 1998). To date, there are no known algorithms for this problem (Jun *et al.,* 1998). However, for architectural space planning problem, we may not be looking for an optimal but feasible solution based on varied parameters.

Per Galle had describe an algorithm which generates all possible rectangular plans on modular grids with congruent cells, subject to constraints (Galle, 1981). Another genetic algorithms concept is grouping activities together and optimally placing these groups at the first stage of the computation. At a second stage, the algorithm is optimally placing activities within these groups (Gero & Kazakov, 1998). Another attempt is a design method based on constructing an evolutionary design model borrowed from nature genetic. (Jun *et al.,* 1998).

Weinzapfel and Handel describe an approach to automated space planning in which a design problem consists of a set of spaces and a set of relationships describing constraints on the spaces (1975). Software Environment to Support Early Phases in Building Design (SEED) is addressing architectural programming, schematic layout design, and the generation of a fully three-dimensional configuration of physical building components (Flemming & Woodbury, 1995; Flemming & Chien, 1995). Grason, designed an experimental computer program called GRAPH Manipulating PACKAGE (GRAMPA) (Grason, 1971). Then, Mitchell developed the system by setting rectangular rooms arranged within a simple rectangular overall plan shape (Steadman and Liggett with W. J. Mitchell, 1976). Roth presents a systematic method for the design of a floor plan when given the list of cells data (Roth *et al*., 1982). Later, Roth developed the Rectangular Dimensioned Plan (RDP) model (Roth *et al*., 1985) which Flemming suggest. In 1978, Flemming described a procedure which generates dissections of rectangles into rectangular components which are restricted through topological and dimensional constraints (Flemming, 1978). Later, he developed the system to include loosely rectangles (Flemming, 1986).

Physically-based space planning is a means to automate the conceptual design process by applying the physics of motion to space plan elements. Baraff uses that method to model the realistic behavior of rigid bodies in resting (non-colliding) contact (Baraff, 1989) and building objects by dynamic constraints (Barzel & Barr, 1988).

The current paper is a contraption for Arvin & House work. They applied the mechanical metaphor technique to the generation of architectural floor plans by using the analogy of mechanical springs and dampers to model a variety of design objectives (Arvin & House, 2002).

3. Problem

The Egyptian government launched the NHP to meet the growing demand of the housing market. The low-income users receive land plot with prototype design and direct financial support to build their own homes. The problem with the prototype is the lack of user participation in the design stage. Consequently, the prototype design does not fit into everyone's needs. Users make modifications to the prototype design without professional intervention because of the high cost and limited time allowed for construction. This paper proposes an automatic interactive space-planning tool that helps low-income citizens to modify their prototype design within social and human aspects set in the original design by an architect.

3.1. ORIGINAL DESIGN

The landform in NHP is an almost identical rectangular shape 8.60 m wide and 17.50 m long. The total area is 150.50 m2 and the allowed built up area is 75m2. The unit consists of a staircase, entrance, two bedrooms, terrace, kitchen, bathroom, reception, and dining (***Figure 1***).

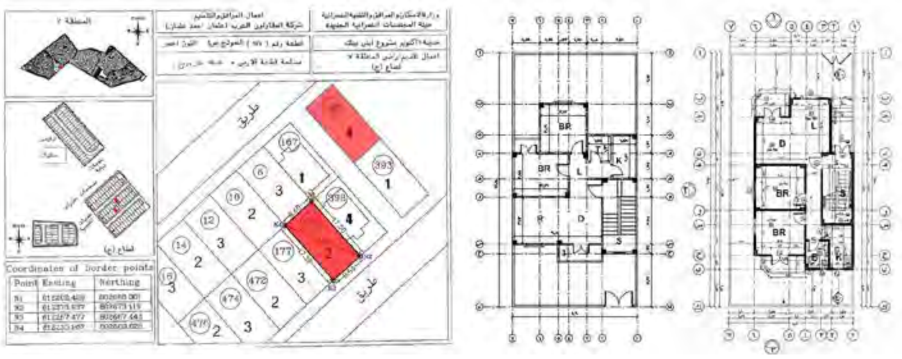

Figure 1. Two prototypes sample: source (6th of October Municipality: NHP).

4. Methodology

The theoretical approach that authors use is the simulation of the analogy of mechanical springs and boxes collision to reorganize and amend architectural spaces proximity.

The authors developed the algorithm in the generative design tool *Grasshopper* and the live physics engine *Kangaroo*, both working within the *Rhino 3D environment*. Users use the spreadsheet interface to set out design parameters. Simulation then goes in two steps. Evaluation messages will help the users to evaluate results. If results are not accepted, users can manipulate design parameters or generate alternatives. There are two versions of the tool for one and two levels.

5. Usability

The usability test aims to evaluate the proposed tool by targeted NHP users. The goal is to identify any usability problem, collect qualitative and quantitative data and assess the participant's satisfaction.

Due to project eligibility terms, all users have almost the same age, marital status (married) and income. Volunteers were randomly selected through an announcement on social network sites and users’ coalitions. The announcement was clearly stating all requirements, conditions and a brief description of the tool.

5.1. INPUTS

The tool interface allows users to control design parameters and provide illustrative tools like coloring spaces, floor area, spaces information chart, and evaluation system. Users can do the following: add or delete spaces, set spaces proximity, set external design objectives, spaces dimensions, each floor setbacks, each floor height, generating alternatives, specify the allowed difference ratio for space dimensions.

The input interface is coded to keep users' modifications within building code. Modifications appear instantly on the software screen as a 3D colored models with dynamic dimensions (***Figure 2***).

Figure 2. User interface

After tool demonstration, Authors asked users to do the following tasks individually in one hour: (1) set spaces names and dimensions; (2) set setbacks; (3) set floor height, spaces dimension tolerance and spaces external orientation; (4) set spaces proximity; (5) start the first simulation; (6) set the second simulation; and (7) check design evaluation part to develop results if needed (***Figure 2***).

5.2. SIMULATION

The simulation goes mainly in two steps. Step one achieves topological objectives which determine how each space relates to another. Step two solves the geometrical objectives which are responsible for the orthogonal aggregation.

5.2.1. Topological design objectives

Users start first simulation step from the interface (***Figure 2:5)***. The first step uses 'spring force' mechanical simulation to solve the space proximity relations which influences the location of individual spaces and affects how one space relates to another. The physics engine *Kangaroo* simulates the spring force physics. It represents the logical relations among spaces as forces that operate on point nodes at the center of each space. It also controls the response to external objectives like street location and preferred orientation. The authors divided the spring forces into groups to achieve the hierarchy in the desired space relations.

The stair is starts in the first level and is represented as a space connected to other spaces. Then, the core is extruded as one mass and the upper part is connected by forces to the spaces on the second level. The core position is thus affected at both levels.

In a hidden step, spaces are simulated as spheres to allow sliding over each other. The sphere size depends on the desired space volume by set users (***Figure 3:a and b)***. The resulting spheres from the first simulation are converted into boxes based on each sphere volume and center ***(Figure 3 :c).***

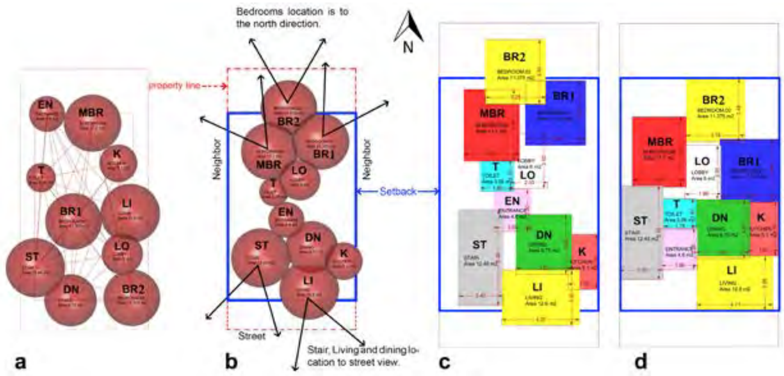

Figure 3. The simulation process: a) The initial position of spaces showing volumes and springs action directions. b) Spaces behavior under spring forces. c) First simulation result. d) Second simulation result.

5.2.2. Geometrical Design Objectives

When the system stabilizes, users can start the second simulation step from the interface ***(Figure 2:6)***. The second step uses ‘box-collide force’ simulation by another *Kangaroo* engine to solve the orthogonal aggregation for these 3D masses which influences dimensions and volume of space boundaries. The concept behind this step is using the analogy of masses collision to fill the in-between gaps by adopting both dimensions and volume of masses depending on the collision strength and setting to achieve the most possible compacted shape. The result of step two is orthogonal compacted spaces ***(Figure 3:d)***.

5.3. EVALUATION AND ALTERNATIVES

After step two is completed, users use the design evaluation section in the interface to help in evaluating the resulting solution ***(Figure 2:7)***. If the solution is accepted, users end the process and print the solution. If not, users can manipulate inputs and redo the process or else generate another alternative because results are affected by the spaces initial position. Randomizing space arrangement before simulation generates a new solution every time ***(Figure 2:3)***.

The evaluation system evaluates both spaces proximity relations and the allowed space dimension tolerance through interactive messages. If users try to run an inappropriate simulation step, the system will send warning messages to guide them.

6. Results and Discussion

The majority of users were interested in adding one more room in both versions. More than half of the users reach a complete solution ***(Figure 4:a and i)*** or complete solutions with comments such as wet areas without natural ventilation ***(Figure 4:b and h)***.

Some spaces were not logically placed or not accessible ***(Figure 4: c, d, e and g).*** Other spaces were deformed due to the conflict between required spaces dimensions and logical relations ***(Figure 4:f and c).*** In some results, solutions were loose and not compacted in setback because of inappropriate results from step one ***(Figure 4:b, c, d and f).*** Switching width and length were useful in improving solutions that require elongation (for example see the kitchen in) ***(Figure 4:c).***

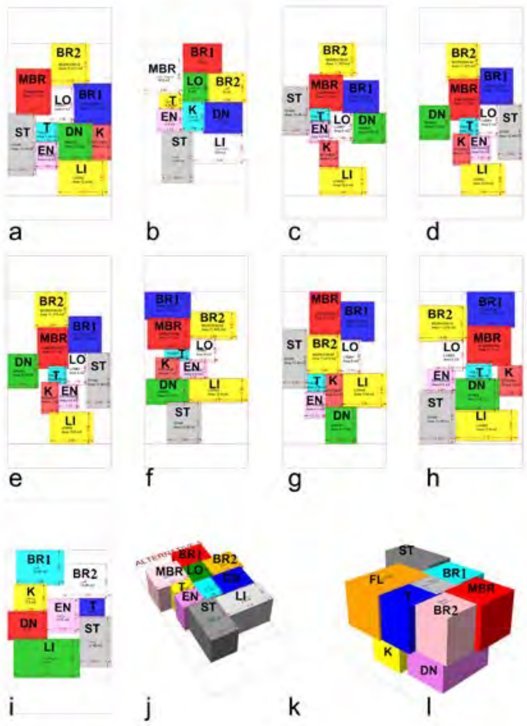

Figure 4. The results samples.

NHP users show a high technical level in construction and good architectural background. The most raised question from users about typical floors is the coordination between the existing structural columns in the ground floor and the new design in typical floors. The on-screen interactive results and 3D dynamic spaces are widely acclaimed by users.

Users feel confused while setting spaces proximity and determining spaces hierarchy, they mostly use the first-degree relation only. Another technical problem is understanding the need for transitional spaces. For instance, entrance in the original design act as a lobby for the two bedrooms ***Figure 1***, but when some users add an extra room that will require a new lobby as a transitional space to access rooms.

Users' survey show that The tool is easy to learn and easy to use. Learning curve increases after repeated usage. Users commented on the evaluation messages 'it's useful to determine the problem, but it is not suggestion a solution'. Users find the final product is much better than traditional architectural drawings *Table 1*.

Table 1. User survey

#	Item	Completely disagree						Completely Agree
		1	2	3	4	5	6	7
1	Tool demonstration was adequate.	■	■	■				
2	It's easy to learn how to use the tool.	■	■	■	■	■	■	
3	I am easily able to perform the required tasks.	■	■	■	■	■		
4	UI convenient and easy to use.	■	■	■	■	■	■	■
6	I totally understand all UI components.	■	■	■	■			
7	I need help in the first time I use the tool.	■	■	■	■	■	■	■
8	I can deal with all raised problems.	■	■	■	■			
9	Evaluation system is helpful.	■	■	■				
10	Tool has all I need to modify my unit design.	■	■	■	■			
11	The tool is sufficient for the initial concept.	■	■	■	■			
12	Final product presentation is better than traditional.	■	■	■	■	■	■	■
13	I am satisfied with the final product.	■	■	■	■			
14	In general, I am satisfied with the tool.	■	■	■	■	■		

7. Conclusion

According to users, the tool is easy to use and functionally working, but they find problems with the final product and design process. The users can take direct design decisions, but cannot take design advanced decisions or setting spaces proximity to achieve relations hierarchy. Normal users get a deeper understanding of the design process and the conflicting nature of design objectives without engaging in the underlying system. The proposed tool is not replacing the architect but helping users to assess the impact of their proposed modifications conserving time and financial cost.

The current paper showed that the physically-based space planning approach is working with multi-level design. The authors explored a new design objective as a result of multi-levels which is the attraction to the vertical core.

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EVOLUTIONARY SOLAR ARCHITECTURE

Generative Solar Design Through Soft Forms and Rigid Logics

LOGAN ARMSTRONG, GUY GARDNER, CHRISTINA JAMES
University of Calgary, Calgary AB
logan.d.armstrong@gmail.com | *gegardner@hotmail.com* |
chrissy-j@live.com

Abstract. This paper describes the development of a workflow for the production of a net zero off-grid research cabin. The workflow deploys a number of affiliated parametric software packages as a form finding tool for the exterior envelope of this structure, with a focus on passive solar design as a generative formal driver. The design was required to incorporate the spatial and programmatic needs of the users in a compact, barrier free, net zero building. Simultaneously, the research question asked the designers to harness the potential of digital design in the consideration of future fabrication techniques, in order to optimize the building's performance and the speed and quality of assembly once the project moves into construction. Parameters considered include solar exposure, external surface area, cost, fabrication, functionality, and aesthetic criteria. This project was developed by a multidisciplinary team of graduate students at the University of Calgary.

1. Introduction

Computational tools allow designers to model and simulate the effects of macro scale formal exploration and micro scale component/detail articulation throughout the design process. Within this system of design, there are a range of potential design outcomes. There are soft parameters, capable of shifting and evolving, as well as rigid constraints and solutions. A flexible approach to the softly articulated formal aspects of the design allows balance between the various objectives of the project and iterations between multiple potential solutions. Flexibility in the approach to the overall envelope allows for the negotiation of generative drivers that exert influence on this form. This paper will focus mostly on this area of the research as, at this stage, it is the primary concern. Simultaneously, the research question asked the designers to harness the potential of digital design in the consideration of future fabrication techniques, in order to optimize the speed and quality of assembly, as well as post-construction performance.

The proposed project site is the home base for local and international researchers conducting studies of a fundamental and applied nature. The project team was given the opportunity to design a new structure to replace the deteriorating accommodations currently on site. Using passive solar design techniques as the generative driver, the proposed design for the new facility is a modern, sustainable, and multifunctional space. The design was required to incorporate the spatial and programmatic requirements of the users in a compact, barrier free, net zero building. Budget, construction techniques and site constraints were all important parameters in the development of the overall formal strategy.

2. Existing Work and Problem

In order to open the design to new possibilities, the design team employed a generative system that required "the computational specification of the principles of the formation of a design (artifact), which open[ed] up a design space for the exploration of design alternatives and variations" (DİNO 2012). This generative system was situated on a continuum between two differing modes of architectural conception. At one end of the continuum is soft form, produced through a design methodology marked by vagueness and indeterminacy, where the parameters controlling output are easily manipulated towards a specific end.

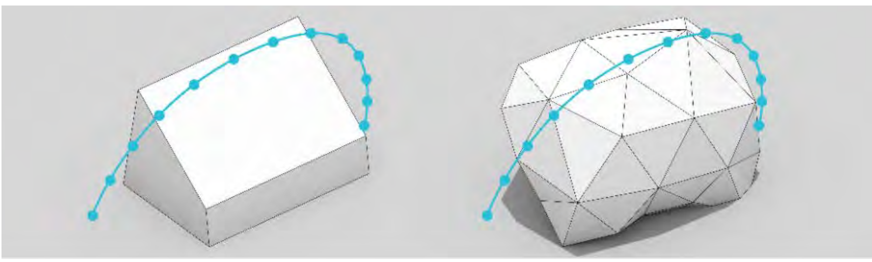

Figure 1. Soft vs. Rigid Form.

The fluid nature of this type of design process lends itself to the creation of speculative projects, such as Greg Lynn's Embryological house, where a "rigorous system of geometrical limits liberates an exfoliation of endless variations" (Rocker 2006). At the opposite end of the continuum is a rigid design process where the final form is a direct result of specific criteria and distinct parameter ranges that constrain variation (Figure 1).

The design of buildings that make use of active and passive solar energy collection lends itself to computational logics that result in rigid form, with optimized energy performance being the primary design objective. An example of this includes the Endesa Pavilion, a rigidly articulated form created by the IAAC, in which a specific, strict set of constraints were driven through computational design tools to create a “wooden solar-tracking facade system... based on parametric modeling and digital fabrication” (Markopoulou and Rubio 2013). Other solar design work is being done to employ computational methods to drive more efficient solar designs, as shown in the work of Luisa Caldas. Caldas investigates the role of evolution-based generative design in creating sustainable and energy efficient architectural solutions (Caldas and Norford 2003; Caldas 2008). The results of Caldas’ work are architectural forms that are energy efficient compositions of highly rigid truncated and full rectangular forms. Recognizing this, Caldas and Norford identify that there is a need for “incorporating dynamic constraints into the system, so that an extra degree of flexibility is added” (2003).

Building from Caldas’ body of work, this project attempts to establish a workflow that incorporates softness and adaptability as dynamic constraints to add flexibility, culminating in the development of a computationally generated yet rigidly articulated form which is responsive to site, climate and program. The resulting workflow engages optimized solar design principles as formal drivers within a computational process geared towards the production of soft form. This workflow acknowledges the solar, aesthetic and functional performance of the architecture simultaneously, allowing for the production of a highly variable formal set that can be evaluated against these criteria. The final form integrates solar optimized geometry, the required spatial criteria, and the aesthetic and programmatic decisions developed by the design team.

The workflow outlined in this paper relies on the methods for introducing temporality and vagueness as described by Greg Lynn in his essay “Animate Form”. The workflow takes advantage of field conditions and point charges to produce soft, or indeterminate geometry, incorporating elements of “force, motion and time” which Lynn describes as traditionally excluded from discussions of architectural form due to their “vague essence” (2004). This project incorporates aspects of the design model proposed in Animate Form. In this case, the elements of “force, motion and time”, which animate the project and produce variation and multiple potential iterations, are the various fitness criteria and design parameters.

In 2003, Branko Kolarevic described a process called “Performative Morphogenesis”. This approach posits an integrated workflow in which “low resolution” performance simulation occurs dynamically at the conceptual design stage, allowing the building form to be shaped by analytic computational tools (Kolarevic 2003). Until recently, the use of simulation and performance optimization tools were limited to highly specialized consultants, and typically took place after the building was designed. Today, with the evolution of parametric design platforms such as Grasshopper to include multi-objective optimization and environmental simulation plugins, this process is readily available for designers and can be implemented to augment the conceptual design workflow.

In the design of the research cabin, a multi-objective evolutionary solver was deployed both as a tool for optimization as well as a form-finding aid, along the lines of Malkawi *et al.*'s discussion of evolutionary-based generative processes: “The advantage of such an evolutionary approach is the creation of diverse sections of the state space that meet performance targets and increase the possibility for discovering a variety of potential solutions” (2003).

This work differs from existing work in the field through its use of animate form, a fluid and indeterminate formal system, to create a matrix of possible geometries, then driving these forms through a series of rigid requirements (in this case, solar optimization), followed by the constant refinement of these forms towards a more rigid end.

3. Investigation

The techniques employed in this workflow (Figure 2) exploit plugins designed for Grasshopper3D, a parametric extension of 3D modelling software Rhinoceros 3D. These plugins include Cocoon, an isosurface meshing tool developed by David Stasiuk; Octopus, a multi-objective evolutionary solver developed by Robert Vierlinger at the University of Applied Arts Vienna with Bollinger+Grohmann Engineers; and an environmental analysis plugin developed by Mostapha Sadeghipour Roudsari called Ladybug. The integration of multiple digital tools allows for a workflow in which a low-resolution building model is able to morph between soft forms, based on point charges and field conditions, and an environmentally optimized form, based on hard geometric constraints.

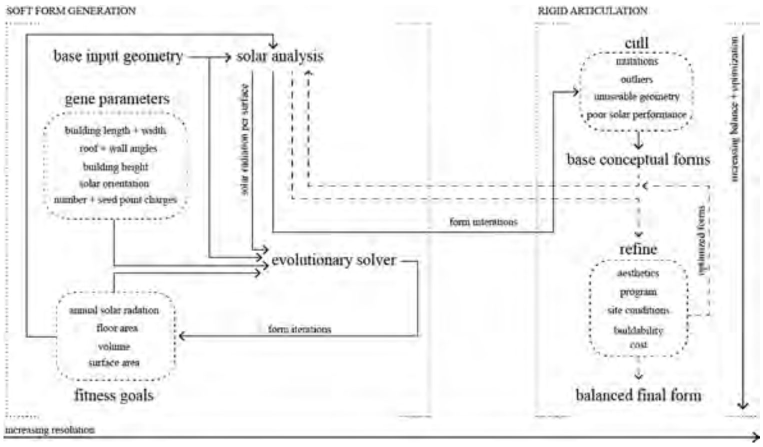

Figure 2. Hybrid workflow diagram.

An optimal range of values based on passive solar design principles was established for length, width, roof/wall tilt angle, orientation towards south, and the floor area of the building (Figure 3). These ranges were input as number sliders into Grasshopper to create a simple, shed-like form which could then be parametrically adjusted.

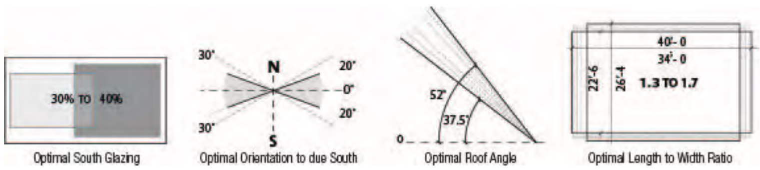

Figure 3. Solar design principles.

This rigid geometry was then populated with randomly seeded points, which were given a variable charge (Figure 4). The resulting field condition was meshed to create a soft form, which was then tested using Ladybug to determine the total annual solar radiation falling on the surfaces.

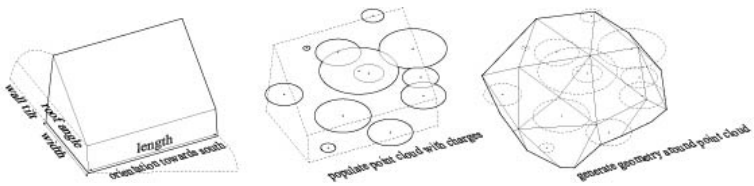

Figure 4. Process of parametricizing base geometry.

The final stage input the objectives and genome into the evolutionary solver. The advantage of using Octopus as the evolutionary solver is that it can compare multiple objectives at once to find the most balanced solution between them. The chosen objectives were the floor area, surface area, volume and total annual solar radiation. The gene inputs were the building length, width, height, roof/wall tilt angles, orientation from south, and the number and seed of the point charges generating the soft form.

As the evolutionary algorithm ran, it continually iterated through variations of form (Figure 5). The response of each iteration to the drivers varied, from the optimization of a single parameter at the expense of others, to a best-fit balancing of all input parameters. The algorithm was allowed to run for ten generations, after which time the variation was limited to a narrow band of optimized values.

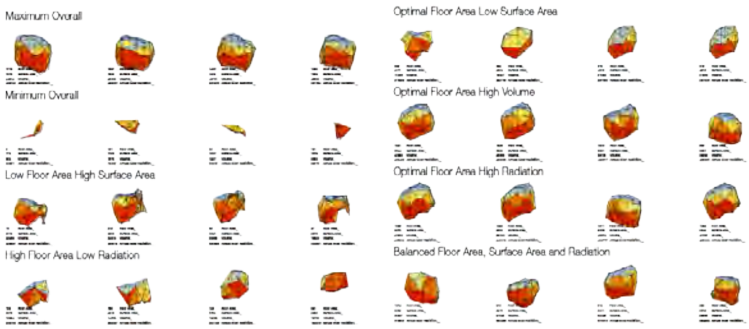

Figure 5. Evolutionary solver form matrix.

The Octopus interface charted the range of potential forms on a 4D graph (Figure 6). This allowed the designers to quickly sort through the hundreds of generated forms, investigating clusters which had developed similar "mutations," eliminating outliers and unusable variations and finding areas where objectives were balanced within optimal "sweet spots."

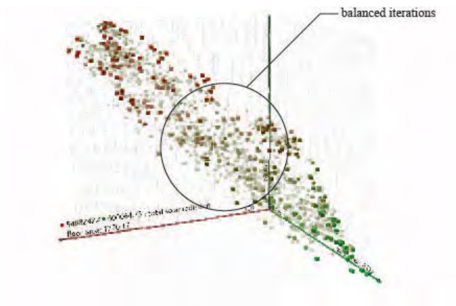

Figure 6. Evolutionary solver 4D graph.

The resulting forms were selected and culled to a matrix of optimized forms with potential for further development (Figure 7). The metrics of material and labor efficiency, assembly, ease of construction, and overall budget became considerations as the form was edited based on the formal, aesthetic and programmatic preferences of the design team in response to site conditions and physical limits, such as maximum height and floor area.

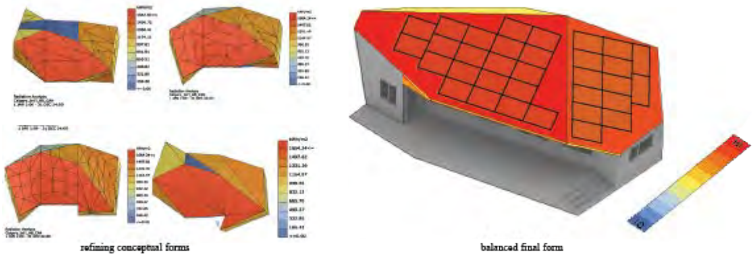

Figure 7. Solar analysis and refining forms

The geometry of the form was refined within these limits to suit the predetermined program requirements. An entry vestibule and a roof overhang were added to protect against excessive glare and solar gain in the summer. The final, edited form was then re-evaluated to analyze its solar performance. The form selected from this secondary workflow was the one that best met the performative criteria for function, solar energy production, buildability and aesthetics, and provided a conceptual model for further design development.

4. Results and Discussion

The workflow presented provides the designer with an opportunity to define a set of soft parameters and a range within which a number of potential solutions can exist. The designer's role involves selecting between various iterations of emergent soft form and subsequent editing towards a more rigid form. The result is a building envelope whose geometry is optimized for the collection of solar energy, while also balancing the optimal ratios for passive solar heating and floor area demanded by the cabin's program. This form provides a model for further testing and refinement.

The form is optimized for solar collection across its southern faces through surface area, orientation, and tilt angle. This provides an opportunity to embed a building integrated photovoltaic [BIPV] system (Figure 8) which is advantageous from budgetary, environmental, and aesthetic standpoints. As demonstrated in Figure 9, a BIPV system has the potential to provide an estimated 8,092 kWh of electricity per annum. The division of one southern face into an easterly and a westerly face, a result of mutation within the form finding process, further increases overall solar optimization, providing a higher daily and yearly consistency of generation. This analysis demonstrates that a workflow which allows for indeterminacy can generate positive results which could otherwise be overlooked in a prescriptive design process.

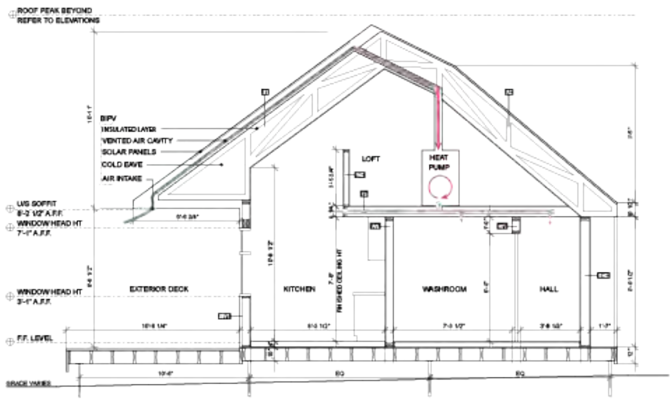

Figure 8. Cross section through BIPV system

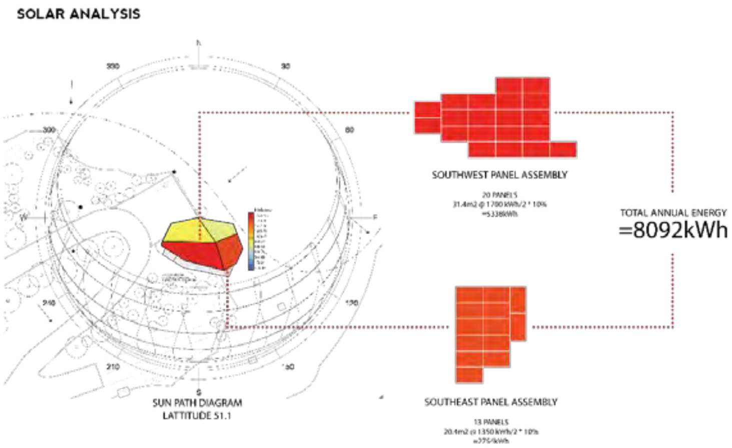

Figure 9. Final form in situ solar/electrical analysis

Inserting floor area and building volume into the workflow as design parameters establishes the overarching programmatic and functional aspects of the design as drivers of the soft form iterations, and provides a functional result. Selective culling of forms ensures an appropriate volume and floor space, allowing for a plan capable of meeting the internal barrier-free requirements, hosting the required number of personnel, and meeting the need for occupant comfort (Figure 10). The optimized envelope provides a unique geometry that, when expressed on the interior, creates an engaging atmosphere.

Editing and refining the form is also paramount to maximizing its balance and efficiency for prefabrication, transportability and budgetary requirements. Through a rigorous editing and evaluation process, complex geometries can be simplified to a more rigidly articulated form without loss of performance or the essence of the soft form that produced it. The amount of editing and simplification can vary greatly across projects, depending on a variety of factors including construction costs, techniques, and overall buildability.

While the workflow was successful in the production of a unique envelope, optimized for a high degree of solar efficiency, opportunities remain for the development of a more robust process. The workflow, with the employment of Octopus as the evolutionary solver, has the potential to include a greater degree of analysis within the generation of soft formal iterations for refinement, including structural analysis and a more robust modelling of site conditions that contribute to the overall solar performance of the project. Additionally, the evolutionary solver does not account for building details that are heavily influenced by the changing form of the project, such as wall/roof connections.

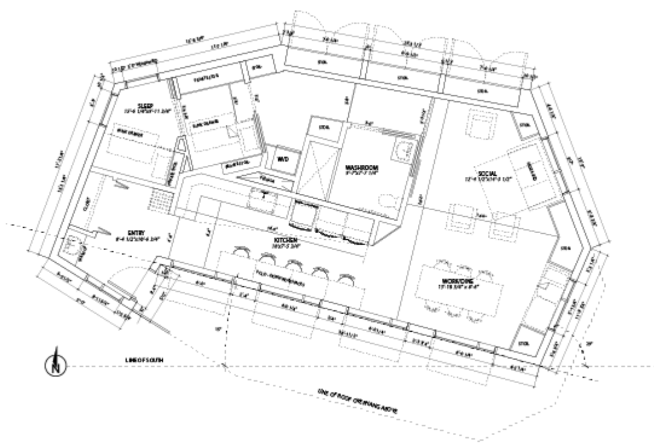

Figure 10. Floor Plan

5. Conclusion

The project provides an originating point for several discrete branches of research, including the potential for future post-occupancy research into the behavioral and energy performance of the built form, and comparative analyses of cost data between the outputs of this project’s workflow and more traditional methods of solar optimized design. In addition, opportunities for refining the developed workflow exist. These range from more accurately calculating the effects of site context and shading within the solar analysis of the generated forms, to the definition of building details that necessarily need to adapt with each formal iteration, to the inclusion of further analytic potentials such as the structural efficiency of each formal output. This increased analytic potential programs a greater degree of performance optimization into the conceptual design of the project, further exploring the potentials of computational generation outlined by Kolarevic (2003) and expanding the range of virtual forces that can contribute to the formal generation of the project (Lynn 2004).

Further research in this area would need to examine construction processes for comparative analysis between projected and actual data, investigating whether construction optimization was achieved through the current iteration of the workflow and developing strategies for improvement based on these findings. In addition, the workflow needs to be further refined in order to relate more directly to questions of buildability, including differences in materiality, structural performance and efficiency of construction. The current workflow is successful at the creation of soft forms containing embedded rigid logics, but the rigid logics contained in these forms are currently limited to energy efficiency and solar optimization. There remain opportunities for the inclusion of more generative criteria in the early stages of the workflow, programming further information into the form itself as opposed to manually editing the resulting form to consider such criteria.

Acknowledgements

We would like to thank Jason S. Johnson for the opportunity to complete this research and his valuable comments, as well as the University of Calgary.

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AN INVESTIGATION ON GROWTH BEHAVIOUR OF MYCELIUM IN A FABRIC FORMWORK

GULAY ELBASDI AND SEMA ALAÇAM
Istanbul Technical University, Istanbul, Turkey
elbasdi@itu.edu.tr | alacams@itu.edu.tr

Abstract. Most progress in designing mycelium-based material to date has been made by using petri dish and 3d printed geometries. In this study, reshaping capabilities of mycelium-based materials using fabric formwork is being discussed. This ongoing study is the result of a series of experiments about mycelium-based material that aims to investigate its potentials as free- form geometry. In this paper, we aim to make a comparison between initial and end shapes by implementing digital and analogue tools based on mycelium-based fabric formwork experiment. The physical experiment setup consists of different initial geometry alternatives and the deformation will be observed and measured numerically by time-based recording on top and section views. With the help of digital tools, experiments will be documented as a process of formation. We aim to discuss the potential of the usage of mycelium as a binding agent in free form geometry since mycelium acts as natural self-assembling glue. By doing so, structural potentials of the material, which is strengthened by mycelium hyphae, were examined. This study aims to contribute to the design research studies and scientific knowledge together to integrate living systems into the material design as encouraging collaborative interdisciplinary research, thereby positioning designer as a decision-maker from the very beginning of material design process.

1. Introduction

The introduction of experimental research into the discipline of architecture also shifts the nature of physical workspace. Nowadays, architects are engaged in experimental tasks such as to prototyping, simulating and testing in design process (Ng, 2013). Acknowledging the recent interest of architects in the design and the customization of material composites, Picon (2010) questions, “Should designers themselves invest in material design instead of relying on the research of others?” In recent years, this question raised by Picon in 2010 is being answered by the uptrends in material design studies conducted by artists, designers and architects.

It is possible to claim that Biology has higher impact on design research and material technology than other sciences. In particular, nature inspired design (NID) has generally been deemed as the state of art in the field of design research. However, NID is usually associated with mimicking the nature in a phenomenological manner, which leads to a reductive interpretation of nature in behavioral manner.

According to Collet (2013), “Hierarchy of possible relationships with nature, and designers are grouped around 5 themes.” The first group, The Plagiarists, lean on nature for inspiration and new solutions. Similar to nature inspired design, they work with biomimicry principles, imitating process or behavior found in the natural world, but working with man-made and digital technologies. The approach of the second group, The New Artisans, takes nature as collaborator. They are working with bees, fungi, bacteria, algae or plants and developing new techniques to grow and craft consumer goods. Collet (2013) describes such relationship similar to gardening and farming. Third group, The Bio-Hackers, try to envisage how the products and interfaces evolve to be by using engineered living organisms in the future. They collaborate with synthetic biologists. The designers among the Bio-Hackers integrate Computer Aided Design (CAD) and digital fabrication technologies and they seek embedding mycelium into their processes. Fourth, to create hybrid environment and organisms; the New Alchemists are designers, architects and artists who explore the merging of biology, chemistry, robotics and nanotechnology. Last, The Agent-Provocateurs explores a provocative far future and encourages a debate around ethical issues related to living technology and high-tech sustainability.

There are several reasons why bio-based materials become widespread. First, opportunities to reach the material easily and cheaply. Second, potentials to be modelled by dynamic computational approaches. Within the domain of bio-based materials, composites with ductile matrix and high-strength reinforcement give the opportunity to design a material for a particular use at low cost (Mallick, 2008). What we call bio-based material is herein defined as: “a material of which one or more of its components are sustainably grown and are fully renewable”. Latest studies in bio-based material design depict that the vegetative part of a fungus consisting of a network of fine white filaments, the mycelium, could be an alternative for these matrices.

However, the existing uses of mycelium-based materials as well as physical and digital modelling of fabric formworks, mostly obtained from academic literature and artists’ works. Moreover, there is an inspiration coming from synthetic biology (synbio) which could be an avant-garde collaborator to art, architecture and design. Current researches at the intersection of synbio and design have shifted interdisciplinary collaborations and brought synthetic biologists and designers together in order to construct new biological parts, materials, and systems.

Analyzing the integral relationship between the design of the fabric formwork and emerging mycelium geometries structures the core of this study by exposing a latent relation between material design and biological design. Furthermore, this paper presents a case study which aims to understand shaping capabilities of mycelium-based materials by using form-finding techniques and experimenting with fabric formwork in order to be able to create re-shapeable products.

2. Related Works on Mycelium and Fabric Forming Studies

Apart from the above, there are artists and designers who are carrying on their living matter-integrated studies on their own.

As the field of designing bio-based materials is becoming a wide research area that Lelivelt *et al*., (2015), a group of researchers from Structural Design unit of Eindhoven University of Technology, published a research work on 'the production process compressing strength of mycelium based materials'. It is possible to claim that their study is based on the experience of microbiologists, designers and local spawn producers. According to Lelivelt *et al*., (2015), the process to create mycelium based materials consists of six steps which are shown in Figure 3.7. The first four steps are needed to be followed to cultivate mycelium and the last two are to make the mycelium a material. Substrate could be straw, coffee ground, hemp and sawdust. Due to the attribute that fungi is able to digest cellulose into glucose while other organisms cannot, cellulose-rich environment is preferred when growing fungi to avoid contamination by other organisms (Wösten, 2014). One of the advantages of using cellulose-rich environment is that at the molecular level, many natural fibers and wood-like materials are a composite of rigid-high strength cellulose embedded in a lignin matrix, so high cellulose content predicts high tensile strength (Faruk, *et al*., 2012) (Satyanarayana, Arizaga and Wypych 2009). A high tensile strength expects a high mechanical performance of the composite as the substrate reinforces the material (Mallick 2008).

In the experiments, spores of mycelium – spawn- were inoculated into sawdust which was composed of nutritional substrate, cellulose. During the growth, they condensed and dehydrated the substrate until they colonize fully in the mold. It should be noted that those experiments were not held in a very well-controlled and sterilized lab environment, therefore the process and the results might have been affected by other known and unknown factors as well.

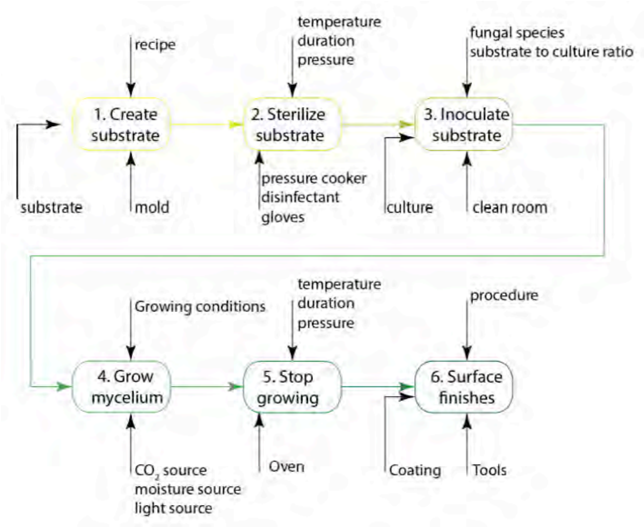

Figure 1. Schema of mycelium-based material production process (Lelivelt *et al*., 2015).

3. Case Study: Computability of Mycelium-based Material Through Physical Form Finding

3.1. EXPERIMENT SET-UP AND CONSTRAINTS

Materialization of mycelium takes time since mycelia need to grow on substrate, so the overall process takes considerable time. Mycelium mixture is mainly composed of substrate and mycelia spawn. In this study, sawdust was used as substrate material.

To use flexible formwork for physical form finding obligates designer to cope with constructional constraints of formwork and deformation at the flexible parts of the formwork after loading the material. Therefore, physical models are subject to constraints such as geometry of the formwork and properties of the materials that are used to build the formwork.

To compare initial - final and predicted – unpredicted forms that are derived from physical experiment, a form-active membrane that can be manipulated by the designer in digital medium is needed to be developed. To create a computational model in digital environment that depicts exact behavior of analogue model is still an uncharted issue.

TABLE 1. The flow chart for applying MbM in the fabric formwork.

Designing formwork structure in digital medium
Assembling the fabric formwork: Developing fabric mold + building framework
Preparing mycelium mixture
Casting: pouring mycelium mixture into fabric mold
Waiting for mycelium growth in mold
Unmolding: removing the fabric mold
Baking
Testing structural qualities of final product

3.3. EXPERIMENTATION

We started our experiment with a set-up which has two different tension conditions and observed the material and growth of mycelium for one week. In the first experiment; form-finding based on material properties and behavior is aimed to be investigated. To observe the behavior of MbM in fabric formwork, a set of adjustable mold, which is composed of two free hanging fabrics, was designed. In addition, the author can manipulate the boundary conditions of the fabric, which means that the author can decide at which locations of the fabric is supported and in what directions these supports are fixed. In other words, the designer wishes to determine the final, resulting shape from elastic deformation (Veenendaal and Block, 2012). The anticipated form-finding situations after the adjustments of the author on the support heights are presented in Figure 2.

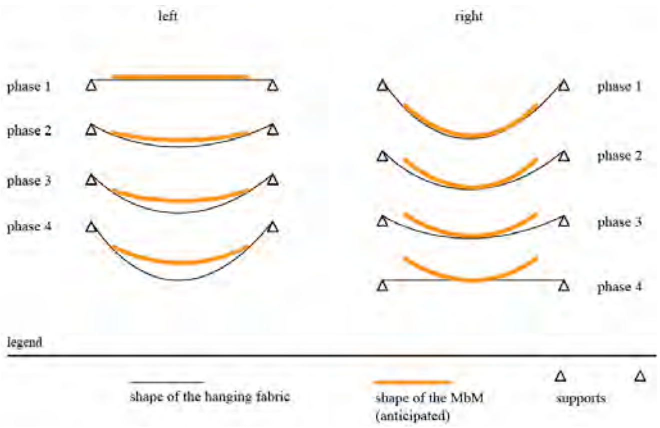

Figure 2. Graphical representation of physical form finding and anticipated form that MbM could take.

The first free-hanging fabric is respectively stretched from the horizontal supports and it is gradually released from the supports (Figure 3). The second free-hanging fabric is draped from the horizontal supports at first and it is gradually released from there. In both situations, mycelium mixture is placed onto the single layer of fabric, and correspondingly, the fabric deforms with the additional load. As the time passes by, in right conditions, mycelia start to grow and expand its network. As more mycelia grow, the material gets harder. This emergent behavior of mycelia is similar to the process during which plaster solidifies through dehydration.

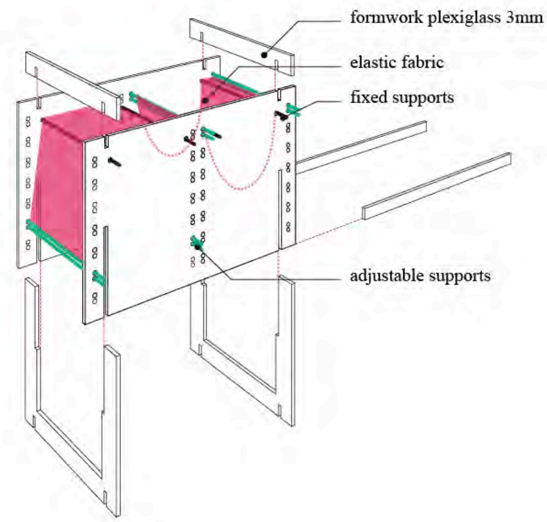

Figure 3. *Free hanging fabric formwork set up.*

By observing the material behavior in the first experiment (Figure 4), we came up with the idea that MbM can act as a re-shapeable material thanks to its living matter ingredient, the mycelia.

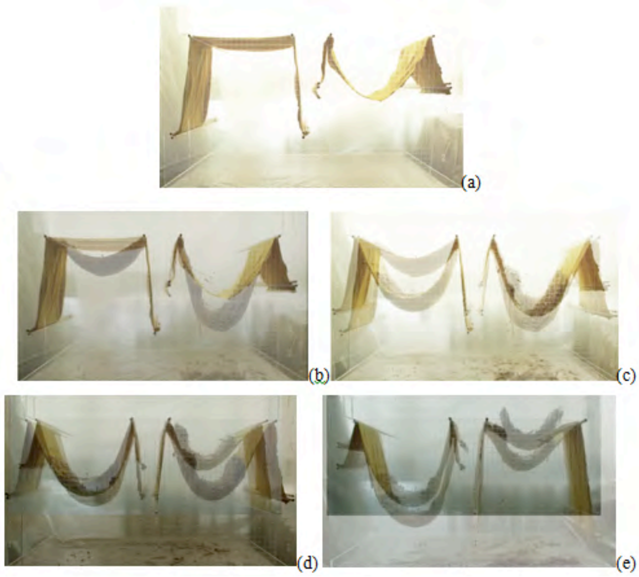

Figure 4. Form finding situations in five phase: (a) initial phase of free hanging fabrics, (b) superposition of initial phase and first phase –form after loading MbM, (c) superposition of second phase and first phase, (d) superposition of third phase and second phase, (e) superposition of third phase and fourth phase.

Next, a set of casting experiment is prepared as an adjustable mold which designer cannot manipulate its boundary conditions from the edges but the surface of the fabric itself. To do this, a point set-up which has individual probes that can be detachable. The experiment executed to experiment becoming of MbM fabric formwork was pre-stressed through the combination of mechanical pre-stress of the fabric (in-plane) and MbM pressure (normal-to-plane). The general sequence of this method is as follows: A piece of fabric is homogeneously stretched over laser-cut plexiglass and wooden probes which are placed vertically (Figure 5). Then, mycelium mixture is placed onto the fabric (Figure 6). The fabric deforms with the additional load. Since we have the knowledge of as more mycelia grow, the material gets hardened day by day. Once the first mycelia pattern get visible, two of the probes are detached each day and the fabric is weakens at those points which results in unpredictable displacement of MbM in section view. This displacement curve of the material which is recorded by camera will display the limits of the material dependent on time constraint.

It should be noted that those experiments were not held in a very well-controlled and sterilized lab environment, therefore the process and the results might have been affected by other known and unknown factors as well.

TABLE 2. Materials used in the experiment.

Material of the shell	**Form-active structure**	**Form-active typology**	**Way to stabilize the mold**	**Technique to handle the rigidizing material**	**Reinforcement**
Mycelium spawn (infected wheat grains), sawdust	Stretchy panty fabric	single layer	Stretched later on overstressed	casting	sawdust

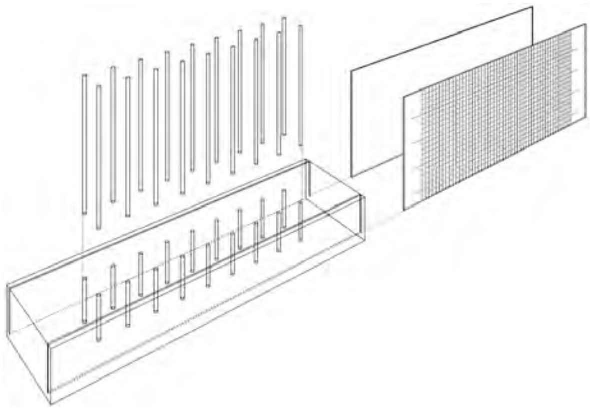

Figure 5. Point model set up.

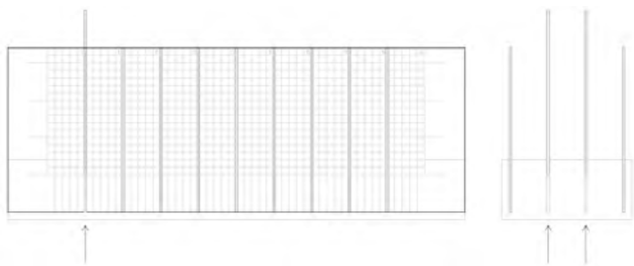

Figure 6. Point model set up section view.

4. Outcomes and Discussion

Methods that have been applied to actualize a form are usually experienced at the end of a design process. However, the study aims to obtain inter-relation between analog and digital design techniques through experimentation in order to examine form-taking potentials of the material.

This aim was obtained through design by research approach which was led the author to focus on the process of materialization and formation rather than resulting shape. In addition, another aim was to understand whether the emergence of forms can be foreseen while working with living materials by applying analogue and digital form-finding methods. In this case, the becoming of form cannot be anticipated and digitalized in a perfect sense without working with materials.

For future work, physical testing of the final shape which was achieved by experimentation and applying Finite Element Analysis methods to digital model are can be the next step of this study.

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COMPUTATIONAL WEAVING GRAMMAR OF TRADITIONAL WOVEN PATTERN

FAJAR I. HARNOMO AND ASWIN INDRAPRASTHA
School of Architecture, Planning, and Policy Development,
Institut Teknologi Bandung, Indonesia
fajarharnomo@gmail.com | aswin@itb.ac.id

Abstract. Weaving technique is one of the indigenous craftsmanship practices that are common in most of ethnic groups in Indonesia. Generally, it uses thin strips of organic material such as bamboo or rattan to make plane of surface that further can be developed into daily utensils or as a traditional architectural building components such as partition wall and floor. The research of weaving grammar as a system and process had been introduced and explored using Shape Grammar theory and principles. Having the potential implementation and to preserve the traditional weaving method, the grammar can be explored as a method of exploration in architectural design by extending the computation method based on the visual embedding of its pattern languages. The aim of the study is to discover the geometrical configuration underlied traditional weaving grammar by reconfiguring and elaborating procedures and further develop generative method using computational approach. We focused on the exploration of single and dual patterns of biaxial types of West Java woven pattern by using shape grammar principles. The result shows computational method is constructed by several rules which are defined as generative procedure. The result advised that traditional woven pattern has similarity according to its ruled-based system of generative algorithm.
Keywords: Weaving Grammar, Traditional Woven Pattern, Shape Grammar, Generative Methods.

1. Introduction

Woven is one of the culture products that has wide range of implementation from decorative arts, toys, daily utensils and building components. The basic form of traditional weaving can be found anywhere among different ethnic groups in Indonesia with relatively similar technique being used (Griffen, 2000). Basically, it uses thin strips of elastic and natural material such as

Bamboo *(Bambusa),* Rattan *(Calameae),* Coconut leaf *(Cocos nucifera)* and also Pandan leaf *(Pandanus amaryllifolius)*. It can be developed into daily utensils or as a traditional architectural building component. (Frick, 1997, 2004; Dunkelberg, 1985).

As a product, woven is defined as a rule-based interlacing of parallel or perpendicular between two or more stripes or bands (Garha, 2001). The interweaving structure is divided into three systems of axis, biaxial structure, tri-axial structure and multi-directional structure (Anandhita, 2014; Tocharman, 2009). According to that context, the woven is a system that has input of materials, rule-based processes and also output (product). The research of weaving grammar as a system and process had been introduced and explored using Shape Grammar theory and principles.

The aim of the study is to discover the geometrical method of traditional weaving grammar by reconfiguring and elaborating procedures and further develop generative method using computational approach. We focused on the exploration of single and dual patterns of biaxial types of West Java weaving ornament by using Shape Grammar principles (Stiny, 1980, 2006, 2010) that are applied to the basic rules of traditional weaving method. Our goal is to codify traditional weaving pattern into computational method that can preserve local and indigenous knowledge.

2. Weaving Grammar

The basic technique of traditional weaving refers to a general instruction of warping and wefting in various modifications. The interlacing is the base structure of any weaving method. In the two-directional woven structure, it has two elements: (1) One that positioned perpendicular to the hand of weaver called warp *(Lungsin)* and (2) One that positioned parallel to the hand of the weaver known as weft *(Pakan).* Arifien (2011) had specified that a woven basic configuration is the baseline for its pattern (product) and methodology (process and procedure). The woven pattern can be analyzed by generating the pattern into a simple and two-dimensional configuration (Garha, 1990, 2001; Arifien, 2011) as shown below in ***Figure 1***.

Figure 1. Two Dimensional of Traditional Weaving Configuration.

Another example by Muslimin (2014) explored a weaving grammar as a basic rule for weaving process based on the interlace structure. A weaving grammar essentially implements parametric shape grammar to define rules of pattern. It encapsulates weaving technique and structure of pattern configuration through computational process (Andino, *et al*., 2013; Jowers, *et al*., 2005).

3. Computational Weaving Method

3.1. UNDERSTANDING WEAVING PATTERN

Using a particular bamboo-based woven pattern called "*Sasag*", the pattern was analyzed and interpreted to be determined into three distinct segment categories by looking into its interweaving structure: (1) One-Way/One-Axis, (2) One-Way/Two-Axes, (3) and Two-Way/Two-Axes. Each segment unit has its own characteristic that determines the interweaving rules to produce generative patterns.

The *Sasag* woven pattern used two stripes perpendicular each other. The procedure starts with understanding rule of the woven where each strip has one state at a time. The state of this pattern is either up (means that a segment is being on top of another segment) or down (means that a segment is being under another segment). ***Figure 2*** described weaving pattern of two groups of stripes in perpendicular direction.

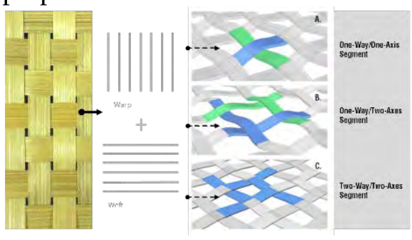


Figure 2. The Conversion of Woven Pattern and Segmentation Categories by Interweaving Structure.

As shown above, each segmentation unit determined procedures in which stripes interweaved and translated each other. Each segmentation units are applied by using five principles of Shape Grammar's theory: rotation, translation, scale, reflection and Boolean operation (Knight, 2000). Rules of each segmentation category are defined by looking at the previous research method. We defined rules into four basic main rules: (1) Labeling Rule as point definition, (2) Rotation Rule that concerns in interlacing the basic line segment, (3) Repetition Rule is the main aspect that generates pattern configuration and (4) Surface Rule can be interpreted as a profiling phase of every woven stripes. For other case to generate different pattern, this main rules can be manipulated or modified by adding or swapping from one and another.

3.2. RULES OF UNIT SEGMENT

The distinctive characteristic of each category of segmentation produces different woven unit pattern while retain the integrity of the pattern. In general, it consists of five rules that are elaborated from previous basic rule.

3.2.1. One-Way/One-Axis

The unit of basic segmentation category involving one-line segment (initial line) with length *(l)* that further generated a basic interweaving pattern by two basic rules, Labeling and Rotation rule. Labeling rule determines start and end point of the segment and the rotation point by taking parameter of ½ *l*, where *l* is the length of the line segment. While Rotation rule determines rotation angle (90^o CCW) from rotation point and producing a boundary line connecting four endpoints. The Repetition rule that is applied using two approaches: (1) Repetition approach that is based on the previous definition, and (2) array approach that is based on the translation. It takes advantage of boundary line connecting each individual unit by repetition order along planar axis of X and Y.

3.2.2. One-Way/Two Axes

This unit has same definition as previous and determination of rotation point uses half length of the initial length with parametric translation vector slightly off the line segment. This parameter takes range between ¼ and ½ of total initial line length. In this part, Rotation rule produces four line segments resulted from two rotation rules. The first rotation of initial line in 180^o CCW from rotation point produced a parallel line. The second rotation takes those parallel lines with 90^o CCW to produce its final formation. Basically, the Repetition rule is generated from rectangular unit boundary, whilst it has different procedure by mirrored in two axes direction X and Y repeatedly.

3.2.3. Two-Way/Two Axes

As same as previous line segment category, this segmentation system is generated by four lines that rotated at a rotation point. The rotation point is determined parametrically using a distance of ¼ *l* off the length of line segment as shown below. Following this rule, the initial line and its rotation point are rotated in three sequential CCW angles: 90^o, 180^o, and 270^o.

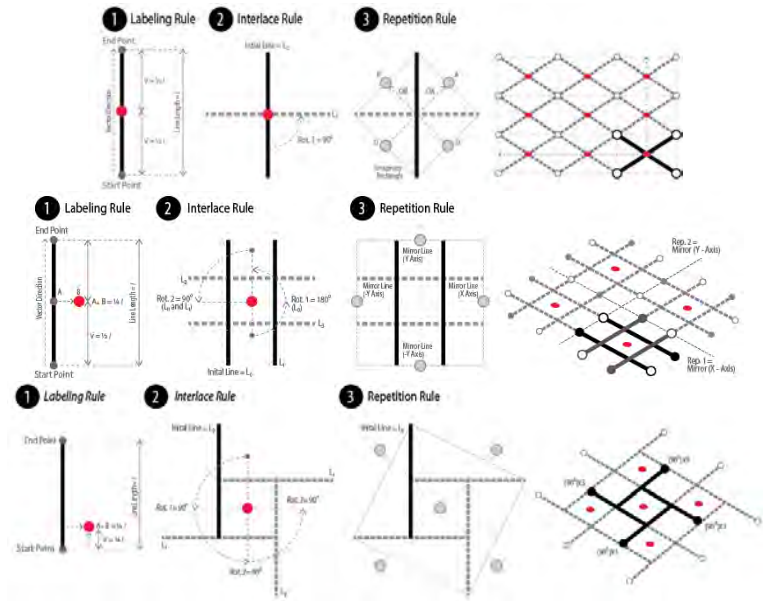


Figure 3. Woven Stripes Profile, Profiling Rule Diagram and Pseudo Code.

3.3 PROFILING RULE

The profiling rule controls parameters of stripe profile which are: width and thickness of those three segment units. This rule decodes material profile of the woven pattern that generally make-up the solid-void composition of the woven pattern. On fabrication point of view, these parameters constitute material properties with bending capacity and also flatness tolerance. Figure 4 shows the actual woven that its characteristic is depended on the width and thickness of its material stripes and interpretation of 'Profiling Rule' to produce parameters for width and thickness of the stripes.

The knot rule divides a line segment into five control points: start point (as control point #1, control point #2, knot point (control point #3), control point #4, and end point (as control point #5). These control points determine the curvature and height of the knot point that transform line segment into control point curve. The height of the knot point is aligned with the normal vector of line segment that in consequence has two states: Up (+Z of normal vector) or Down (-Z of the normal vector).

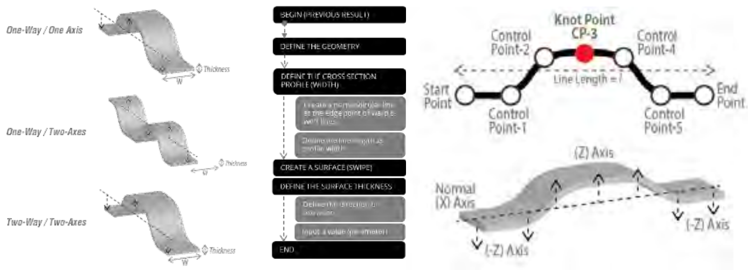
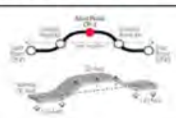
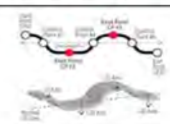
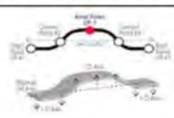


Figure 4. (Left)Woven Stripes Profile; (Right) Profiling Rule Diagram and Pseudo Code.

3.4 ANALYSIS OF INTERWEAVING RULES

We experimented weaving grammar by developing rules of three segment units of a woven pattern. The analysis of its interweaving rules displayed in TABLE 1 below with purpose to know the degree of flexibility and robustness of the rules to be applied to the surfaces.

TABLE 1. Interweaving Structures

Segmentation Categories		Interweaving Structure System		
		One-Way/One-Axis	One-Way/Two-Axes	Two-Way/Two-Axes
Computational Weaving Method	Labeling Rule	1 Line with l length; 2 line segments	1 Line with l length; 2 line segments	1 Line with l length; 4 line segments
	Interlace Rule	1 x 90° (on mid point of initial line)	2 x 90° (rotation point from vector cross product)	3 x 90° (rotation point from vector cross product) with collision rule
	Repetition Rule	Translation and rotation of line segment in certain direction / Rectangular Array in X and Y axis of unit module	Mirror / reflection unit module in X and Y axis	Translation and rotation of line segment in certain direction / Rectangular Array in X and Y axis of unit module
	Knot Rule	1 knot point and 4 control points	2 knot point and 5 control points	1 knot point and 4 control points
	Profiling Rule			
Shape Grammar Principles	Rotation	Yes	Yes	Yes
	Translation	Yes	No	Yes
	Scale	No	No	No
	Reflection	No	Yes	No
	Operation	Union	Union	Union & Intersection (Reciprocal)

The One-Way/One-Axis unit has advantage regarding its visual pattern and its rules as implementation of the Shape Grammar theory (Stiny, 2010): (1) The One-Way/One-Axis unit has the simplest configuration unit with basic structures remain as with traditional weaving technique, (2) The repetition rule is robust and flexible to be applied to planar and non-planar surfaces with possibility for additional and recursive rules. The Labeling Rule is the base rule that has significant impact to the subsequent rules and determine the definition of the woven pattern.

4. Discussion on Experiments

Experiment of the computational weaving method has been conducted on two types of biaxial woven pattern which are single and double pattern. Both patterns have been digitally interpreted and analyzed as previously explained. *Figure 5* showed the difference of single and double pattern of biaxial woven pattern.

Figure 5. Single and double pattern of biaxial woven patterns.

In the single woven pattern, interlace rule is located at the center of line segment which was divided into two equal lengths and cause a symmetrical interlace as seen in ***Figure 5***. By using the same logic in the interlace procedure, first, the line segment should be divided in eight segments. Considering control points and knot points of its woven pattern. By adjusting input parameter of curve evaluation in Grasshopper, the rotation point can be determined parametrically according to the length (*l*) of the segment (***Figure 6***).

Figure 6. (left) Input value for rotation point.(Right) Result of rotated segment by point of rotation.

On the double pattern (or *Kepang*), the segments are determined by two segments that interlaced over a knot point. As such, numbers of control points on segment are higher than a single pattern.

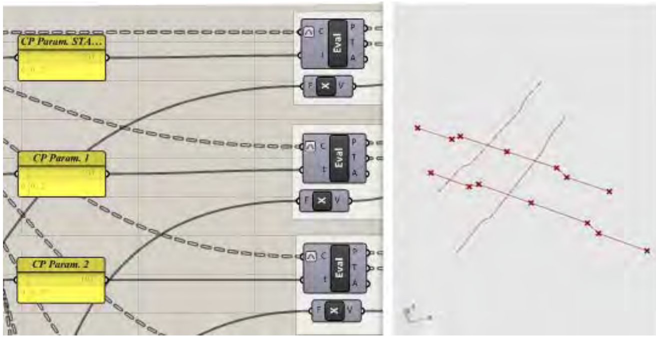


Figure 7. Determination of control points for interlaced segments.

Figure 7 depicted procedures and rules for double pattern biaxial woven, or *Kepang*. In this type, rule for labeling is crucial to determine points of interlacing segments. The result of this rule is two interlaced segments as a base unit for computational biaxial woven pattern (***Figure 7***, right).

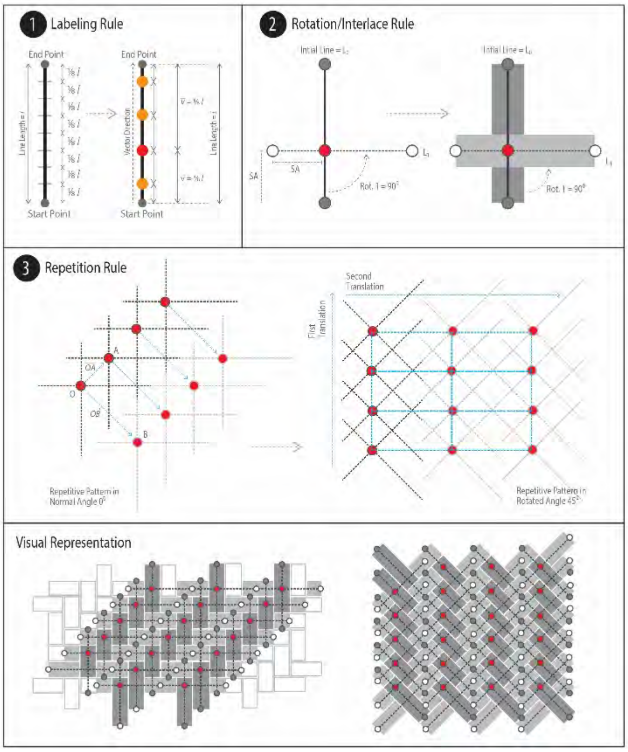


Figure 8. Pattern elaboration of Biaxial Weaving types.

Figure 8 showed three types of rules: Labeling Rule, Rotation/ Interlace Rule, and Repetition Rule along with its visual representation of *Kepang* woven.

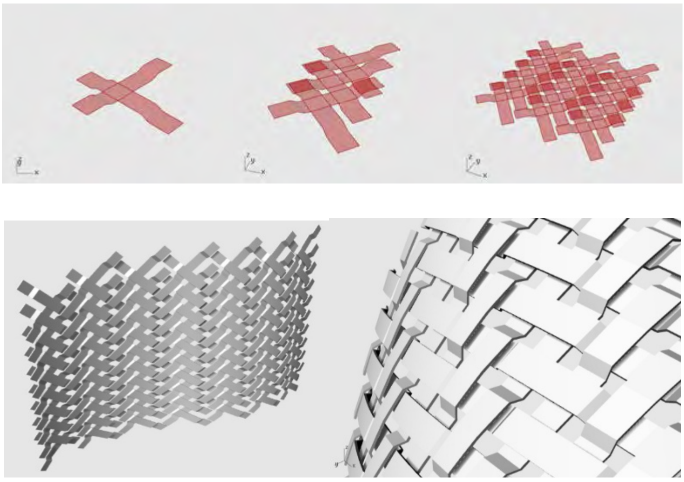


Figure 9. Hasil dari implementasi pola anyaman kepang pada suatu surface.

In ***Figure 9***, *Kepang* woven pattern was implemented into non-planar surfaces as 3-dimensional object by means of Profiling Rule. It is shown that the difference weaving grammar between single (One-Way/One-Axis, single pattern) and double (One-Way/One-Axis, double pattern) lied on the number of its control points. The case showed that a woven basic configuration is defined by the number of control points of its base segment unit.

Furthermore, control points of the segment unit used to regulate amount of the "weaving" or, the normal vector distance of the stripes from the planar surface. ***Figure 9*** also showed detail of the patterns implemented on a curved surface. Control points parameter of Knot Rule determine the weaving factor of the pattern.

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MORPHOLOGICAL CODE OF HISTORICAL GEOMETRIC PATTERNS

The Digital Age of Islamic Architecture

MOSTAFA W. ALANI
Clemson University, SC, USA
mostafh@g.clemson.edu

Abstract. This study intervenes in the long-standing paradigm that considers compositional analysis as the key to researching the Islamic Geometric Patterns (IGP). The research argues that the compositional analysis of the geometry is not solely sufficient to investigate the design characteristics of the IGP, and the better way of achieving this emerges through a consideration of the design formalism.

1. Introduction

The science and technology of the digital age is revolutionizing architectural practices (Kolarevic, 2004). Digitals, both computerized and computational, advance the design and manufacturing processes. This opens new opportunities to explore complex formal compositions and has recently shifted the focus toward form generation, which challenges the dominant representational logic of traditional architecture (Oxman & Oxman, 2014). Several writings (Greg Lynn, 1993; Migayrou Frederic, 2003; Kolarevic, 2004; Hadid & Schumacher, 2002) of theories of the digital emerged that are centered on procedural processes and mathematical form generation that turn the focus from the curvilinearity and blobby forms of folding toward digital design thinking. These theories emphasize formalism, or the mechanisms that govern the structure of relations within an architectural form rather than formal compositional aspects (Oxman & Oxman, 2014; Kolarevic, 2004). In other words, it is a shift from form 'making' toward form 'finding' (Kolarevic, 2004).

When it comes to the design and research of Islamic architecture, the discipline is still over-dependent on approaches that focus on the formal representation of historical models. However, it has been argued that limiting Islamic architecture to particular compositional characteristics degrades its real value and segregates it from the general architecture of the world (Rabbat, 2004). Instead, the inquiry should concentrate on the understanding of “the emergence and evolution” of architectural forms that reestablish an open-ended search for forms and make Islamic architecture an active contributor to the world’s architecture (Rabbat, 2004).

2.Islamic Geometric Patterns

Islamic Geometric Patterns are a prominent characteristic that demonstrates the diversity of geometric designs in Islamic art and architecture. These simple to complex interlaced geometric forms are made from a variety of materials and cover various architectural and non-architectural surfaces throughout the Islamic world. The earliest attempts at producing geometric designs date to the 9th century during the Abbasids Dynasty (750–1258 CE). Followed by major innovations that occurred between the 10th and the 16th centuries (Necipoğlu & Al-Asad, 1995).

Historically, Islamic art and architecture took advantage from the mathematics of its age. The enormous diversity of complex forms that exist in Islamic art and architecture are products of mathematical and geometrical advancements as discussed in available historic documentation. One such document is *Risâla fimâ yahtâju al-sâni ʼ u min a ʼ mâl al-handasa* (On the Geometric Constructions Necessary for the Artisan), by al-Būzjānī, (998). Yet, when it comes to the design and analysis of Islamic architecture, mathematics is mainly discussed in terms of proportion with less focus on the computational nature of form generation that encompasses mathematical and algorithmic thinking.

This paper focuses on the design formalism and presents a method that incorporates mathematics and morphology to construct a shape-code that packs the necessary information to construct a particular geometry and utilizes this code to investigate and design IGP.

3. Precedence

A few studies “breached” the representational approach and its “Orientalist roots,” emphasizing the relationship between mathematics and the historic IGP. The first study that scientifically investigated the IGP was conducted by Edith Muller (Müller, 1944), who analyzed the symmetry of the patterns based on group theory. This research was followed by other publications by Wasma’a Chorbachi (1989), Herash Lalvani (1989), and Sayed Abas and Amer Salman (1995). These later studies attempted to identify a method to mathematically engage the design of the IGP. They acknowledged the important contribution of group theory in studying the patterns, and used scientific notation to identify individual geometric designs in a discrete manner.

Although these studies either examined a particular design (for example, Chorbachi examined interlocking geometry), a particular design feature (such as symmetry in Abas's study), or a small population of designs (Lalvani), all of these methods provide an approach that is concerned with designing a scientific method rather than describing the mere formal qualities. However, none of the above studies have developed methods to capture continuous transformation of design topologies –morphology– or reflected back and analyzed historical designs.

4. Methods

This research utilizes mixed methods in two sequential phases. In phase one, simulation modeling is employed to develop a parametric model that describes the formalism of the IGP and construct the representational code of historical designs. In phase two, content analysis is utilized to study the representational codes with consideration to related historical manuscripts on mathematics and geometry.

4.1 ANATOMY OF A PATTERN

In general, the periodic IGP consist of a repeat unit (RU) and a repetition structure. The RU is the minimal region that contains the basic geometrical composition; it is possible to have more than one type of the RU. The repetition structure is the product of systematically repeating RU to fill the space. The shape of the RU affects the type of the repetition structure. The repeat unit itself can be subdivided into several fundamental units (FU). The FU are the minimal compositions within the repeated unit that cannot be obtained by symmetry. Figure 1 shows the process of identifying the fundamental unit of geometry at different levels of geometric complexity.

4.2 THE MORPHOLOGICAL DESCRIPTION

The morphological description provides the minimal amount of numerical information that is necessary to produce a series that refers to a particular historical IGP, and encompasses the possible transformations. In previous paper (Alani & Barrios, 2015) , a description that utilizes absolute values was presented. In this paper, however, the morphological code is based on a relative description of the geometric composition within the FU. The method proposes types of parameters that represent the percentage of how far a point is from a reference point (RP).

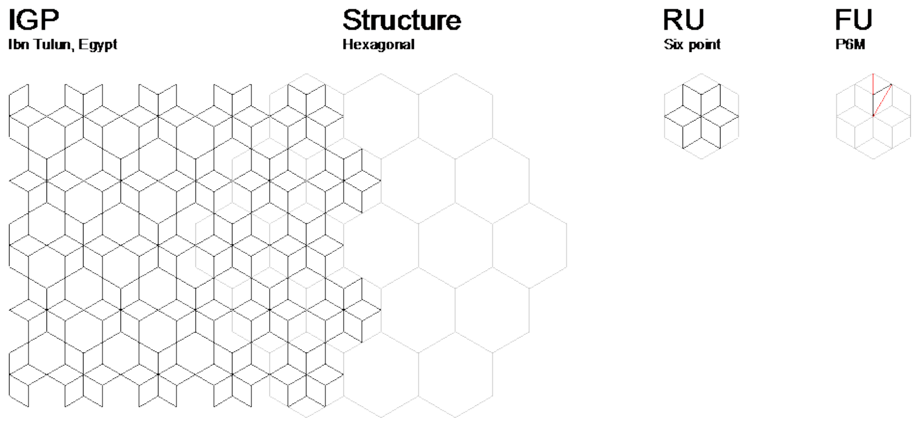

Figure 1. From left to right, the analysis of pattern structure, the repeat unit, and the fundamental unit.

While the RP can be any point in the space, this paper proposes positioning the RP on the outer segment of the FU. The placement of the design elements depends highly on the RP. Each line in the design requires two points, called targeted points (TP), to be constructed. Each point requires two vectors to be defined: the construction vector (CV) and the pointing vector (PV). The CV emits from RP toward a Construction Point (CP). The CP is always the point that lies at the outer border of the FU and is determined by the intersection of this segment with a vector that emits from the center of the RU passing through the TP (Figure 2). The length of the CV is identified as the proportion from the outer segment of the FU. The PV emits from CP toward the center of the RU. The length of the PV is a proportion of the vector constructed from the center of the repeat unit and the CP. The end point of this vector is the TP. Connecting all the TPs creates the basic lines of a geometric composition. Therefore, it is possible to code any geometry using the following parametric model:

$$\text{Symmetry Type: } \{TP1 - TP2 - \ldots - TP\textit{n}\}$$

Where *n* is the number of TPs in the geometry.

By substituting CV and PV for TP, the above model can be written as follow:

$$\text{Symmetry Type: } \{[CV1\text{–}PV1] - [CV2\text{–}PV2] - \ldots - [CV\textit{n}\text{–}PV\textit{n}]\}$$

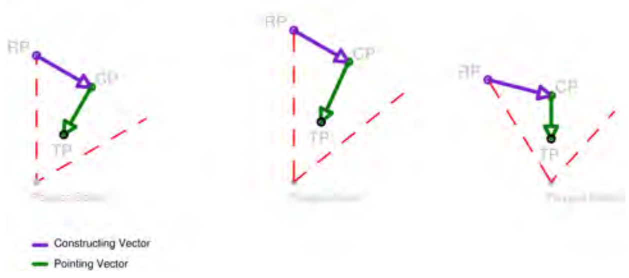

Figure 2. Illustration of the proposed method.

The parametric model can be used to derive representational codes that refer to particular historical designs. Consider the geometry shown in Figure 3. The description of this geometry can be written using the above model as:

P6M : { [0 – 1] - [0 – 0.5] - [1 – 0] }

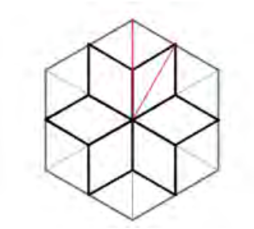

Figure 3. Six-fold star found in the mosque of Ibn Tulun in Egypt from the ninth century.

In this representational code, P6M refers to the shape of the repeat unit and the type of the symmetry. The rest of the code refers to a series of connected points. Each point is coded in the form of CV and PV.

Figure 4 shows the advantage of using relative values in the description. Regardless of the shape of the repeat unit, the description can always fit the composition in the hosting cell unit. Such an approach enables the mapping of an IGP on a variety of surfaces as explained in the 3D printed model shown in Figure 4.

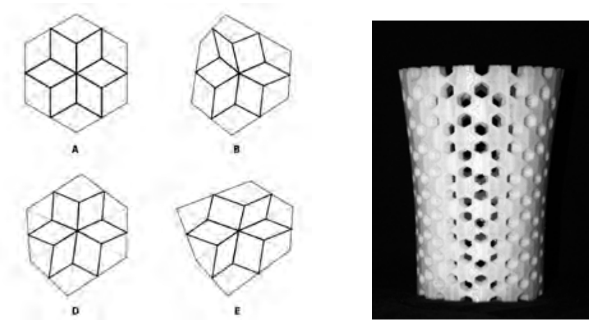

Figure 4. Left: Mapping of the geometry into a deformed CU. Right: 3D printed model demonstrating the mapping of an IGP onto a non-flat surface.

4.3 CODING PROCESS

The parametric model utilized to derive the representational codes of historical designs. Data was sampled from Islamic monuments from various regions from the Islamic world dated between the 9^{th} and the 16^{th} centuries. Each morphological code can be stored with identification information such as the geographical location, chronological information, and the governing dynasty.

4.4 MORPHING

Values within the representational code for historical designs were manipulated, and new codes were derived. The manipulation of data was performed to cover all possible variations; this resulted in continuous transformations of geometry to cover all possible morphological states. Figure 5 illustrates the morphing process of the original geometry of Ibn Tulun mosque.

5. Results

When the results of the morphing process were compared with the representational codes of historic IGP, it was found that some of the newly derived codes exactly matched historic designs. Therefore, three different types of relationships between designs were identified: identity, topological similarities, and morphological similarities.

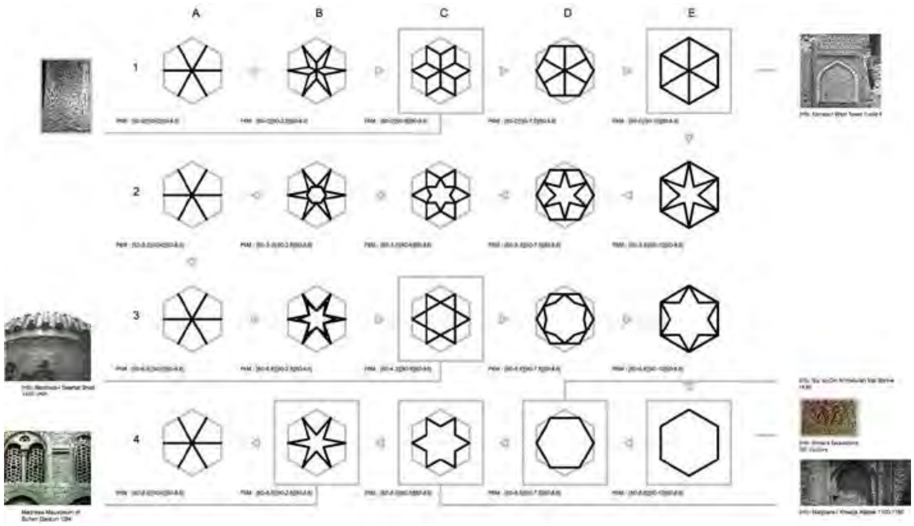

Figure 5. Following the arrow, this figure explains selected transformations of Ibn Tulun geometry through various topological states.

Identity refers to historic IGPs that have the exact same code. Although some identical designs may look different because of using different embellishments for each design, these geometries still have an identical geometric composition.

A topologically similar IGP refers to a design that has the same “spatial relations” of the composition and is less concerned with “spatial distinction.” For instance, Geometries 4B, 4C, and 4D in Figure 6 are topologically equivalent.

Geometry 4B: P6M : { [1 – 0] **-** [0 – **0.75**] **-** [1 – 0.33] }
Geometry 4C: P6M : { [1 – 0] **-** [0 – **0. 5**] **-** [1 – 0.33] }
Geometry 4D: P6M : { [1 – 0] **-** [0 – **0.25**] **-** [1 – 0.33] }

Morphologically similar IGP refers to all designs that can be derived from a particular IGP regardless of the topological transformation. For instance, all designs in Figure 5 are morphologically equivalent. Figure 6 explains how new relations can be established between historic IGPs based on morphological similarities.

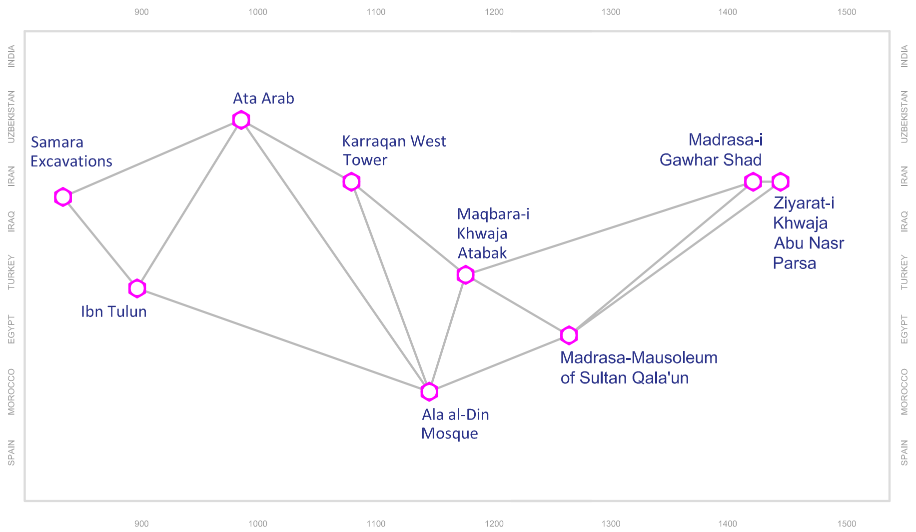

Figure 6. morphological relations between historical designs

6. Conclusion

Mathematics is essential for understanding IGPs. The identification of design formalism of the IGP enables the construction of databases of representations of design singularities, which can be an extensive source of information. These representations are useful not only to the archiving of information but also to investigate and empirically analyze the morphology of historical designs for possible correlations. As this study found, the relationship between various historic designs goes beyond formal relations to a deeper structural level.

7. Discussion

The goal of this research is to provide a different understanding of the historical IGP that is based on mathematics and morphology as an alternative to the conventional formal understanding, aiming at establishing a new platform to engage the research and design of the IGP.

The significance of developing the parametric description is also to establish a lower level interaction with the methodology that grants designers complete control of the model's components and its mathematical structure. Such an approach enables exploration beyond known historic designs, or what is intuitively obvious, to search for new, uncharted forms. One practical implementation of the parametric description is to control the form of the geometry in responsive pattern system through direct manipulation of the PVs.

Although the focus of this research is on the IGP, the underlying goal is to provide a method to actively engage the design of Islamic architecture, based on mathematics and morphology, to construct a version of history that represents the digital age through incorporating innovative computational tools into the design process. Eventually, this will reduce the gap between the contemporary world’s practice of architecture and Islamic architecture by allowing the latter to contribute to current design practices.

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ON SLIME MOLDS AND CORRIDORS

The application of network design algorithms to connect architectural arrangements.

PEDRO VELOSO AND RAMESH KRISHNAMURTI
Carnegie Mellon University, Pittsburgh, PA - USA
pveloso@andrew.cmu.edu | ramesh@andrew.cmu.edu

Abstract. The use of adjacency graphs to represent and generate architectural arrangements tends to favor direct connections between contiguous rooms. These disregard specialized circulatory systems (such as corridors), which consider connections between non-contiguous spatial units or accesses. This paper addresses two specific issues: (1) how to represent a circulation network for a specific access/adjacency graph embedding; and (2) how to design good circulatory solutions for the arrangement that optimizes this network. To represent a complete circulation network, we propose a scheme, an adapted straight skeleton, based on the boundaries of the spatial units. To design possible circulation alternatives, we adopt the Slime Mold model (Tero *et al.,* 2006; 2007). Using this model, we develop an original method, termed Adjacency Graph Selection (AGS), to generate circulation solutions for arrangements. As an initial test case for AGS, we use floor plan of the Louvre Abu Dhabi, designed by the French architect Jean Nouvel.

1. Introduction

In the field of computational design, one of the most prominent structures to analyze and generate spatial arrangements for buildings are networks. Graph theory specifies vertices (or nodes) and edges (or connections) as the basic elements to represent a network. Different approaches to graphs have been established to deal with different aspects of architectural arrangements. From the pioneering work of Lionel March and Philip Steadman (March & Steadman, 1974; Steadman, 1976; 1983), we can cite three types of graphs for spatial representation. Plan graphs encode the physical compartment of the building such that edges are walls, and nodes are corners. Adjacency graphs represent the proximity of spatial units in plan – nodes are the spatial units while edges connect spatial units that should be close or even share a wall. Lastly, access graphs represent the real connection between spaces. It is a subgraph of the adjacency graph as the nodes represent spaces and edges represent only those adjacent spaces connected by doors or openings.

In particular, these connective representations of spatial units (adjacency and access graphs) have been widely influential in space planning research. The early pioneers considered the data structure of these graphs as an architectural representation through which to explore possible graph embedding – that is, a particular drawing of a graph – and its translation to arrangements. Current research examines the adjacency/access graph through different computational techniques such as physical simulation or agent-based modeling, in order to explore solutions dynamically.

2. The problem

Despite the potential of the adjacency graph as a representation for space planning, it is still too abstract to represent the geometry of an architectural circulation system. There is one important difference between configurations of corridor systems in architectural arrangements when compared to other systems, such as transportation or biological networks. Corridor systems establish indirect connection between individual spatial units. One historical explanation is that over the centuries, in complex buildings, the *enfilade* system (sequences of interconnected rooms) has given way to a network of corridors, enabling each room to exert a specific function and to keep a sense of privacy (Evans, 1997). Therefore, the distinction of specialized rooms and specialized circulatory systems is problematic for the generation of spatial arrangements based on an adjacency/access graph representation. Different computational techniques can result in satisfactory embedding for the graph. However, the spatial configuration of the embedding can indicate only direct access between contiguous rooms, not the possible corridors.

To address this problem, we assume the existence of a set of well-defined spatial units connected by an adjacency graph embedding, which is neither necessarily planar nor devoid of crossings between its edges. Spatial units that are supposed to be connected are not always adjacent, due to a dispute with other spatial units or even due to external constraints such as visibility, orientation, lighting, etc. In this case, the circulation network should ensure that the pair of spatial units connected by the adjacency graph has a good and efficient corridor system among them.

Our method provides a solution to two questions: (1) how to represent all possible and feasible circulation elements of these spatial units; and (2) how to generate good circulatory solutions from subsets of this complete network, based on the adjacency graph.

3. The method

In this paper, we adopt a constructive research method by developing a computational design approach that addresses the limits of the adjacent graph representation, which we then apply to a test case in order to evaluate its initial feasibility. The method addresses early iterations in the design process. It assumes that there might not be sufficient information for complex simulations and that the exploration of alternatives and opportunistic structural changes be pervasive. The method, therefore, should allow for on-the-fly changes to the initial parameters, and should generate a diagram of the corridors properly adapted to different initial parameters without requiring additional steps. We now consider the two questions.

(1) To generate possible feasible circulation elements of the plan, we investigated techniques for developing from the positions of the spatial units a complementary network that considers the geometrical qualities of a circulation system. This network may not only contain *enfilade* connections, but also corridors between the boundaries of the spatial units.

(2) We investigated an algorithm that selects and dimensions a subset of all different possible connections in the complete network, in order to represent a circulation system. In essence, this is a form of combinatorial optimization guided by the adjacency graph and the parameters of the algorithm.

We looked at a specific project to test both steps, namely, the Louvre Abu Dhabi, designed by the French architect Jean Nouvel. It comprises an arrangement of galleries and services in which circulation operates with both *enfilade* rooms and a pier between all spaces, providing the opportunity to explore computationally different design alternatives. In the future, we will employ the method in the generation of new spatial arrangements.

4. Generating a complete network (CN)

As any potential corridor borders a spatial unit, the generation of a complete circulation network does not depend on the configuration of the adjacency graph, but on the actual positions of the spatial units and the shape of their boundaries.

In Rhino, Grasshopper and GH Python, we can extract a vector representation of the rooms of the Louvre Abu Dhabi. We cluster close and small rooms and apply a convex hull algorithm to ensure that all spatial units are convex (Fig. 1a-c). Then, we apply a Delaunay triangulation with a filter to generate a graph with the actual adjacency of the units (Fig. 1d). The Delaunay represents all direct connections between the units or, in other words, the complete *enfilade* network.

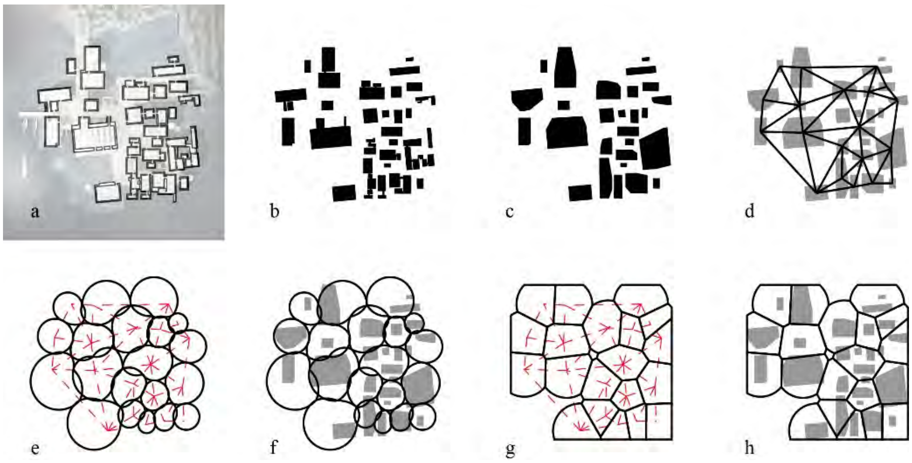

Figure 1. (a-c) Development of the spatial units; (d) Delaunay triangulation as *enfilade* system; (e-f) Pseudo-graph as corridor system; (g-h) Voronoi as corridor system

The next step is to produce the complete network of corridors between the existing spatial units. We tested two initial alternatives. The first is a pseudo-graph that connects the midpoints of the edges of the Delaunay graph with curves, generating a bubble diagram enveloping the original nodes (Fig. 1e-f). The second alternative is the dual graph of the Delaunay triangulation: the Voronoi diagram. It generates divisional lines in the midpoints of the Delaunay triangulation, forming polygonal cells around the original nodes with an optional control of maximum radius (Fig. 1g-h).

Both alternatives had the advantage of connecting the original triangulation in the midpoints (not all midpoints in the case of the Voronoi), forming a coherent combination of graphs. However, they are not sensitive to the geometric boundaries of the spatial units, generating a network of edges that would require extra steps to be translated to diagrammatic representation of corridors.

4.1. STRAIGHT SKELETON

For the final complete network, we adopted the straight skeleton. It consists of offset line segments between the pre-existing geometry, forming an internal or external skeleton connected to the original nodes by diagonals.

We tested the implementations using kinetic triangulation, proposed by Palfrader, Held and Huber (2012) and the consolidated CGAL library.

In order to set the space between the spatial units and around the perimeter as the site for the skeleton, we defined an adaptive concave hull with all the units and then we offset it (Fig. 2a-b). After defining the external boundary (offset concave hull) and the internal boundaries (spatial units), the skeleton occupies all interstitial spaces for the corridors, forming cells (Fig. 2c). Then, the external boundary and diagonals of the skeleton are eliminated (Fig. 2d).

In order to define the accesses from the units to the corridor network, we defined two options. Multiple accesses use the intersection of the edges of the adjacency graph with the cells (Fig. 2e) to select the nodes representing accesses (Fig. 2f). This stimulates circulation through a room and even enfilade systems. Single access uses the same method to define the access point, however it selects only the edge of the adjacency graph connected to the largest neighbor unit (Fig. 2g).

The straight skeleton forms an adaptive network of polygonal cells adapted to the boundaries of the spatial units. It consists of centerlines that inherit the geometric complexity of the units. When there are more points and segments in the spatial units, the network will also have more segments. In our examples, the convex hulls of the spatial units are not completely orthogonal and the units have different sizes, orientations and alignments.

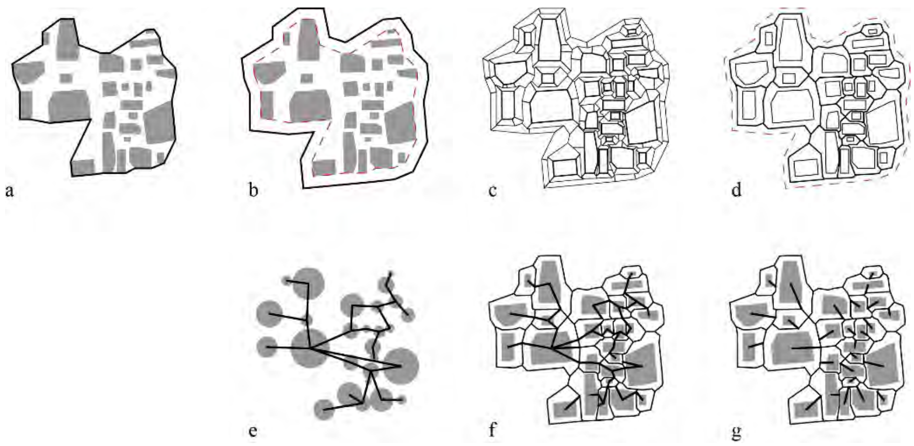

Figure 2. (a-d) Straight skeleton development; (e) adjacency graph; (f) multiple accesses per unit; (g) single access per unit

5. Let a slime mold design our corridors

With a developed complete network, the method next has to generate alternatives of the circulation systems. To address this issue, we looked at the Slime Mold (*Physarum polycephalum*), a unicellular organism that, in its vegetative phase, depends on a natural adaptive network of tubes (or edges) to find sources of food in the environment and then to distribute the nutrients and chemical signals around its body. The hydrostatic pressure due to rhythmic contractions of actomyosin fibers to transport nutrients increases the amount of flux that in return activates a shear effect on the tube, orienting the actomyosin fibers in the direction of the stretching force (widening the tube). As a result, dead end tubes and longer tubes tend to disappear while shortcuts between food sources are reinforced. In other words, it solves the combinatorial optimization problem using feedback between the flux of nutrient and thickness of the tubes.

5.1. THE SLIME MOLD MODEL

We adopted the model proposed by Tero *et al.* (2006). It interprets the behavior of the Slime Mold, using the Pouseuille flow principle associated with one food source and one sink, and avoiding pressure oscillation and rhythmic contractions. It comprises four steps:
(a) Assignment of an initial value for the conductivity (D) and length (L) for all tubes, and assignment of the constant of the flux from the source (I_0).

(b) Setting the sink pressure as zero and solving the system of Network Poisson equation to find the pressure of all other nodes.

$$\sum_i \frac{Dij}{Lij}(pi - pj) = -I_0 \; for \; j = 1; +I_0 \; for \; j = 2; \; 0 \; otherwise \tag{1}$$

(c) Using the Poiseuille flow formula to obtain the flow of the tubes.

$$Qij = \frac{Dij}{Lij}(pi - pj) \tag{2}$$

(d) Updating the conductivity of the tubes using the dimensionless form of adaptation equation associated with a monotonically increasing function.

$$\frac{d}{dt}Dij = f(|Qij|) - Dij \tag{3}$$

In order to optimize railroad networks, Watanabe, Tero *et al.* (2011) modified the original model to operate with multiple food sources. They proposed three methods to select the points to be sources and sinks for each unit step. In Two Points Selection (TPS), the size of the food sources define the probability for the selection of two points for source and sink. In Multipoint Selection Method (MPS), the same food-based biased sampling defines *n* pairs of points. In Complete Multipoint Selection Method (CMPS), a combination of all the nodes define the pairs. These methods normalize the flow and the conductivity according the number of pairs selected at each step.

These methods can be adapted to design circulation networks, as parameters, type of function, and the food sources can control the output. However, there are still some limitation. TPS and MPS rely on probabilistic selection, which means that the output can vary (Fig. 3a and 3b) and converge to sub optimal results depending on the number of iterations and on the values of the food sources. CMPS combines all the elements of the network for each time step. It can be deterministic, but it is always computationally expensive.

5.1. ADJACENCY GRAPH SELECTION METHOD

The method proposed in this paper is Adjacency Graph Selection (AGS). We implemented it in Python and integrated it with the complete network developed in Rhino, Grasshopper and GH Python. We treat each spatial unit as a food source of the slime mold, dimensioned according its area. The complete network consists of tubes between nodes without food - potential candidates for corridors – connected to these spatial units (nodes with food). Instead of probabilistic selection (TPS or MPS) or complete combination (CMPS), AGS uses the adjacency graph to define the source-sink relationships. At each step, the selection consists of all paired combinations of one spatial unit with all its neighbors in the adjacency graph (as sinks). In total, it operates with a selection of two times the edges (2xE) of the adjacency graph for each time step.

This method avoids discovering a proper *n* values for probabilistic selection, avoids using repeated pairs and constrains the selection set only to desired connections. In combination with the settings of the original model, the adjacency graph is the device that allows the designer to control bias of the system towards specific optimum solution with an efficient selection of sources and sinks.

The initial results confirm that AGS can direct the development of the slime mold (compare Fig. 3c, 3d with 3e), but it does not follow the tendency of MPS (combined with our initial settings) to quickly define spanning trees. AGS accentuates the weight hierarchy of the corridors, suggesting even areas that look like halls or foyers. The filtering of the accesses also affects the type of solutions. Additionally, the results confirm that with multiple accesses, the slime mold tends to form *enfilade systems* (Fig.3c). With single accesses, the slime mold privileges a hierarchy of corridors (Fig.3d).

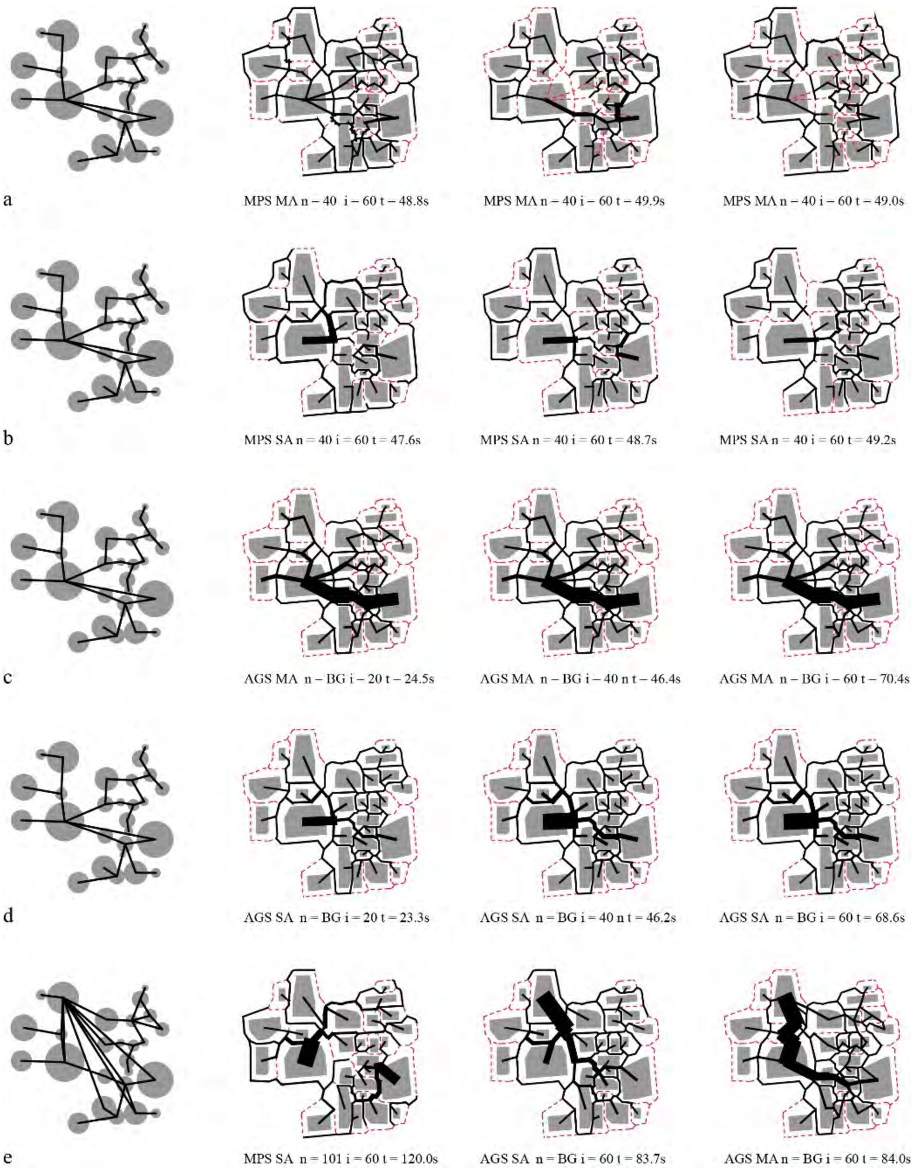

Figure 3. (a) Three variations of MPS and multiple access (MA), 40 samples per step and 60 steps; (b) Three variations of MPS and single access (SA), 40 samples per step and 60 steps; (c) A sequence of AGS and multiple access, samples defined by graph, 20, 40 and 60 steps; (d) A sequence of AGS and single access, samples defined by graph, 20, 40 and 60 steps; (e) A different graph with corresponding MPS + SA, AGS + SA, and AGS + MA

6. Conclusion and future steps

The initial results offer evidence that the proposed method is able to generate a complete network and to design new connections under the control of the adjacency graph. However, some limitations were identified. In future implementations, the filtering of edges for single access mode will occur during the optimization, in order to ensure that optimal corridors will concentrate the accesses. The method for multiple sinks and sources has to be improved in order to control the redundancy of the corridors and to converge to good alternatives. Another drawback is that current generation of the complete network and optimization are slow for a real time interaction. Future implementation will consider scientific computing methods to integrate it with a space planning interactive tool.

Acknowledgements

This research was supported by CNPq (National Council for Scientific and Technological Development). We also thank professors Ziv Bar-Joseph and Matt Ruffalo from the Computational Biology Department at CMU who provided insight and expertise with Bi-directional studies of natural networks.

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PARAMETRICISM FOR URBAN AESTHETICS

A flawless order behind chaos or an over-design of complexity

ELİF BELKIS ÖKSÜZ
Istanbul Technical University, Faculty of Architecture
elifb8807@gmail.com

Abstract. Over the last decade, paradigm shifts in the philosophy of space-time relations, the change from space-time to spatio-temporality, caused significant changes in the design field, and introduced new variations and discourses for parametric approaches in architecture. Among all the discourses, parametricism is likely the most spectacular one. The founder of parametricism, Patrik Schumacher (2009) describes it as “a new style,” which has “the superior capacity to articulate programmatic complexity;” and “aesthetically, it is the elegance of ordered complexity in the sense of seamless fluidity.” In its theoretical background, Schumacher (2011) affiliates this style with the philosophy of *autopoiesis*, the philosophy that stands between making and becoming. Additionally, parametricism concerns not only the physical geometry in making of form; but also discusses the relational and causal aspects in becoming of form. In other words, it brings the aesthetic qualities in making through the topological intelligence behind becoming. Regarding that, parametricism seems an effective way of managing /creating complex topologies in form-related issues. However, when it comes to practice, there are some challenging points of parametricism in large-scale design studies. Thus, this work underlines that the dominance of elegance for urban planning has the potential of limiting the flexible and dynamic topology of the urban context, and objectifying the whole complex urban form as an over-designed product. For an aesthetic inquiry into urban parametricism, this paper highlights the challenging issues behind the aesthetic premises of parametricism at the urban design scale. For that, Kartal Master Plan Design Proposal by Zaha Hadid Architects (2006) will be discussed as an exemplary work.

1. Making, Becoming, and the Autopoiesis in Between

When it comes to aesthetics in design, art and architecture are the disciplines that prioritize the assessment of the two key phenomena in aesthetics, *form* and *idea*. However, compared to art, architecture is the one that directly involves causalities and programmatic experience in these phenomena. Hence, the production and representation of an architectural form is likely the most problematic issue among all the others in the design field. 'Form' is a phenomenon defined by artists and evolutionists through the philosophy of 'making' or 'becoming' since Plato (Karatani, 1995); and the philosophy behind *making* and *becoming* of form depends heavily on the space-time dialectics. While making refers to space-based relations, becoming refers to time; yet, most of the form studied in architectural design seems to be stuck in between these two for a long time. Nevertheless, over the few decades, the paradigm shifts in the philosophy of space–time relations, the change from space–time dialectics to spatio-temporality, also caused significant changes in the design field, and introduced new variations and discourses for parametric approaches in architecture.

Right after the modern era, most of the theoretical discourses in architectural design such as postmodern, avant-garde, and emergent systems tend to see form as a process, a complexity that is a becoming of different causal relations; and most of them tend to represent architectural forms through non-Euclidian forms. Within this regard, the space we talk as an architectural form serves no longer for the probabilities, but it serves for the possibilities, for the unexpected events and new experiences. In other words, the use of geometry has gained new meanings in architectural design process, and its representation as well. As designers, we are now describing the architectural geometry not only to represent fully programmatic functional and material relations, but also to represent complex topologies – social relations, cultural aspects, events and movements. Currently, computational design tools are widely used to parameterize, and control complex dynamic relations of form. More, these dynamic relations also affect the aesthetical aspects of form. The paradigmatic shift, from space-time to spatio-temporality, has increased the parametric design approaches in architecture. And, among all the approaches, parametricism is likely the most spectacular one. Over the last decade, the paradigm shifts in the philosophy of space–time relations, the change from space–time to spatio-temporality, also caused significant changes in the design field, and introduced new variations and discourses for parametric approaches in architecture. Among all the discourses, parametricism is likely the most spectacular one.

The founder of parametricism, Patrik Schumacher (2009) describes it as "a new style," which has "the superior capacity to articulate programmatic complexity;" and "aesthetically, it is the elegance of ordered complexity in the sense of seamless fluidity." From interior design to urban planning practices, parametricism has been evidenced at different scales (Schumacher, 2009). And it seems that, this new style provides new perspectives for urban design and its aesthetic inquiry.

As a computational approach, while parametricist approaches help to manage heterogeneous complexity of an urban context, they also give us a chance to discuss the urban context through aesthetical values. Regarding that, parametricism seems an effective way of managing/creating complex topologies in form-related issues. Nevertheless, when it comes to practice, there are some challenging points of parametricism in large-scale design studies. Whereas the use of computation represents the becoming of form; the elegance or the aesthetic intentions represents the making. Thus, this work emphasizes the dialectic of making and becoming philosophies in parametricism. In this dialectic, it claims that focusing more on the aesthetical values weakens the power of parametricism for large complex systems, such as urban design. This work also notes that the dominance of elegance for urban planning has the potential of limiting the flexible and dynamic topology of the urban context, and objectifying the whole complex urban form as an over-designed product. Therefore, with an aesthetic inquiry into urban parametricism; this work highlights the challenging issues behind the aesthetic premises of parametricism at the urban design scale. For that, Kartal Master Plan Design Proposal by Zaha Hadid Architects (2006) will be discussed as an exemplary work.

2. The Elegance

As part of a computational design theory, the capacity of parametric approaches is much wider than the capacity of intuitional/analog techniques. Regarding the part-whole relations and inner-outer values, the tools and techniques that are developed in the digital media provide a variety of problem solving alternatives for designers (Simon, 1997). The heterogeneous pattern of different relations can be assessed in more complex and efficient ways for numerous solutions.

After the modern era, the aesthetic phenomenon of an urban form has been affected by the paradigm shift in architectural geometry. All the post-, neo-, avant-garde or even computational discourses in design have changed use of dimension for architectural geometry from 2D to 3D. And, with parametricism, the architectural geometry now reconsiders time as the 4th dimension to be represented and generated by new computational tools and techniques. This new style has affected the making and becoming philosophies of form in every design scale. In its theoretical background, Schumacher (2011) affiliates this style with the philosophy of *autopoiesis*, the philosophy that stands between *making* and *becoming*. Additionally, parametricism concerns not only the physical geometry in making of form; but also discusses the relational and causal aspects in becoming of form. In other words, it brings the aesthetic qualities in making through the topological intelligence behind becoming.

Though, unlike modern or post-modern approaches, the aesthetical inquiry in parametric approaches takes a place in the design process, not at end of the process (Rahim and Jamelle, 2007). However, Antoine Picon (2003) emphasized that computational design has some challenging issues under the aesthetic phenomenon. According to Picon (2003), there is a significant amount of arbitrariness in the design and selection process of form; and from micro- to macro- scales, that particular form can be applied on any scale. Therefore, recent parametric applications in form finding studies are not only about generating complex geometries, but also using tools and techniques with a sophisticated intelligence. Parametricism for that matter, aims to reach the aesthetic beauty of form through the relational and heterogeneous complexity (Schumacher, 2012). Schumacher (2009) claims that, parametricism is 'the new architectural style' to achieve elegance, the sophisticated beauty of form.

3. Urban Parametricism and Its Aesthetic Inquiry

As Brian Massumi (2002) emphasizes in his book named *Parables for the Virtual*, choosing the proper geometry for design is not only choosing the potential modulations of form, it is also choosing the lives for that particular form. In this framework, the weakest point of parametricism for urban design is prioritizing the aesthetic values in the design process. Regarding its theoretical background and practices for the urban scale, it seems that parametricism has the potential of being an over-design approach for a complex system, and objectifying the urban form.

In this framework, to discuss the aesthetic inquiry of parametricism with its theoretical background and its practical premises over an exemplary work, this paper examines Zaha Hadid Architects' (ZHA) winning proposal for Kartal-Pendik Urban Design Competition (2006) in Turkey (Figures 1–4).

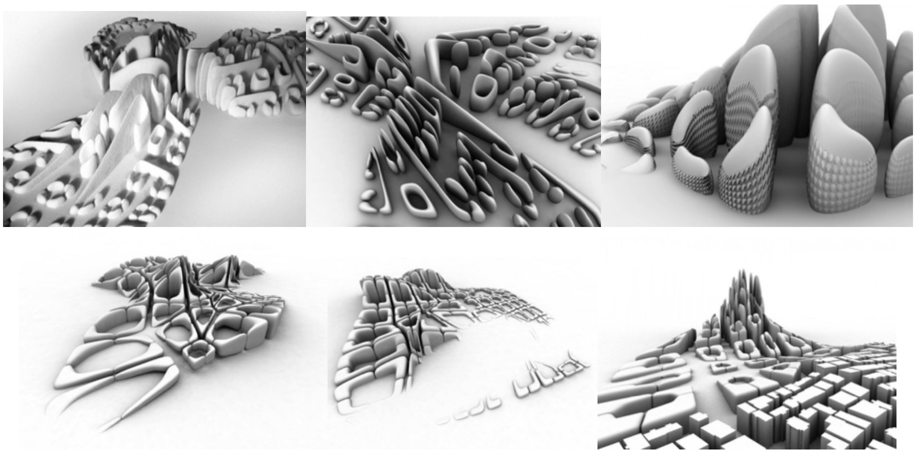

Figure 1. Stills from the design process, ZHA, 2007

The design process starts with the hair tool for creating roads, transportation lines, and building blocks (Figure 2). Then the process continues with the form finding studies for the topological evaluation of different functional, social, and topographic values.

Figure 2. The representation of emerging roads and blocks with hair tool during design process, ZHA, 2007.

As an architectural style, parametricism relates to use of computational techniques and the generation of tools for the design process (Schumacher, 2012). Hence, each of these tools or techniques is also designed with a particular aesthetic prospect. In their design projects, the team designed a particular design tool with 'calligraphic' features for the building forms. Considering the user equality, Schumacher claimed (2009) that approximately a hundred different building forms are generated with this calligraphic design tool (Figure 3).

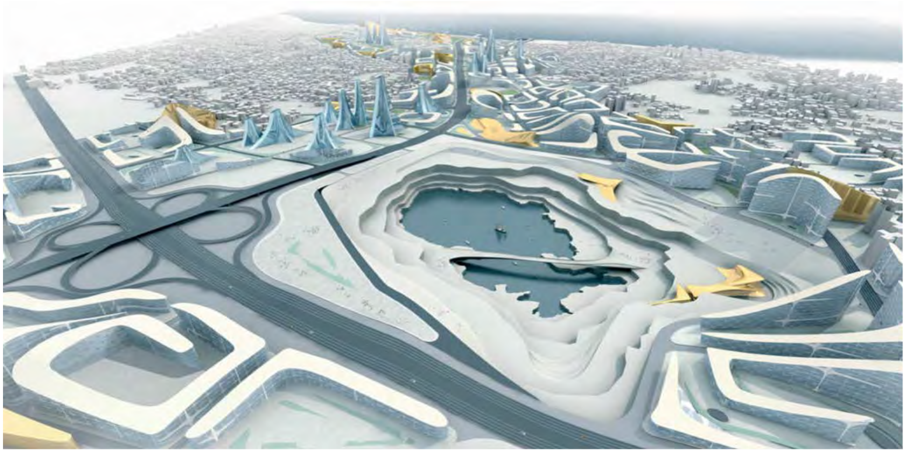

Figure 3. Examples of generated building forms with calligraphic design tool, ZHA, 2007.

While a parametric approach has the power of generating one hundred alternatives for different type of users at once, the aesthetical intention behind the calligraphic tool in the project is recognizable only in the urban planning. Therefore, it is difficult for the users to acknowledge the sophisticated intelligence behind the building forms or perceive the aesthetic intentions (the calligraphic concept) of those buildings (Figure 4).

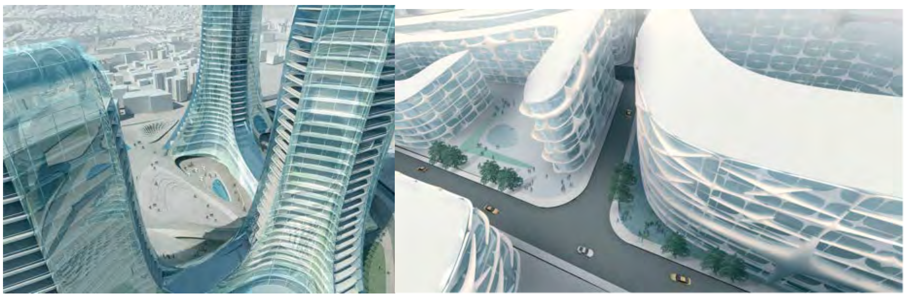

Figure 4. Stills from the buildings, ZHA, 2007.

4. Discussion

Regarding the numerous social, programmatic, ecological, and economical parameters in the urban system, an urban form can be seen as an organic form of dynamic relations. And no matter how slow they are, there are ongoing transformations and changes in these relations which will eventually affect the form. Therefore, an urban design should not be seen as a single problem to solve at once, but it should be seen as a complex of different problematics that requires time or becoming. Accordingly, compared with intuitional design approaches, parametric design has great potential for implicating spatio-temporal dynamics of form. In parametric approaches, various programmatic, social, conceptual and environmental relations are used or tested for real-time simulations. All these parameters can be simultaneously managed and enhanced as inputs for different computational design tools and algorithms. Hence, parametricism has the advantage of controlling complex topologies of an urban form and creating systematic organizations under different concepts.

Still, when parametricism is considered as a style and applied under conceptual approaches for an urban design, we are likely to face over-designed, arbitrary solutions. When parametricism is defined as a style where aesthetics meets sophisticated intelligence, we may claim that its dominance on the aesthetic beauty weakens the intelligence of its topological relations at urban scale. Whereas all the parametric relations are based on multiple topologies of different systems; and all these relations can be simultaneously applied, their outcome as a whole represents a single homogeneous form or a pattern. In parametricism, whenever any of these parameters change, the whole form is affected by that change. No matter how sophisticated or intelligently designed, the aesthetic intentions of a conceptual parametric form or the homogenous part-whole relations behind that form would eventually stand against the urban transformation.

4. Conclusion

Although parametric approaches in large-scale studies, as in urban planning, have the great advantage of controlling multiple relations or creating simultaneous, flexible, and complex organizations, the aesthetic inquiry or conceptual intentions behind parametricism seems ‘arbitrary.’ As in ZHA’s exemplary work (2006), the implication of computational tools for aesthetic intentions (the implementation of calligraphic features) in building scale is not as effective as it is in urban scale. Since each system has its own parametric rules for its own scale, the aesthetic response of an urban form cannot be compared to the aesthetic response of a building form. Also, using the same computational design tools for different design scales, might suppress the sophisticated intelligence behind the aesthetic values of parametric forms. Therefore, parametricism for urban design stands at the edge for now. Even though it seems like a flawless order behind chaos, it also seems like an over-design of a complex system for its users.

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ZAHA HADID ARCHITECTS, Kartal-Pendik Master Plan, 2006, image, open source: http://www.zaha-hadid.com/masterplans/kartal-pendik-masterplan/ (last accessed on 25.05.2015

Section

II

DESIGN FABRICATION

DESIGN CONSIDERATIONS DUE TO SCALE EFFECTS IN 3D CONCRETE PRINTING

ZEESHAN Y. AHMED, FREEK P. BOS, ROB J.M.WOLFS AND THEO A.M. SALET
Eindhoven University of Technology, Netherlands
z.y.ahmed@tue.nl | f.p.bos@tue.nl | r.j.m.wolfs@tue.nl | t.a.m.salet@tue.nl

Abstract. The effect of scale on different parameters of the 3D printing of concrete is explored through the design and fabrication of a 3D concrete printed pavilion. This study shows a significant gap exists between what can be generated through computer aided design (CAD) and subsequent computer aided manufacturing (generally based on CNC technology). In reality, the 3D concrete printing on the one hand poses manufacturing constraints (e.g. minimum curvature radii) due to material behaviour that is not included in current CAD/CAM software. On the other hand, the process also takes advantage of material behaviour and thus allows the creation of shapes and geometries that, too, can't be modelled and predicted by CAD/CAM software. Particularly in the 3D printing of concrete, there is not a 1:1 relation between toolpath and printed product, as is the case with CNC milling. Material deposition is dependent on system pressure, robot speed, nozzle section, layer stacking, curvature and more – all of which are scale dependent. This paper will discuss the design and manufacturing decisions based on the effects of scale on the structural design, printed and layered geometry, robot kinematics, material behaviour, assembly joints and logistical problems. Finally, by analysing a case study pavilion, it will be explore how 3D concrete printing structures can be extended and multiplied across scales and functional domains ranging from structural to architectural elements, so that we can understand how to address questions of scale in their design.

1. Introduction

Not many years back, the architectural profession was confined to a blank sheet of paper and set of hand tools (pencils, T-squares, compasses and so on) to start on a new design for every client. The introduction of computer aided design (CAD) changed this process. Desktop design software like AutoCAD, Revit, CATIA, Sketch-up, and so on, have substituted hand drawn design. With CAD being more detailed, easy to correct and replicable by simply 'click, drag and drop,' enormous freedom was granted to designers to perceive and visualise geometries which were difficult with manual drafting. Digital design further evolved to more complex CAD forms collectively known as 'computational design'. These approaches are responsible for the introduction of new freeform types of architecture known as 'blobitecture' or 'fluid architecture'. This further evolved to a more radical approach for digital design called 'algorithmic design' where the designers set out design criteria rather than determinate designs (Susskind, 2015).

In the 1990s, Digital Architecture was often criticized for not contributing enough to fill the gap between materialization and construction with CAD strategies. However, in the 2000s, with the widescale introduction of CNC machines in the market, the gap between what is physically feasible to build and digitally possible to design narrowed, eventually enabling designers and architects to bring their designs into the physical world from the virtual medium. The scope of the digitally controlled fabrication process widened with the introduction of industrial robots to architectural research (Lauer, 2014).

This generic, anthropomorphic and versatile nature of robots has inspired engineers, architects, researchers, etc., to equip these machines with tools for assembling, printing, milling, weaving, cutting or painting, etc. Even though in the field of building construction, robotic fabrication has been introduced recently, a remarkable amount of small yet sophisticated structures (icd.uni-stuttgart.de, 2016), have already been built displaying a high degree of special and structural differentiation, and have impressively demonstrated the flexibility of such robots. Even though a lot of proofs of concepts have been achieved through various research with high quality and intricacy using the full potential of CAD, CAM and CAE. until now large-scale applications in construction have barely been investigated (Lauer, 2014).

One of the manufacturing methods that has been enabled by the introduction of robots is 3D printing of parts in various materials, such as polymers, steel, glass (Klein *et al.* 2015), and concrete. Additive manufacturing of concrete is being developed and investigated by several private enterprises and academic institutions around the globe. Eindhoven University of Technology (TU/e) is operating a 3D Concrete Printing (3DCP) facility to research the potential of this method (Figure 1), which is expected to include increase of design freedom, mass customization, and reduction of CO_2 footprint, physical labour and material use (al, 2016).

Figure 1. 3D printing facility at TU/e, with some examples of printed objects.

Although the term '3D printing' might suggest any shape can be printed with 3DCP, in fact what is printable is bound by specific constraints. The parameters governing the design of printable concrete objects have hardly been investigated. The objective of this paper is to show that scale is one of the governing parameters in the design of 3D concrete printed structures, by discussing a case study pavilion recently constructed at the TU/e.

2. State of the Art

Most of the existing efforts of 3D printing of concrete are based on the Contour Crafting method introduced by Prof. Behrokh khoshnevis (Hwang and Khoshnevis 2005) . This method uses the Fused Deposition Modelling principle, where layers upon layers of concrete filaments are deposited to obtain the required form. Similar pioneering research was done by the University of Loughborough (Lim *et al.*, 2011). Shanghai-based construction company Winsun (yhbm.com, 2016) and Total Kustom in Minnesota, United States (totalkustom.com, 2014) has shown commercial application of this process.

Another method of large scale 3D printing was introduced by D-shape, research pioneered by Enrico Dini which instead of using an extrusion process of printing, is done by Stereolithography that requires only mortar and an inorganic binder (d-shape.com, 2016) With 3D printing technology, entire constructions can be done without any human intervention. The main advantage of this system is being able to fabricate any kind of concave geometrical structures without the use of any kinds of mold or scaffoldings.

More extensive overviews are provided by Lim *et al.* (2011) and Wolfs (2015). The TU/e operates a 4-DOF gantry robot with a printed bed of 9 x 5 x 3 m. The facility, its capabilities and limitations are extensively described in Bos *et al.* (2016). For the research, a custom concrete mix was developed by SG Weber Beamix. The mortar is comprised of Portland cement (CEM I

52,5 R), siliceous aggregate , limestone filler and specific additives for ease of pumping, rheology.

3. Design and Fabrication of Concrete Pavilion

For the purpose of demonstrating and exploring the impact of scale on the capabilities of the TU/e 3DCP facility, a case study pavilion was constructed in the TU/e structures laboratory and presented during a public demonstration session on June 24, 2016. It helped in exploring design possibilities and understanding the relationship between a CAD design and its printability with the TU/e printer. The initial design of the pavilion was proposed by I'M Architects and Witteveen+Bos consulting engineers (Figure 2). The size of the pavilion amounts to 3.5 x 2.5 x 2 m with a layered dimensions of h x w = 10 x 40 mm. The design was based on initial understanding of 3DCP process and the capabilities of the printer available at the TU/e. However, while printing the pavilion there were numerous issues that were caused by the scaling up of the printed object, which needed to be addressed. Not all of these were initially anticipated and taken into account while doing experiments on small-scale prototypes. These issues are discussed further in the following sections. Eventually, the research team redesigned the pavilion to the capabilities of the printer. The final result is shown in Figure 3.

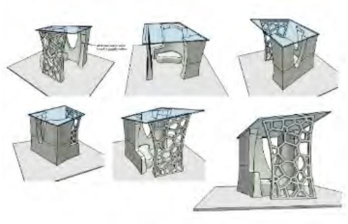

Figure 2. Initial proposal for the pavilion

Figure 3. 3D concrete printed pavilion

3.1 MATERIAL DEPOSITION

3DCP process as adopted at the TU/e is based on extruded deposition of concrete filament layers upon one another to print the desired form. The concrete used in this process is a viscous low slump concrete which is pumped though a hose to the print head mounted to the robot with an external pumping machine. The entire process of material extrusion depends on various tangible and intangible parameters, such as the pressure with which the concrete is pumped though the hose, speed of the robot kinematics, cross sectional opening of the nozzle which defines the dimensions of the printed filament, number of stacked layers and curvature of the printed geometry, and so on. All these mentioned parameters or variables are either directly or indirectly affected by scale of the printed form or printing time.

3.2 PRESSURE IN THE SYSTEM

As the scale of the element increases, the printing duration increases proportionally. The 3DCP facility uses a standard mixer-pump to mix and pump the concrete in two subsequent processes (Figure 1). This allows separate control of the mixing and pumping processes which is required to align the pumping with the printer movement. To obtain a linearly controllable pressure in the concrete flow, the pump mechanism uses a frequency-controlled positive displacement screw. While printing, the cement and other additives are mixed with water to produce concrete that lands in a vessel before being pumped to the print head under 1 to 3 bars (10-30 MPa) of pressure. During this process there is friction produced in the screw due to prolonged pumping of concrete. This results in a temperature increase within the pump, which affects the chemical hardening reaction of the concrete. With the long duration of printing the concrete, this further reduces its workability, which either results in corroding the insulated rubber in the pump or depositing substandard filament layers with poor structural properties.

The influence of this scale effect can be limited by restricting the number of layers in individual elements. This, however, leads to an increase of joints between the smaller elements, which in itself can be detrimental to the overall structural performance.

3.3 ROBOT KINEMATICS

3.3.1 Corners

The initial design (Figure 2) proposed by the architect had sharp or pointed edges. These had to be mellowed down to blunt edges because of the robot kinematics. The print head follows a toolpath, the path through space to produce the desired results. This toolpath is independent of any dimensions, so the robot kinematics moves along this toolpath with point blank accuracy without considering the dimensions of the printed filament. However, printed concrete filament naturally has a finite size, e.g. of 10 x 40 mm. This results in a difference in radius of curvature for the inner curve and the outer curve. With the toolpath being the centre line of the filament, if we make sharp turn in the toolpath (e.g. 90°) the material deposited in the smaller inner curve tends to pile up, thus affecting the section dimension of the filament (Figure 4a), while the outer curve tends to expand which also affects the dimension of the filament and can cause cracking. When printing continuous layers above one another, this error starts to build up and it eventually results in slanting of the layers on one side, which in turn results in substandard or even failure of the printed elements.

Figure 4(a, b, c, d). (a) Irregular material deposition, (b) Tangential nozzle positioning to filament, (c) Concrete printing adopted by University of Loughborough, (d) Fileted curvatures

3.3.2 Translation and rotation interaction

Another scale effect, that actually *de*creases when scaling up, is related to interaction between translational and rotational movement. During printing, the nozzle head needs to be tangential to the toolpath, otherwise twisting in the layers will occur (Figure 4b). To avoid that, C-axis of the robot rotates keeping the nozzle head tangential to the toolpath. However, if the curvature of the toolpath is too steep the rotational axis of the robot cannot keep up with the translational axes. This causes jerky movements of the robot, and likewise affects filament. In addition, extremely pronounced or abrupt toolpaths can cause (frequency induced) vibrations in the print arm, which will result in poor print quality as well. These problems can be solved either by reducing the linear print speed, preferably in combination with scaling down the dimensions of the printed filament as demonstrated by the University of Loughborough (Figure 4c), or by scaling up the overall geometry so that curvatures become less extreme. In the pavilion project it was resolved by simply fileting two curves with enough radius of curvature that it did not affect the dimensions of the printed filament (Figure 4d).

3.3.3 Print Bed

The 3D printer having a printed bed of 9 x 5 x 3, has a direct relation to the scale of the element to be printed and has to be within that scale. However, the built forms, which require elements to be larger than the printed bed, need to be printed in parts. This means that during the design process these joints or the assembling of parts needs to be taken into account. While doing so it needs to be considered that whether it's a 4-axis gantry or 6-axis robotic, in most cases it has a flat printing bed due to concrete being a slow hardening printing material – while printing it settles on the printing bed due to its material properties unlike other 3D printed materials like plastic which dries immediately, and scaffolds can be printed in space to support any form of geometrical forms.

Each element of the pavilion was printed flat and stacked one above the other and this ease of assembly was an important consideration in the design of the pavilion (Figure 5a, b).

Figure 5(a,b). (a) Printing of elements flat in parts, (b) Assembly of the printed elements

3.4 DIMENSIONAL CROSS SECTION OF THE NOZZLE

The tip of the print head is a hollow cross sectional element through which the concrete is pushed out to form layers of concrete filament and the shape and area of the cross section of the nozzle governs the dimensions and the geometry of the concrete filament. The initial tests were conducted with nozzles of round cross sectional dimensions of Ø25 mm (491 mm^2); however, the resultant round filament was unstable as the number of layers deposited over each other increased. The geometry of the cross sectional opening was improved with a square cross section of 25 x 25 mm (625 mm^2). This resulted in increasing the extrusion pressure to synchronize with the speed of the robot kinematics as there is a direct relationship between the nozzle opening and extrusion pressure in the system. However, this did not have any significant negative effects as it increased the speed of the printing process, but as the number of layers increases it had stability issues as like the previous case and was restricted to a certain number of layers. Currently, a 40 x 10 mm (400 mm^2) opening is being used which has shown promising results in increasing the number of stacked layers and thereby increasing the scale of the printed element. In each of the above mentioned cases the scale and cross section of the nozzle plays a governing role in the layered geometry of the printed filament and in turn of the printed element.

3.5 LAYERED GEOMETRY

As mentioned earlier the dimensions and layered geometry of the printed filaments has a direct relation to the stacking capacity of the printed elements, and scale plays a clear role in the design of the printed elements. In theory irrespective of the design the printer can print all geometries with the same efficiency; however, material behavior changes with scale. While printing, the concrete filament deposited is in its dormant period which gains strength with time (Wolfs 2015). The initial design of the pavilion was adjusted considering this limitation of the printed geometry. While printing large curvatures, as the number of layers stacked upon each other increases, there is a horizontal pull in one direction which could be a result of substandard layer deposition as discussed earlier, or material deformation. Consequently, the layers start slanting in one direction ending up collapsing while printing.

During this phase the tool paths of large curvatures of the printed elements are broken down to smaller curves. These smaller curves provide enough stability for the printed layers without significantly affecting the overall design of the element.

4. Logistics

One of the most important scale dependent parameters in the construction or manufacturing process is logistics. The research direction adopted at the Technical University of Eindhoven on 3D concrete printing is to print smaller blocks of pre-fabricated elements and assemble them together to form larger objects (Figure 5a, b). The main argument to justify this approach is due to the fact that the printed design is limited within the printing bed of the robot. So to scale up the constructed element there can be only two solutions: either having a robot printing bed always larger than the building or printing in parts and assembling them. The latter approach is the most widely adopted approach for 3D concrete printing (totalkustom.com, 2014).

However, with this approach logistics plays an important role. For the printed pavilion according to the initial design the entire pavilion was printed in one go without dissecting the pavilion in parts. However, as discussed above, with problems of layer strength, and due to their heavy self-weight, the elements failed while moving them from the printed bed.

An important point to consider while comparing traditional construction with pre-fabricated 3DCP parts is the fact that the assembly of parts for traditional construction does not affect the design of the element. For example, for the construction of columns in a multistorey building, for each floor of columns that gets constructed, the reinforcement bars of the columns get welded together and the concrete column is casted within a mould. Here the reinforcement bars act as the assembly joint for the columns. But for 3DCP assembly of parts completely relies upon the interface joins between two elements, which may be joined with an adhesive or an interlocking joint.

Taking into consideration the assembly and logistical issues mentioned, it is extremely important that the overall design of the element considers this issue within the design problem.

In case of the pavilion being a temporary installation for stability the parts were stacked upon each other with hollow steel sections of 50 x 50 mm bars. However, for the ease of logistics, to move the pavilion there are no materials in the interface between two parts for adhesion, to easily disassemble it into parts to shift to another location.

5. Conclusion

Additive manufacturing with 3D concrete printing shows a promising alternative to traditional subtractive manufacturing, with which virtual computer aided designs can be more accurately realized with minimal or no manual inaccuracies. However, the technology is still in its infancy, and most structural and design research conducted at universities and research centers limit the scale of the prototypes manufactured. There are considerable avenues of research due to the effect of scaling up, which needs to be explored in detail to have an in-depth understanding of the limitations and potentials of this technology and to evolve it to be commercially applicable in the building industry.

The above discussed issues related to additive manufacturing also reveals limitations with the present CAD (computer aided design) processes to translate designs to computer aided manufacturing (CAM), taking the limitations of material and the manufacturing process into account. This upgrade in the process would transform the design and manufacturing process from “designed to manufacture” to “manufacture to design”. The latter having the edge over the former with the fact that, at the stage of manufacturing, designs need not be compromised to meet the requirements of manufacturing.

Acknowledgements

The TU/e research program on 3DCP is co-funded by a partner group of enterprises and associations, that on the date of writing consisted of (in alphabetical order) Ballast Nedam, BAM Infraconsult bv, Bekaert, Concrete Valley, CRH, Cybe, Saint-Gobain Weber Beamix, SGS Intron, SKKG, Van Wijnen, Verhoeven Timmerfabriek, and Witteveen+Bos. Their support is gratefully acknowledged. Furthermore, we would like to thank MSc students Jutinov, E.R; Doomen, C.C.M;, Strien, E.C.F.van; Bartels, N.A.J; Houben, T.F.L; van Alphen, J.M.J. and Marijnissen, M.P.A.M for their work on the pavilion.

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INTEGRATION OF DIGITAL TOOLS AND FABRICATION METHODS FOR LEARNING CAAD

Innovative pedagogy methods applied in a design college in Abu Dhabi

MARCO SOSA AND LINA AHMAD
ZAYED UNIVERSITY, Abu Dhabi, United Arab Emirates
marco.sosa@zu.ac.ae | lina.ahmad@zu.ac.ae

Abstract. The interior design curriculum at the College of Arts & Creative Enterprises (CACE), Zayed University in Abu Dhabi, offers two CAAD courses; the first is concurrent with first-year Interior Design studio; the second is a year later. The objectives of the first is equip students with the tools needed to represent and communicate their designs, while the second looks in-depth into the process of documentations. This paper will focus on presenting our pedagogical approach in the first CAAD course, as well as tracing students implementation, knowledge utilization and how it is carried over into their main interior design studio. It will also shed light into CAAD influence on expanding student technical and material knowledge through direct space survey and documentation. The paper aims at presenting and reflecting upon a dynamic devised adaptable pedagogical method that identifies two student categories; those who learn how to 'practice design' (majority), and those who unfold the realm of 'being a designer' (minority). It is the latter few that continue their path, emerge into various international settings, and have a major influence on their local communities.

1. Introduction

The two researchers are architects acting in their capcaity as Assistant Professors of Interior Design at Zayed University, a Federal University in Abu Dhabi. Our students' come from a unique demographic, they are all Arab females and local Emirati with a unique background that is rich with culture and tradition, situated amidst a global and international setting, yet still in an isolated protected sheltered environment. Zayed University was founded in 1998 as an all-women's university based on the American liberal arts college system. It houses five colleges and over 8,000 students attending classes on two main campuses, one in Abu Dhabi and the other Dubai. The University became co-educational in 2008 with the introduction of the men's program, but undergraduate education remains gender segregated and

80% of the students are female. Zayed University is accredited by the Middle States Commission on Higher Education. In addition, the College of arts and Creative Enterprises holds substantial equivalence accreditation from the National Association of Schools of Art and Design. The Interior Design program is one of the four majors offered by the college. Our students join the program with limited exposure and very basic acquired design skills, yet with extensive ambition and yearning for learning. They spend their first three semesters fulfilling university and language requirements, and join their selected major on semester four, very often with a misinformed understanding on the difference between design and decoration. As educators, we find ourselves having to address simultaneously two main tasks: to instil, in our students, design thinking process, and to equip them with basic knowledge and representation tools and skill sets to be competent designers. We offer two CAAD courses; the first (CAD 1) offered concurrently with their first interior design studio and the second (CAD II) a year later. The first aims at equipping students with the tools needed to represent and communicate their designs, while the second is more an in-depth look into the process of documentation.

2. CAD I

This course aims at providing interior design students with sufficient skills to be intermediate users of CAD 2D in relation to interior design and space planning of both residential and commercial spaces. Upon successful completion of this course, students are normally able to understand which digital CAD/BIM technology is applicable to which target audience and demonstrate proficiency in the use of industry standard vector-based CAD software and associated hardware technologies. The normal learning process applied consists of presentations and discussions about contemporary digital design techniques and implementations in the Interior Design practice, lectures and hands-on training in the use of the software packages. The primary software used is Autodesk's AutoCAD Architecture (ACA). Traditionally, the course was taught through a series of exercises encouraging learning by repetition. We have been experimenting with an alternative way that builds on the student's needs and encourages exploration and search for the 'right' answer. Basic CAD commands are introduced over a few consecutive classes. Students are then given an assignment that requires more knowledge than they had been given to successfully execute. Students are left to experiment and discover based on their needs and project requirement. This, straight away, separates students into two categories; those who inquire about the process to find information and those who 'demand' to be given the answer.

3. The new approach - extended

“A new digital revolution is coming, this time in fabrication, it draws on the same insights that led to the earlier digitizations of communication and computation, but now what is being programmed is the physical world rather than the virtual one. Widespread access to these technologies will challenge traditional models of business, aid and education.” (Gershenfeld, 2012).

We believe that teaching is directly connected to self-learning and experimenting, especially when teaching design. Whereas there is a set formula to learn technical skills, software, history, facts and figures, design involves intuitive learning. This is achieved through inquisitive and active experimentation, especially in investigating how materials ‘form’ spaces and how people occupy spaces and their effect on their environment. These experimentations are carried out using digital or physical models, using digital or artificial light or actual daylight. These findings must then be recorded meaningfully using video, photography, sketches and drawings for them to be successfully represented as ‘atmospheres’ in design proposals. The system follows learning by making, doing, discovering and experimenting. We believe that these factors should be applied to skill learning class such as CAD for interior designers. We believe that learning such a valuable technical skill should be integrated into the student’s journey developing as a designer. “A prototype is both a question and an answer. An agent provocateur. A dry run. A rehearsal. A preview. And, at its best, a revelation.” (Burry & Burry, 2016).

During the summer 2014, Zayed University, received two digital fabrication machines; laser cutter and 3D printer per campus. Although we recognize that the two machines and the adjacent wood workshop are not enough to put the students on the forefront of the ‘maker’ movement, it allowed us to explore the possibility of integrating these machines into the studio environment and CAAD labs, test students recipients, and utilize the teaching tool as a mean to produce meaningful research. Therefore we engaged in a process of linking deliverables in a studio/lab project to larger body of ongoing research, allowing for more experimental and progressive project studio design briefs. This approach gives the opportunity to students to have meaningful deliverables that are not simply generated as skill or design exercises but are research contributions, while adhering to the required learning outcomes set in the syllabus. Our interior design students excel at following instructions, and learning technical skills such as: drawing, painting and CAAD skills. However, they quite often find difficulty in transferring the learnt technical knowledge to utilize it in their studio design proposals and scheme representations.

4. Case study I

On June 2014, the United Arab Emirates inaugurated its first architectural pavilion at the 14th Venice International Architecture Biennale. The pavilion's title was; "Lest We Forget; Structures of Memories" with Dr. Michele Bambling, as curator. The exhibition chartered the impact of modernist architecture in the UAE and provided a timeline of the history of architecture in the UAE for the past 100 years. Part of the problem encountered at the time, was the lack of available and accessible information, this is partly due to the rapid development of the nation. Some of the material had to be generated and the curatorial team was keen to involve higher education institutions. One of exhibits required the production of architectural facades of modernist buildings. This was a coordinated effort between professor Deborah Bentley from Abu Dhabi University and us. A method was adopted to record a series of modernist building facades in Abu Dhabi. Students were introduced to two main prototyping technologies; subtractive and additive (computer controlled laser cutting and 3D printing). At this stage, majority of the students either lack or have very basic understanding of 3D modeling techniques. With the help of this technology, and through rigorous outline of production and implementation steps, students produce detailed elevation façade drawings and sectional physical models of assigned buildings. The exercise has a series of outcomes; teach students the basic skills for drafting in 2D using CAAD, Teach the students how to use CAAD to generate three-dimensional structures using digital manufacturing technology. Through the drawing and physical model production, we teach the Interior Design students how to analyze the façade and help them understand how these facades are composed in a series of layers making transitional spaces between private/home and public/street. In addition, the models show the simplicity of the designs adopted by architects of the period to be economical with materials (due to shortage of locally source materials) and adapt to cultural and climate needs in the region. The chosen buildings were built between 1975 and 1990, which define the 'growing' period and nation forming of the UAE. A period often referred to as "settling the nomad" (Elsheshtawy, 2011). The purpose of the study was to create awareness in the built environment in the UAE and engage in a conversation about a possible approach to architectural sustainability by keeping and the maintaining of existing build environment. (Sosa & Ahmad, 2015). This exercise was a form of preservation as well as drawing the public attention to the time specific tectonic intricacy; usually hidden under layers of accumulated poor maintenance. The method we followed was a sequence of activities; photograph the facades of the buildings on site. Assign a scale to the elevation photograph using the building façade components and the street elements. Use CAAD to draw the facades generated by the elevation photographs to produce a two-dimensional elevation drawing of the building's façade. Use the DWG file to rationalize the make up of the façade and produce a sectional model of the pattern. Students analyze the construction sequence of the building by breaking it into sections. Usually these elevations are repeated modules that elegantly form a façade. The students then rationalize the construction of a module of the façade using subtractive digital fabrication technology using the laser cutter machine.

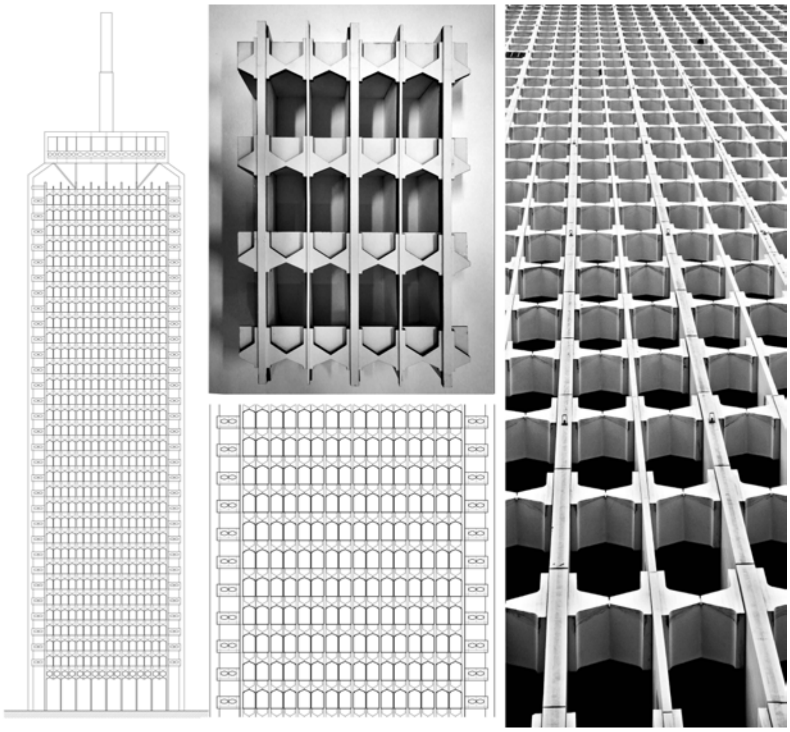

Figure 1. Rashid Tower, Dubai, CAAD drawing & model generated in class. © Lina Ahmad.

5. Learning outcomes

The students learnt how to use different media (photographs and video) to survey and generate two-dimensional architectural line drawings from them. In the process, they learn how to use the specific CAAD software and hardware available. The students then use critical thinking through devising a strategy to make the three-dimensional physical representation. They are required to think of materials composition, cutting sections and assembling process, as well as keep an eye on the overall aesthetics of the piece. They understand that machines are not magical pieces of hardware that produce beautiful objects for them, but rather sophisticated equipment that needs specific kind of data to output defined results. They learn how to use digital fabrication hardware and its possible applications to other projects. We had three objectives to the approach; 1) Test the initial response of students with zero design experience and no previous exposure to technology. 2) Initiate first steps towards the model of “learning by doing” while simultaneously integrate basic parts of current technology; thus challenging the traditional modes of how knowledge is taught and acquired. 3) Experimenting with the notion of learning outside the classroom boundary, where work progress is the main driver and lead initiator for steps to follow and knowledge to acquire; forming a piece of a larger research body. The results of the class were very successful, especially as the skills were transferred to the students work in the studio. One of the triumphs of the class was to successfully add another dimension to what students usually perceive as a tedious but crucial technical class, such as CAD. By introducing a studio aspect into it, students fulfilled all the necessary skills and learning outcomes and simultaneously produced and participated in a larger research body.

6. Case study II

On Spring 2015, The Porcelanosa Group launched the 1st Architecture & Interior design award in the UAE. Students were asked to design a bathroom within the constrains of a particular space size and limited materials available from the Porcelanosa material catalog. The competition was integrated into the syllabus of the design studio class curriculum. The timing of the exercise was specifically relevant because the participating student cohort was the first one to have gone through the Modern heritage building façade project. This was the first opportunity by which we tested the improvised pedagogy approach through assessing the process by which students utilized the learnt skills not only to represent their designs via CAAD drafting, but also via three-dimensional physical models representation for concept exploration and final design proposals presentations. The design competitions we incorporate into the syllabus, tend to be contests opened by government institutions, private companies and other organisations. The course integrated design competitions allow the students to experience the competitive conditions that will be encountering in the industry. These studio-integrated opportunities have so far been very successful, as they provided opportunities and experiences outside the studio classroom environment. This is of particular significance to our students as they are all female and mainly local Emiratis with limited opportunities to experiencing these on their own because of regional cultural challenges.

The semester culminated with the students' successful application of the learnt CAAD skills in the previous term; not just as methods of representation but also as exploration and testing tools. During the previous CAAD project some students expanded their skills to start using 3D printers through 3D modeling, while others aggregated laser-cut sections. In addition, this enabled them to reproduce complex objects, test their spatial 3D occupation, as well as push the boundaries with the laser cutting. The produced models were then carefully photographed resulting with a showcase of the atmospheric conditions of their spaces.

Figure 2. Visualization of bathroom space created through utilizing laser cutter and 3D printer technology in Interior Design Studio. ©Asma Al Mukhaini.

We kept an eye on the cohort who underwent the previous two presented case studies at their senior year, to evaluate their independent implementation. The summary of our observations is as follows; All of the 18 students used AutoCAD either to generate or as basis from where their orthographic drawings were generated. One student (A. J.) was inspired by the leftover laser cut elements. Aggregating and subtracting them, she ended up basing her interior space materiality and tectonics on the aesthetic achieved through her models. Two students (A. M. and R. K.) conducted their building site studies and analysis via CAD drawings and laser cut models. One student (K. S.) designed furniture components through laser cutting, which then informed her overall design. One student (S. O.) ventured into another Autodesk program - 3D max. Through self-taught activities that complimented course that she outsourced, she used the rendering method to communicate the materiality aspect of her environment. She also referred to laser cutting methods to design a bespoke piece of furniture that later informed her conceptual design. One student (T. W.) experimented with movable laser cut models to inform her project design. As a reflective outcome, 100% of the students' utilized CAAD software for drawings production and 33.33% of them demonstrated direct benefit from the introduced extended approach.

7. CAD II

The second CAD course takes a very different approach; whereby and due to the nature of the BIM (revit program), the outcome is geared to produce a documentation package of a space. BIM strength lies in the parametric modeling, analytical capabilities and its coordination capacities between different disciplines and design parties. Despite the encouraged industry integration, mimicking the complex procedures of actual projects in an office environment remains a challenge. This is partly due to the absence of engineering discipline in our university, but also is a direct result of students' inexperienced level. They very quickly get overwhelmed with the required hierarchal thinking process and frustrated with the alternate modeling approach through data; they perceive to dispute the familiar free hand scribbling approach. The method followed in the classroom utilized a number of BIM principles to develop and nurture students' skills and abilities; the design workflow and drawings order was reversed; generating the two-dimensional orthographic drawings from three-dimensional modelling. An emphasis was placed on understanding the difference between modelling and annotation components, and their behaviour across the different views. Parametric relation of information was highlighted and the power of data coordination was demonstrated by asking the students to produce a basic documentation package for a space using two software; AutoCAD and Revit. Throughout the term an emphasis was made on the 'tool'. When a different tool is used, the process as well as the outcome changes. In the technical class selected CAAD 'tools' are taught. In our interior design studio classroom, we do not dictate the software to use. Students are rather encouraged to explore different 'tools', understand the strength of each one and to experiment by mixing and integrating them. We stress on the importance of information relayed through the presented outcome rather than the method used to achieve it. Students are free to develop their preference, nurture their abilities and find the means to fulfill the expected requirements. Observed shortcomings; 1) Students are usually impatient and are expecting quick result, similar to those experienced in CAD I. 2) Students experience difficulty in fully understanding the Building Information Modeling methodology, and remain for quite sometime clinging to the generic automated representations offered by the program. 3) Students struggle with notion of 'family' in Revit. This obstructs and limits the elements they design with. They find themselves dependent on the available very generic families – found across the net, or on the very specific ones sources from suppliers and manufacturers. This has up-to-date availability prevented them from utilizing bespoke elements from their own design. 4) Majority of the students' work remain in the concept / schematic stage. This prevents them from experiencing the BIM strength at the detail and coordination stages.

CONCLUSION

"The transition from processes based on craftsmanship to more industrialised ways of building calls for new tectonic strategies and a rethinking of our conception of architecture." (Beim & Madsen, 2014)**.** Not that long ago, fabrication was seen as a process that follows a 'product' design. Fabrication and design were clearly differentiated as two detached non-concurrent processes. Fabrication merely led to the final outcome. Today, it very much relates to the design process, to the designer intellect and to the end users' specific needs. It manifests itself as not only an integral part of a design process but also as means of learning and knowledge acquiring journey that extends itself beyond the traditional boundary of a classroom. Fabrication methodologies combined with the recent shift to computational tools, has enabled designers to realize and "Manage high orders of complexity, experimenting with new forms of iterative graphic space" (Ahmad *et al*, 2015). We seek individual self-empowerment, whereby students learn via doing and experimenting. We recognize that our current student's work does not fall within the category of 'cutting edge design', but this paper aims at presenting and reflecting upon a dynamic devised adaptable pedagogical method that produces two categories; those who learn how to 'practice design' (majority), and those who unfold the realm of 'being a designer' (minority). It is those later few that continue their path, merge in various international settings, and have a major impact on their local communities. As design instructors and researchers, these constant changes of the design studio briefs keep us in touch with the design industry's trends and needs, and keep our teaching relevant and our students at the forefront of expectations within the industry once they graduate.

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MODELLING IN ARCHITECTURE

physical or virtual?

HATEM A. HADIA[1] AND SOOFIA T. E. OZKAN[2]
Elmergib University, Khoms, Libya[1]
archhatem@gmail.com[1]
Middle East Technical University, Ankara, Turkey[2]
soofia@metu.edu.tr[2]

Abstract. The use of models is one of the oldest media for creating, communicating and representing ideas throughout the ages. An investigation into the nature and characteristics of two modelling techniques in architectural design, i.e. physical and digital modeling, was conducted in the educational and professional domains in two countries. The aim of this study was to establish: (a) the degree of tangibility in model making as opposed to conventional and computational design approach; and (b) the *iconic* limitation of both types of modelling in design. To this end a survey was carried out among practising architects and students of architecture to establish their preferences and practices with respect to physical and virtual modelling. Some face-to-face interviews were conducted and an online questionnaire was distributed to both the aspiring and established architects. Data gathered through the questionnaire survey, interviews and photographs of the modelling process was analysed to come to tangible conclusions. Hence, this paper presents an insight into the merits and demerits of both the physical and virtual modeling techniques as seen through the eyes of professional and training architects.

Keywords: Architectural Modelling, Virtual models, Physical models

1. Introduction

Modelling during the design process is one of the most important ways by which any architectural composition can be tangibly perceived. The model, which may be physical or virtual, is a powerful medium through which a designer can fine-tune his design ideas and also present them. Hence models not only help creation but also creativity in design by virtue of their embodied characteristics.

It is argued that the performance and level of creativity in designing have been affected by the toolbars limitation brought by 3D software and digital technology. This has been a debatable issue since the emergence of the digital technology and virtual reality. The argument is that the direct interaction between the designer and the model is lacking, from the point of view of spatial interactions and tangibility, in digital models projected on the 2D computer screen; whereas, in physical models sculptured objects inhabit the real space of the viewer. Therefore, to enforce such an interaction between the designer and the objects, advanced modelling techniques have been developed in VR (virtual reality) modelling; however, physical models are still the best way of experiencing the spatial characteristics of design tangibly.

The design idea is essentially generated within the human brain three-dimensionally. Until realized, a 'design is essentially a figment of the designer's imagination', although, ideas may be communicated through drawings or specialized design media (Collopy, 2004). As opposed to architectural drawings, which are essentially a two-dimensional interpretation or representation of a design, the architectural model is a powerful design tool that is used not only for representation purposes but is also dedicated to generate multiple design ideas.

Thus, physical models are used to compensate for the lack of clarity found in the two-dimensional representations of design, while digital models may provide a more effective way of visualizing objects with greater accuracy. In fact, the fundamental differences of these two approaches play a significant role in today's architectural design practices. The questions that arise are: "Where do the fundamental differences between the use of physical models and that of the new computer technology lie?"; "What can digital models offer that the physical ones cannot?"; and "if digital models can compensate for the role played by the hand-made models, then why are we still engaged in making hand-made models?

The two types of modelling, digital and physical, have been investigated and compared in various studies in terms of their differences and value-added features in design. It has been found that unlike physical modelling, users of digital models tend to lose a sense of measurement and space. The scale factor is another issue that is detected as problematic through digital modelling. Another drawback of the restricted use of digital models is that the outcomes are often perceived as being 'too perfect, too clean, lacking individual expression and the charm of a handmade' artefact (Breen *et al.*, 2003).

Some recent studies identified four major characteristics of physical models that are different from digital models; i.e., “the vision depth effect”, “real-time shadow”, “quality and quantity effect” and “palpability” (tangibility) (Wu, 2003). Hence, the physical model has some unique characteristics that a digital one does not, that is physically processed, controlled, oriented, and tangibly experienced.

Table 1 presents a comparison between manual, digital and CAM modelling based on the studies of Lim (2006) and Bettum and Schillig (2007)

TABLE 1. Comparison of findings between handmade modelling versus digital & CAM modelling in terms of user & model interactions.

Handmade modelling versus Digital & CAM modelling

Factor	Handmade modelling	Digital modelling	CAM modelling RP & CNC	Notes
Modelling stages	2D-3D	2D-3D	3D	(RP) directly produce from the 3D file data (layer by layer printing)
Time consumption	slow	slow	fast	Except when using laser cutting
Accuracy	less	High	High	
Materials	More option	More option	Limited	Unrealistic in 3D modelling
Structural analysis	manually	Computerized	Computerized	Deriving diagrammatic thinking
Constructability	Direct interaction	No interaction	No interaction	An immediate experience becomes possible
Tangibility	Occurred from start to end	Not occurred	Only after production	only exist during HM modelling
Spatiality	Occurred during the whole process	Not occurred	May occurred during assembling	In HM outside-in & inside-out

The role of architectural models in the design process is indubitable and it would be unusual to find a design project that does not include a model. Be it physical or digital. The aim of our study was to find out the importance and impact of different types of models in both architectural education and practice.

2. Method of the Study

In order to obtain detailed information pertinent to our study interviews and questionnaire survey was used. Students and teachers were randomly selected from the schools of architecture at the Middle East Technical University (Ankara, Turkey), University of Benghazi (Benghazi, Libya) and Elmergib University (El-Khoms, Libya). Participants from each university were interviewed to obtain information on their design approach and modelling abilities; the face to face interviews were based on 18 questions.

An online questionnaire survey, based on 42 questions, was also prepared in English and Arabic, and promoted through social media networks. A random selection of practicing Turkish and Libyan architects from various design offices in Turkey, Libya, and USA was made and the link to the online questionnaire was sent through emails. 65 students of architecture and 22 practicing architects participated in the questionnaire survey. Among them nine students and six architects had already been interviewed and some of their projects' models were photographed (digital and handmade models with different materials).

Students from various nationalities had participated in the survey; 3.4% were from Turkey, 78.2% from Libya, 2.3% from UK, 3.4% from Canada, 8% from USA, 2.3% from Japan, 1.15% from Sudan, and 1.15% from Iran. Among the 87 participants (architects and students) 52 were male and 35 females, of whom 58 were undergraduate students, while the rest were graduate students or professional architects.

Data from the interviews as well as the online questionnaire survey determined the design approach and modeling preferences of the architects and students. In terms of tangibility, the interaction between the designer and the model (physically or virtually) was also investigated. Another crucial issue that concerns most of today's designers is the software limitation and characteristics of materials (physical and virtual models); i.e. which software is preferred; which modelling techniques are used; what modelling material is representative of which real one? To what extent would it be appropriate from the point of view of its structural integrity? Finally, the relationship between the production of models and marketing projects was also investigated from the interviews and questionnaire survey. The questions posed to gather data have not been listed in this paper due to page restriction; however they can be provided if desired.

3. Results of Survey and Discussion

This section presents the outcomes of the face-to-face interviews, and the questionnaire survey in both domains; educational and professional. To begin with, 9 undergraduate students in Turkey were interviewed, all of whom were from different academic levels, 1st to 4th year. Almost all the interviewed students stated that their design approach begins with collecting data for the proposed site, diagramming/zoning the collected data, making 2D sketched and sometimes making handmade compositions. Only one student stated that he usually starts with making several physical compositions using as varied materials as possible.

How students are transferring their design ideas from thought to reality was discussed in the interview. It seems that some students still were confined within the conventional design method based on 2D sketching and zoning, despite their preference for the use of digital technology. Other students preferred not get stuck between what they called the “X and Y” coordinates. Other issues such as the sense of scale and modelling materials properties were also discussed during the interviews.

The participants were initially asked why a designer should make a model. They were given multiple choices to answer in addition to the possibility of adding their own comments. The data on their answers is summarized in Figure 1.

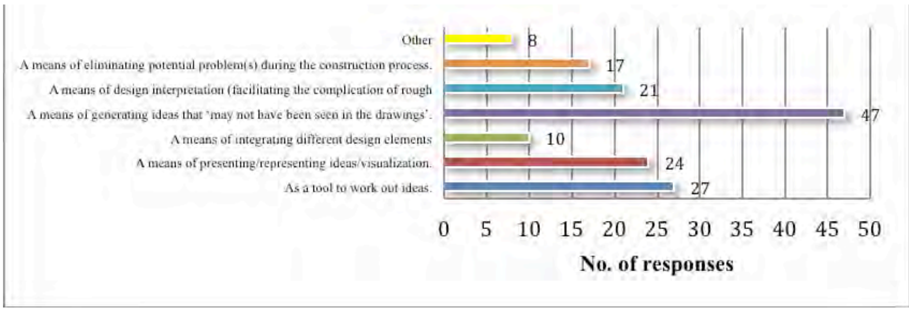

Figure 1. Primary purposes for which designers should make their models.

When given a choice between two different modelling techniques, handcrafted and digital modelling (rapid prototyping) the 61% of the 87 participants, preferred to use handmade modelling techniques while 39% chose digital modelling techniques.

Additionally, when participants were asked whether any difficulties in model-making limit their imagination and creativity as designers, 64% answered NO while only 36% answered YES. To find out the reasons behind these two different ratios, participants whose answers marked (YES) were asked to specify their reasons, which were mainly two: the difficulty of modelling complex shapes or free-forms, which sometimes forced the students to abandon or modify their initial design concept, or the lack of skills or tools to make the models.

When asked “what may force a student & designer to change his/her decision- in selecting the applicable material for making their models” Among the 87 participants, 55 chose the availability of materials, 29 chose properties of materials, 24 chose standard dimensions (size & thickness), and 14 the price. When asked about the fastest and easiest medium preferred to present an architectural idea in a hurry, 36 participants indicated their choice to be hand sketches; 29 preferred 3D digital models; 12 use physical models; 9 used 2D CAD drawings; while only one opted for animation.

Having attempted to find out more details of what may be restricting or influencing the design approach of a student or an architect, 67% of the participants say that their design approach is almost influenced by their modelling skills, while 33% did not think so. Accordingly, for having more additional information about the reasons that restricted a students' design approach, it was necessary to investigate whether students had practiced or had some modelling courses to improve their skills. Thus, participants were asked whether they had any courses allocated to model making training in their schools. 38% of the participants stated that they had model-making training in schools, while 62% declared that there were no model-making courses in their schools program. Some mentioned that model making training and practice was usually organized unofficially between the students, i.e. some experienced students offered to train other students to learn some modelling techniques.

To find out how students/architects start their design process, 45% opted for making 2D sketching (on sketch paper) then moving on; 9% preferred starting by 2D sketching using CAD application software then moving on; 13% for 3D sketching using CAAD application software, 30% for those making composition models by hand, and 3% devoted for using both techniques, making 3D composition and 2D sketches together (Figure 2).

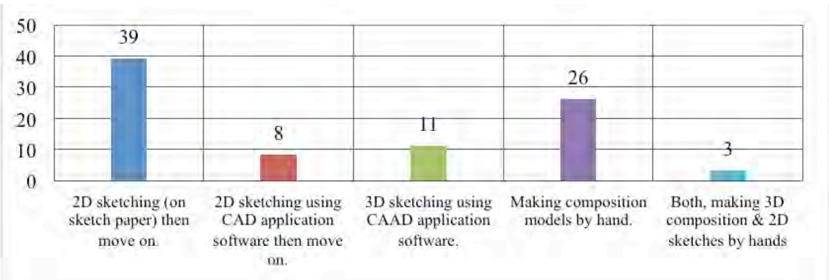

Figure 2. Five different design methods preferred by the participants.

Interestingly, although the highest percentage (45%) was given to the use of 2D sketching when starting a design process, most of them (63%) declared that a designer should start working in 3D at the beginning of the design process. Hence, participants were asked, "When do they start modelling or working in 3D?" 55 out of 87 chose at the beginning; 20 in the middle; 10 at the last stage; and 2 said it depended on the size of the project.

Participants were also asked to specify which 3D application they had mastered; choices of the participants are given in Figure 3.

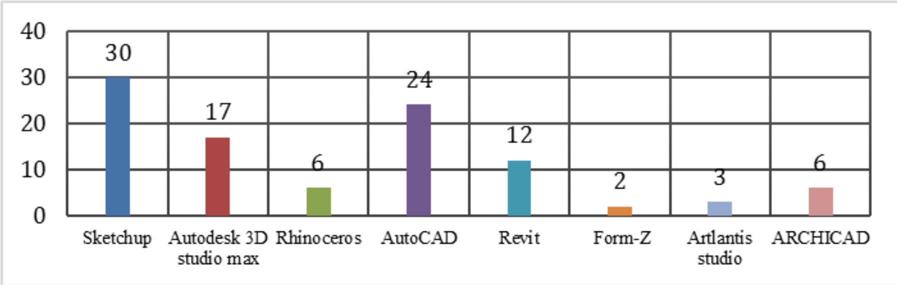

Figure 3. The various 3D software used by the participants

General opinions about the usability of models in design are elicited from the survey, 68% stated that models contributed to the design development, while 30% of the participants think that a model may just convey the design intention and 2% for both answers and only one mentioned that models do facilitate the vague of design issues to the client.

Those who used the model in their design analysis (64%) indicated that mostly working with several models helped in the development of generating design ideas and detecting orientation deficiency, i.e. for placing the proper proposal in the location. Others mentioned their use for testing structural behaviour and stability or the analysis of the inefficiency of spaces (thermal behaviour and functionality of materials).

In order to test the structure or for testing the design efficiency some computer software such as SAP, Ecotect and Designbuilder are used for digital models. On the other hand, an example of using the physical model for testing the structural stability and the interactions between the design and the surrounding is given in Figure 4.

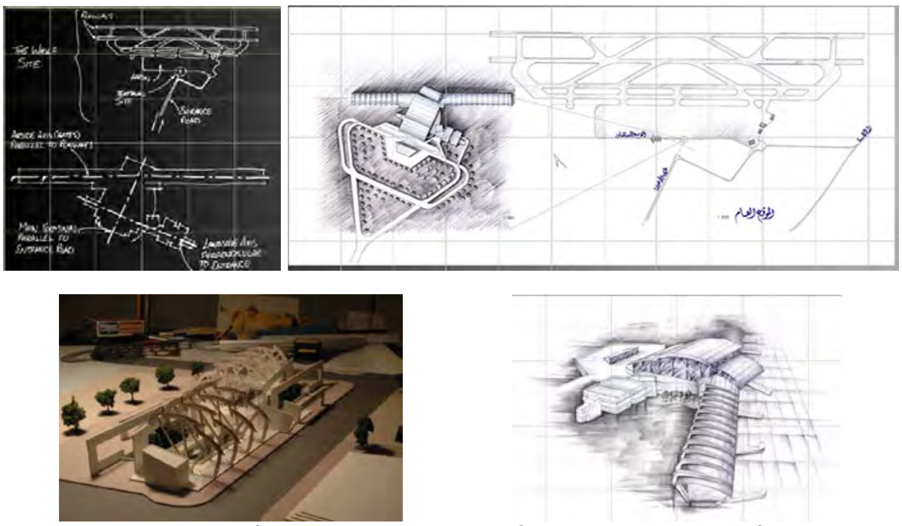

Figure 4. Development of an idea through 4 stages of representation by one of the Architect: conceptual sketch; site plans; working model to resolve the structural concept

The questionnaire represented the commonly used scales in 3D modelling among students and architects, and shows whether or not they work with different scales at various modelling stages. Some students mentioned that in schools, scales are usually determined by their instructors. While 38% believe that the use of scale depends on the degree of details for the work required. On the other hand, 46% of the participants stated that they tend to work in different scales when they came up with the main idea of their design, and this is the highest percentage among other selections. 24% usually tend to work in different scale at the detailing stage.

Participants were also requested to state the purpose for which their models were being used. 28 indicated design analysis to be the purpose; 30 indicated final presentation; 26 stated they were used to open up design discussion while only 2 said they were made to test technical/structural issues.

Another impact (of models) that was investigated was the usefulness of models in conveying the design idea when presenting their project model to others or in a discussion. Figure 5 gives data on the 5 possible responses.

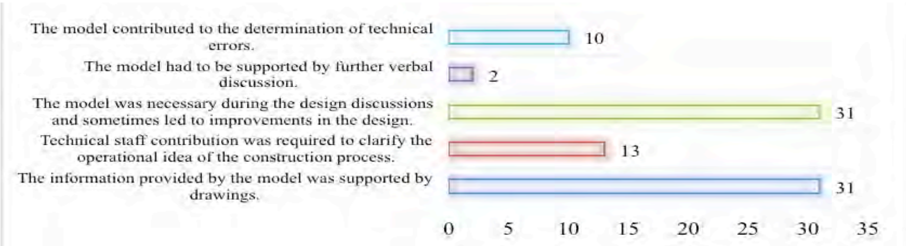

Figure 5. Experiences of participants when presenting their project model to others.

To find out the impact of models on the project outcome for both students, and architects, they were questioned separately. The students were asked whether the quality of the project model had an impact on their getting higher grades and 92% of the students agreed. The architects were asked if presenting models to the client had any impact on increasing or decreasing the chance of getting the job? 77% said “Yes” and asserted that not having made a physical model would lose their chance of getting the job, while 23% believed that there was no impact

6. CONCLUSION

The face-to-face interviews made with the participants from the three universities included in this study helped to determine the nature of the online questionnaire so as to avoid bias. Accordingly, the informal interviews highlighted some basic concepts of students’ design approach, modeling abilities and experiences; that were supported by the data obtained from the online questionnaire.

With respect to the preferred modelling techniques, most students indicated that given a choice they opt for digital modelling rather than physical. They think that making models by hands takes much more time than with computers, especially since the lack experience in handling modelling materials and techniques. They think that they lack these skills because most courses are extensively focused on the use of digital technologies while there are no training courses for manual techniques.

On the other hand, most of the students were not keen to use the hand modeling technique to create and develop their design ideas due to time constraints, limited availability of materials and the lack of experience to cope with making complicated shapes by hand. This drawback reflected the lack and negligence of incorporating model-making courses or training programs in their school. Hence, this led to touch upon how students think and express their design approach for transferring their design ideas from the unknown or invisible state into physical state.

Defining the ideation progress for each student was very complicated to identify. In other words, students were asked to define the transitions of ideas from their minds (unseen concept) until it is visually formulated. Students declared that most of the time what externalized from their minds did not correspond with the nature of their idea that they already had in their minds; they attributed this failure also to the lack of their sketching and modelling abilities and experience. Therefore, some training and practical courses with respect to the modelling techniques may contribute to help students overcome many of obstacles during their design process.

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PROTOTYPING GENERATIVE ARCHITECTURE

Experiments on Multi-Agent Systems, Environmental Performance and 3D Printing

SEVIL YAZICI[1], AND DAVID J. GERBER[2]
[1] *Faculty of Architecture and Design, Ozyegin University, Turkey*
sevil.yazici@sevilyazici.com
[2]*School of Architecture, University of Southern California, USA*
dgerber@usc.edu

Abstract. Computational design was developed to solve complex problems in architecture and to enable the establishment of systems with complex properties in a holistic manner. With the enhanced capabilities of computational design, there are possibilities to develop integrated approaches to adapt to multi-faceted design problems. Swarm-based multi-agent systems (MAS) are already used as generative bottom-up methods in various design operations, including form-finding and optimization. This study presents a systematic approach, in which multi-agent systems are informed by the environmental performance assessment data where the output is directly linked to the 3D printing process. The intent is to increase efficiency within the design and prototyping process by integrating performance and fabrication into the early stages of the design process. The proposed method has been applied as a case study to a diverse group of students and professionals. The results have proven that applying this systematic approach enabled the designers to achieve highly sophisticated, formal and organizational outputs, with enhanced spatial and geometric qualities.

1. Introduction

Goel defines design process in four phases, including problem definition, conceptual design, design development and detailing (1992). Although there are different definitions of the design process, it is possible to accept that there is a hierarchical order between different phases in conventional design processes. These phases differ based on the type of information they include and their level of detail. They also differ in terms of abstraction, parameterization and kinds of design exploration in each phase. Architecture and engineering professionals need to define objectives, propose and iterate on options, by analysing these options with respect to the existing goals and make uncertain decisions in early design phases (Schön, 1983). As Simon states, design is by definition an ill-defined problem computationally as there are multiple solutions typically as a result of multiple objectives (1973). So the synthetic endeavour of design is in part a human design decision making process in which the privileging of viable design alternatives is always a goal of the design workflow.

An integral computational model promotes an understanding of material, form and performance not as separate elements, but rather as complexly coupled interrelations (Hensel & Menges, 2008). Solving design problems in the systematic CD methodologies, including form, performance, material and fabrication constraints have been investigated through different perspectives (Menges, 2008; Oxman, 2009). However, there is a necessity to develop a more comprehensive approach to adapt to these multi-faceted problems in the design process, by expanding the formal and organizational capabilities of architects and design teams' tools, techniques, and methods. Multi-agent systems (MAS) have been used in the design process as generative bottom-up strategies for form finding, optimization and search in the design domains (Gerber, 2014). Our hypothesis asks if it is possible to enhance formal and organizational capabilities of design in concert with performance assessment, MAS and fabrication constraints. This paper presents a systematic approach for form-finding, and where 3D printing is used in the architectural design process, in which MAS are informed by environmental performance data, specifically solar radiation values.

2. Methodology

The methodology of our design experiment was developed as design protocol deployed in a CD workshop setting. The research is develop in an educational setting in which the participants learn the design protocol and present data and results which provide the evidence for our discussion. Different design tools are used in the process, in order to explore their impact and role on design. The design protocol consists of four stages including 1) form-finding, 2) deploying a multi-agent design system, 3) performing environmental performance analysis based on solar radiation, and 4) digital prototyping of the complex geometric results via 3D printing. The workflow, data and model flow are explained for the system and possible iterations are created by the system.

The workshop was planned for a two and a half day time frame and there was no pre-condition for the selection of the workshop participants, which are considered as novice designers and non-expert computational designers. Twenty-seven undergraduate students, graduate students and professionals from various local universities, with diverse backgrounds and differentiated level of knowledge attended to the workshop.

2.1. SYSTEM COMPONENTS

System components can be described according to the design protocol [FIGURE 1]. The workflow is built upon the NURBS modelling design environment Rhino, the visual and parametric scripting environment Grasshopper and physical simulation based via the Kangaroo Grasshopper plugin for the form-finding. Simulation plug-in Ladybug for Grasshopper is implemented for the environmental performance assessment, specifically solar radiation. The necessary weather data for the solar radiation is ascertained via the EnergyPlus software and database. Prior to the simulation, GhPhyton is installed and activated to enable the data transfer from Ladybug and EnergyPlus software. A custom swarm based algorithm developed in the Processing 2.0 environment is implemented for the multi-agent design system. In the final stage, the resulting models associated data sets are brought back to Grasshopper, Rhino and Autodesk Project Miller respectively, to process the model further for the digital prototyping. Two machines are used for the 3D printing, including ProJet 1000 and 3D Touch

2.2. FORM-FINDING

The graphical interface of the Kangaroo Grasshopper plugin physics engine is used for interactive simulation, optimization and form-finding. The parametric script used in the process is defined as a physical model established by defining strings and weights, based on the hanging chain model of Gaudi. It is used to test the feasibility in terms of design context and constraints established by the designer and to find the static equilibrium of the complex formal geometry of the experiment (Sweeney & Sert, 1960). A stable form is generated based on effective forces, and the geometry is hence optimized i.e. form found. Through the Kangaroo physics engine, springs and unary force is connected to force objects. Following the assignment of the curves drawn by the users, and the designers changing simulation parameters in order to design explore formal configurations, a solution space of design geometries is generated. In parametric design when the design parameters change, the overall design can respond as a holistic system through computation. Thus, various options are generated with great geometric variability and yet topologically similar. Because it was possible to generate this solution space of design variants, a rich formal repertoire is created during the process, affording the designer to make informed choices based on a larger palette of design alternatives. The geometries are then scaled to fit in a 1000 by 1000 unit square, in order to normalize the sizes for compatibility with the Processing based multi agent system (MAS) for design.

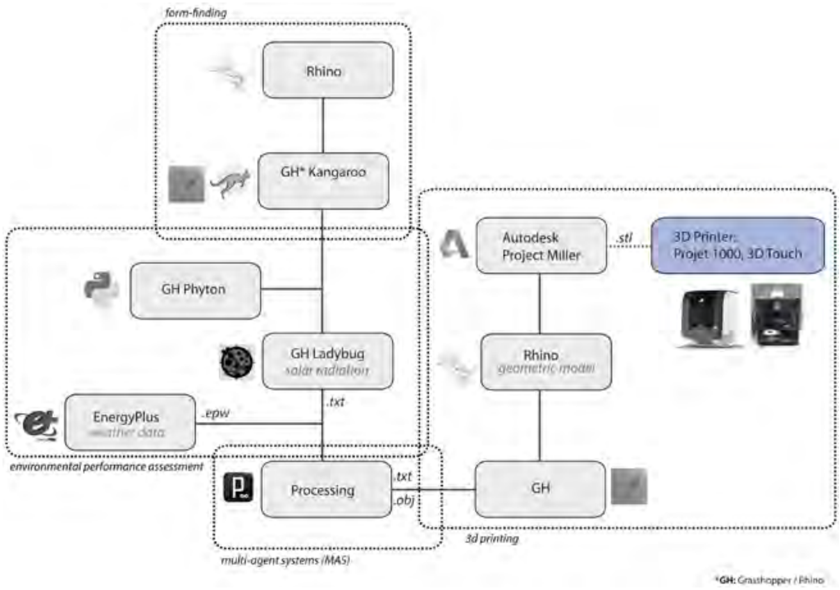

Figure 1. Illustrates the workflow, data and model flow of the MAS for design experiment and research method.

2.3. ENVIRONMENTAL PERFORMANCE ASSESSMENT

Our design experimental models are representation of systems with which we assess the system performance based on defined conditions and objective functions. Following the form finding process, an open source environmental performance analysis software Ladybug within Rhino Grasshopper is integrated to undertake solar radiation analysis. Ladybug allows the design team to import and analyse weather data within the Grasshopper visual scripting environment facilitating a connection to the database and simulation engine EnergyPlus for running radiation analysis. The environmental data, '.epw' file, is read by EnergyPlus for ascertaining the radiation values of the design geometry for a specific location, based on data from the US Department of Energy. Climate data for Los Angeles, California is used and then further detailed by specifying time ranges based on hours, days and months in the analysis. Thus the radiation values are calculated for the geographic location specified and the numerical values determined are exported as a text file for use by the our bespoke Multi-Agent Systems scripts in the Processing Integrated Development Environment (IDE).

2.4. MULTI-AGENT SYSTEMS (MAS)

Following the form finding and environmental performance analysis, the output data (the mesh as a tessellated '.obj' and the unit values for each tessellation) is imported into one of our bespoke scripts, '.pde file', developed on the open source programming language Processing 2.0 environment (Sanchez, 2013). Through these scripts, it is possible to re-generate the geometry through the interaction of the MAS with the mesh i.e. surface. The agents are programmed to make movement and trajectory decisions based on local information including intensity values from the simulation, proximity to neighbours and trails left by other agents. The agents are modelled on the Boid by Craig Reynolds and have stigmergic behaviour in order to approximate connectivity requisite of a tectonic system. The MAS is based on simple flocking behaviours weighted by the data and recursive response to the overall dynamics. Each agent has ability to extract the data from the simulation, paired with its corresponding point on the mesh object. The agent's environment is a collection of points to which it is constrained, and each point is assigned an intensity score (that of more or less solar radiation) based on the data taken from the simulation (Gerber & Shiordia, 2014). Based on the agent movement, new geometric configurations are generated. By adjusting the parameters, separation, cohesion, alignment, and solar radiation weighting factors, of the agents or how the agents are spawned, new formal organizations are achieved. The workshop participants were able to adjust and design to explore these parameters in order to generate feasible forms in conjunction with assessing the overall formal organization. The numerical data generating geometry were exported as text file and re-generated in 3D geometric modelling medium, Rhino. By running the Processing scripts, it is observed how the model is displayed, and problem areas were identified. The intensity of the agent behaviour parameters is adjusted by increasing or decreasing a set of limited parameter and ranges. This is done to ensure the participants are learning without too much cognitive overload and to focus on the most influential agent parameters and hence behaviours. Our workshop scripts are automatically configured to export a text file every 30 frames. Each text file obtains a list of coordinates for all the agent positions at that particular frame used in final geometrical operations to move from point based positions into 3D models that are solid geometries, for 3D printing.

2.5. 3D PRINTING

Based on developments in digital tools and techniques, it is possible to generate forms with high level of complexity and to translate model input into a building or a building component through digital fabrication

accurately. The widely used term digital fabrication is described as computer aided operations, in which material is formed by subtractive or additive methods. These processes are investigated in two fundamental groups: Computer Numerical Control (CNC) and Rapid Prototyping (RP). In our RP operations, the product is generated by adding layers of material (Seely 2004), through the use of 3D printers. Although in 3D printing geometries of all types of complexity can be produced, there are a series of practical constraints based on the material and machine. Here the workshop is mostly limited by material thickness, bounding box, and time limitations.
Following the MAS application, text files, generated with Processing code, as well as '.obj' files were brought in Grasshopper parametric design environment, to re-generate the geometry, based on the MAS. The intent was to generate the geometry derived from the emergent motion paths of the agents. Each line of the text file represents a set of points in 3D space corresponding to the positions/ paths of the agents. When the text file is brought into to the Grasshopper, the position of the agents at a given frame is represented by coma-separated values, as simple XYZ coordinates. Through our Grasshopper definition we automatically draw points corresponding to the coordinates in the text files as a set of curves. Finally, the curves are given a parameterized thickness in the script in order to be RP fabricated. The curves are given volume by a piping operation, where the profile is also parameterized within the script. Circle cross-sections were assigned to the curves in these experiments for consistency and cross comparison. By baking the geometry, further adjustment and rendering is performed for final presentation and RP fabrication using Autodesk Project Miller. By this tool the single surfaces were merged into one to be fabricated in 3D printer. Two different printers were used in the process, including ProJet 1000 and 3D Touch. ProJet 1000 are used to fabricate plastic pieces in high resolution with a detailed and smooth surface finishing. One or more geometries can be fabricated simultaneously by arranging the models in the build volume. The speed of fabrication is 12.7 mm per hour in layering vertically. The material used is a white polymer. The speed of the 3D Touch for the fabrication is a maximum of a 15 mm^3 per second. Acrylonitrile Butadiene Styrene (ABS) is used as material and could be selected in green or white. The simplified geometry could be fabricated seamlessly in 35 minutes by 3D Touch printer.

3. Results

The participants in the workshop ranged from 1st-year undergraduate students to professionals with different levels of architectural knowledge. It was determined that the CAD experience of participants was based primarily on conventional representational techniques, including 2D drafting, 3D geometric modelling and visualization. Interpreting new concepts, such as algorithmic design and performance issues, internalizing the knowledge, and transferring the data among six different software programs are significant challenges considering the time limitations of the workshop, which lasted for two and a half days. Although the participants had different interpretations regarding the concepts and terms, the results show that applying this method enables highly complex and differentiated tectonic organizational outputs with enhanced spatial and geometric qualities. While the participants worked with objective data, parameters and computational algorithms, they also used their intuitive knowledge in setting the parameters, resulting in a high degree of variation in the solutions [FIGURE 2-3].

The constraints during the workshop are identified; they were based largely on the digital fabrication, i.e., 3D printers. ProJet 1000 and 3D Touch were used as 3D printers, which were restricted by their table dimensions 171*203*178 mm and 275*275*210 mm respectively. The speed of digital fabrication played a significant role in the process, since the fabrication was limited to two days. One important challenge encountered in the process was the complexity of the geometries generated by MAS and their translation for the 3D printing process.

Figure 2. Output of the studies; Hasan Caner Uretmen, Ege Simsekalp and Ece Alan.

Figure 3. Output of the studies; Melis Baloglu, Omer Kirazoglu and Merve Akdag Oner.

4. Conclusion

As part of the applied method, the computer is used not only as a tool for representation but also as a generative design tool, in which form, performance and fabrication constraints are evaluated in an integrated system. In this approach, the architectural designer becomes an actor who directs the design process with parameters, rules and relationships in the conceptual design phase. Although the method in this paper proposes a comprehensive system, in which form-finding, multi-agent systems for design, environmental performance assessment and digital fabrication are holistically evaluated, it is necessary to develop automation through feedback loops between different steps of the method. For future lines of inquiry in this work, the intent is to incorporate real-time data transfer between the form-finding and the environmental performance assessments, as well as an improved optimization module.

In parallel with the technology, computational design and digital fabrication tools are widely used in the architectural design process. Thus, architects and designers need to be proficient in terms of these skills. For that reason, the issues of re-evaluating architectural design process and re-designing architectural education to include innovative approaches should be widely investigated. An integrative approach is necessary in which form-finding, performance assessment and digital fabrication are evaluated holistically. More studies should be undertaken that reflect upon this issue in the practice and education of architecture. We investigated through the workshop how different groups of people, including novice designers at the beginning of their careers; professional architects and researchers approached the problem in a similar way. All the process was considered unknown and new. Although the novice designers and professional architects approached to the problem in a similar way, their outputs were very different. In terms of future research, more studies should be undertaken to investigate complex design problems in the architectural education and profession. Architectural design involves managing multi-faceted problems, which means the field must also address complexly coupled performance criteria.

What we did uniquely is to do the workshop in a very short time frame. We also brought together the physical and the digital in order for students to learn about bottom up design and for them to see how we currently and very easily prototype with these forms. In that regard we previewed a set of potentially influential techniques and workflows that will effect design exploration and by rapid prototyping the palette of locally (bottom up) informed global (top down) design alternatives. While bottom up design models and methods are unwieldy, they have the potential for generating surprising and unexpected results of both aesthetic intricacy and beauty and of higher performance than can be manually designed, given the real limitations of time, cognitive load, and resource. The workshop itself is a prototype of a new methodology already on the horizon for architects and others to begin to work with and incorporate into their tool kits, and workflows. What our work begins to presents is new ability to design explore formal intricacy and to link this aspect of design to both performance criteria embedded in bottom up local rules of agent models, with those of global outcomes made tangible for human design decision making and subjectivity, via rapid prototyping.

Acknowledgements

The workshop was held at Ozyegin University, Faculty of Architecture and Design in Istanbul, Turkey on the Fall Term of 2013-2014. We would like to thank and acknowledge Rodrigo Shiordia, formerly a Masters student at USC, for his contributions to the workshop materials and development.

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INTEGRATING PHYSICAL AND DIGITAL PROTOTYPES USING PARAMETRIC BIM IN THE PURSUIT OF KINETIC FAÇADE

ZAKI MALLASI
College of Architecture and Design, Effat University, Jeddah, KSA
zaki@iconviz.com

Abstract. Architectural facades are designed to respond to environmental, social and functional considerations among others. Advancements in Digital Design Computation (DDC) emerged as an essential support for exploring and creating contemporary architectural facades. Current research into responsive kinetic facade suggests different methods of integrating kinetics into physical facade. However, research indicates that physical façades struggle to achieve the anticipated kinetic responses. In addition, the process is formal, prescribed, lacks flexibility and mostly assists the designer in the visualization of design. Consequently, the challenges in understanding the creative process that mediates between digital/physical kinetics are important to address in the early design stage. Digital and physical façade prototypes would allow designers to test the qualities of such system before constructing full size mock-ups and discover new modes of parametric design thinking in architecture.

We report on an ongoing development of a custom add-on utilizing Autodesk ® Revit application that connects between the kinetic properties of digital and physical model to control dynamic façade. We deployed the Revit Application Programming Interface (API) C# programming to manipulate the kinetic response through linear actuation. The system framework proposes a practical mechanism connecting solar exposure values to a Building Information Model (BIM). In this process an Arduino Mega board, servo motors, tooth-beam and tensile-fabric material were used to construct the small physical prototype and program its automation.

We tackle three challenges. The first is to dynamically harness the response mechanism of kinetic façade so as to avoid uninformed design decision making. The second is to map the digital/physical kinetic properties in terms of: modeling, process and function. The third is to assess the benefits from our approach of connecting BIM parametric model with physical prototypes. We conclude by observations from this work on how BIM parametric modeling with design computation could influence the future direction of kinetic façade systems.

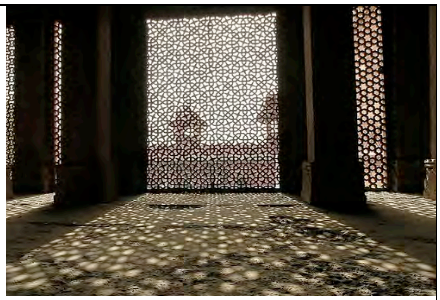
1. Introduction

Building envelopes, or a façade, have a considerable influence on the way we perceive the architectural quality and performance of buildings. Recently, there has been a increased interest in creating elements of the facades with responsive properties to meet the aesthetics and environmental design goals (Sharaidin & Slaim, 2011). In vernacular architecture, traditional features like the *Mashrabiyas* (or sun screens and shading devices) are designed with geometrical characteristics and system to reflect specific cultural aspects while shielding the building from harsh climate conditions. Using manual mechanism, the occupants can adjust the geometrical characteristics of the façade elements (e.g. open/close, stretch/retract, rotation, twist, etc.) according to the sun position to possibly provide optimum shading (Bader, 2010).

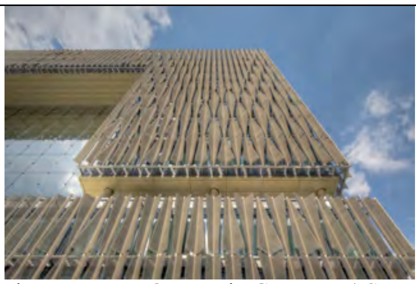
Several case studies in engineering and architecture reported some drawbacks from manually adjusting building facades as well as their responsive systems. According to Loonen *et al* (2013), the current built projects (e.g. American Pavillion, Expo67, 1967; Institute de Monde Arabe, 1987; Kiefer Technic office building, 2010; and Al Bahar Tower, 2012) using responsive facades are under researched when demonstrating how building energy optimization is achieved (see figure 1). For such projects, there is clear reference in literature to the common problems the facades are facing such as:

- The projects are yet to be constructed simply (Linn, 2014) and the process of manipulation is extremely underdeveloped.
- The motor mechanism that was controlled by 600 motors constantly failed during the operational of the building (Massey, 2006).
- The dynamic moving elements in a responsive systems are logistically complicated, too slow, and of high maintenance cost.
- There is minimal discussion about the impact of the kinetic and the composition of the facades towards environmental conditions.
- Although the outcomes of real-life case study projects indicate creative digital design processes, the facade performances results are rarely published in scientific literature (Loonen *et al*, 2013).

Al-Bahr Tower in UAE (AEDAS UK)



Mashrabya Screen



ThyssenKrupp Quarter in Germany (JSWD Architekten, Chaix & Morel et Associés)

One Ocean Thematic Pavilion in South Korea (soma)

Figure 1. Traditional Mashrabiy and modern kinetic facades projects (source: http://www.archdaily.com).

The kinetic facade behavior is an emerging concept rooted in the façade panel component. It is a performance-base design approach that assumes every component is adjustable according to its performance goals (e.g. environmental, functional, aesthetics, privacy, etc.). John Frazer (1995) in his book "An Evolutionary Architecture" explains that new forms of responsive structure emerge on the basis that flexible facade components constantly adapt to the surrounding changes. Each component is supported by use of receptors and actuators which controls the facade components transformation. A truly responsive structure could be established in a two-way relationship between the different conditions, facade structure and the user (Kolarevic, 2014). These ideas that buildings are "*alive*", "*adaptable*", "*evolving*", "*flexible*" and "*intelligent*" have profoundly influenced the architectural discourse of the 21st century and continue to do so.

Traditional building facades in essence face different conditions that are transit and constantly changing. Tashakori (2014) writes about common drawbacks of traditional buildings facades in that they are all rigid and resistant to design conditions in a static way. As a result, it is arguable that conventional buildings equipped with "static" facades configuration may not perform sufficiently as the conditions change. The author suggests the need for responsive facade elements that are constantly adapting to the changes in their environment.

This paper presents the research outcomes of the first phase experiment, examining a dynamic self-updating-loop when manipulating the individual façade elements. Further motivation was creating a small prototype as platform for future studies on this basis of "dynamic" visualization approach. It is also necessary to highlight research output that encourages further integration of (DDC) that drives prototyping of parametric BIM façade with self-update features (Harfmann, 2012). This experiment is further assisted by: parametric modeling, BIM, receptors technology and utilization of digital/physical prototyping technology.

2. Kinetic Façade Research Approach

It is important to acknowledge that the "Creating-Making" approach used in this on-going experiment aims at understanding the mechanism of the responsive façade. "Creating-Making" is not entirely new in the design process but it is flourishing as a result of development of inexpensive open source microcontroller board called Arduino UNO (see Figure 2 below). Since its release, it enabled worldwide design enthusiasts to create all sorts of interactive objects and responsive environments (Kolarevic, 2014). In doing this, digital receptors, maturity in BIM technology with visual programmable geometry sparked imagination to reignite the vision of responsive facades (Kensek, 2014).

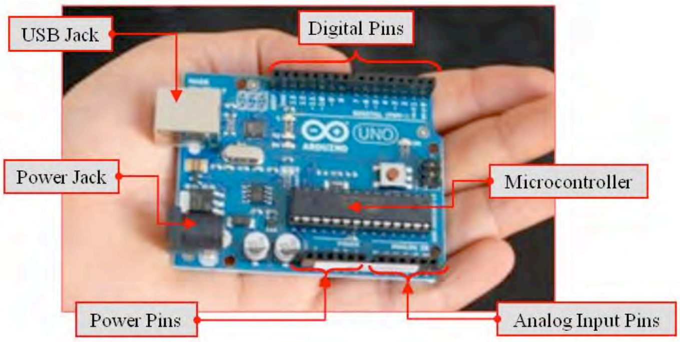


Figure 2. The Arduino UNO microprocessor board (source www.sciencebuddies.org).

2.1. CREATING AND MAKING LOW-COST PROTTYPES

There are many references made to similar research attempts in dynamic façade using programming scripts, DDC and the hardware automation process. Especially in (Kensek, 2014) who attempted to evaluate in eight case studies to connect simple BIM model, Arduino and environmental sensors to control sunshade 3D model. In the examples, a movable light-shelf was adjusted using Rhino and Grasshopper with Aruino, in support from DIVA daylight analysis. In addition, other examples utilized Revit and Dynamo as link between the 3D model and Arduino to control the model parameters. Regardless of the several attempts, our approach in particular explores three important aspects:

- How the physical model objects and digital geometry are synchronized to adapt and respond to data.
- How to map the script program procedure that triggers the responsive action.
- How to define the time-scale for the response in the prototype because it plays a major role in creating an effective a kinetic system.

As we begin exploring this approach, our small dynamic façade prototype experiment re-visits the dataflow and processing of a responsive dynamic facade. As discussed by Sharaidin (2014), this is mainly because static facades totally contrast from designing dynamic facades, which involves various configurations. It is in this context that “Creating and Making” approach and convergence of dataflow into the early design phase requires careful representation and change to the designer mindset to achieve high quality end product (figure 3). Furthermore, there is a need to investigate how effective DDC tools links with the kinetic facade mechanism. As a consequence, the process of implementing DDC optimization for dynamic facades is underdeveloped and requires further testing and evaluation.

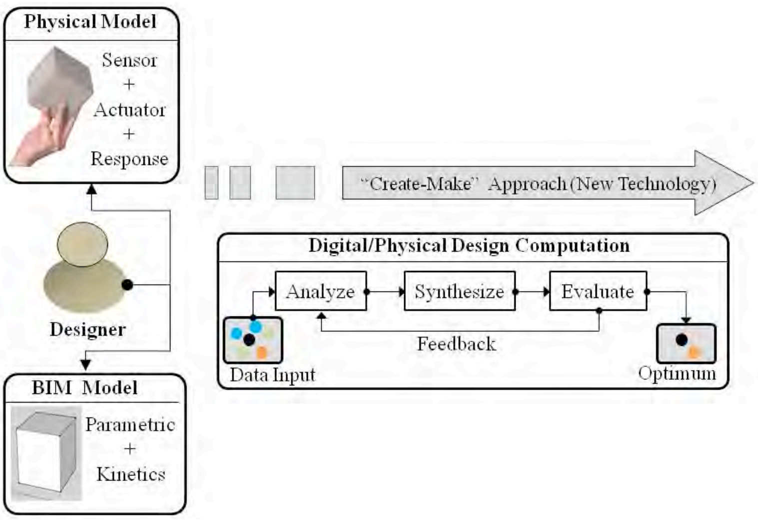


Figure 3. A Create-Make mindset approach and discovery process.

3. Physical/Digital Façade Experiment Framework

Our experimental prototype is of a small façade and assumed to be automated with a dynamic self-updating-loop data flow. In Phase (1) of this research we aim to achieve the kinetic transformation by mapping the Revit digital façade panel properties to the real small prototype according to solar exposure (figure 4). In Phase (2), the real small prototype components dynamically change according to sensor solar exposure values which "Self-Update" the digital façade panel.

As far as movement of dataflow in kinetic facade, this prototype expands BIM working environment while taking into considerations facade geometrical properties like: panel shape and panel size to reflect the feature of the intended design. We created a digital-hardware-physical computation framework between the prototype parts and set of dataflow involved in the kinetic movements. As shown in the figure 4 below, this experiment is an exploration of a new approach to implement our proposed "Self-Updating" BIM model for effective analytical design process of responsive facades reacting to variety of conditions (e.g. solar exposure, function, and aesthetics)

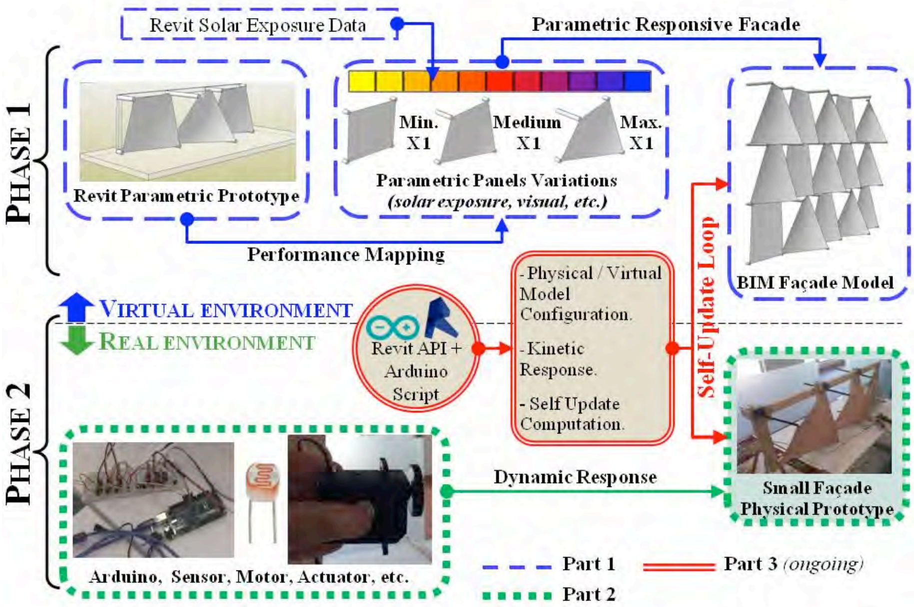


Figure 4. Proposed research framework self-updating.

3.1. THE SMALL PROTOTYPE PARTS

Over the course of developing the conceptual framework shown in figure 4 above, we realized the difficulty of installing an actual scale 1:1 prototype on the entire building façade. The data and development framework intersects within four parts as visual expression is resulted from user input and simulated environment. The four parts described below is intended to follow a typical "Creating-Making" design process while simulating a wide variety of technical challenges that may present themselves in everyday practice.

3.1.1. PART (1) – Parametric Façade Panels Utility

This part utilizes Revit ® BIM parametric modeling to construct 3D façade panels prototype. The core concept in parametric modeling is that objects and sub-objects are associated with one another thru parametric rules keeping their association as one framework. Single change to one parameter would affect the panel properties.

The panels are assigned an "X1" parameters to control the stretch/retract distance, and hence panel opening area (figure 5, c). Every "X1" parameter within the Revit ® façade panel response is assumed to react to the variation of the solar exposure produced by the Revit ® Solar Analysis plug-in. Using the color-range values from the solar analysis, the three façade configurations produced are:

[**Small Opening Size =** High Exposure = Yellow Color = Minimum X1].

[**Medium Opening Size =** Medium Exposure = Red Color = Half X1].

[**Large Opening Size =** Low Exposure = Blue Color = Maximum X1].

And so on, the opening size is determined by range of "X1" parametric values. The "X1" parameters are dimension "Length" type Revit parameters. We implemented the change of "X1" values and rule using Revit ® API C# programming that figures the solar exposure range value (low, medium, and high. In a conceptual manner, the solar exposure images are bitmaps of made of pixels whereby each pixel Red Green Blue (RGB) values can be obtained to evaluate solar exposure range values. These RGB values of a solar exposure image were implemented using C# programming language available in the Revit API.

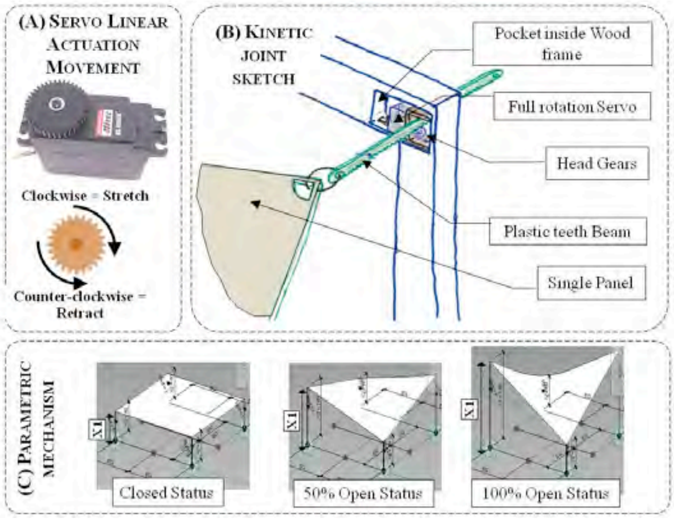
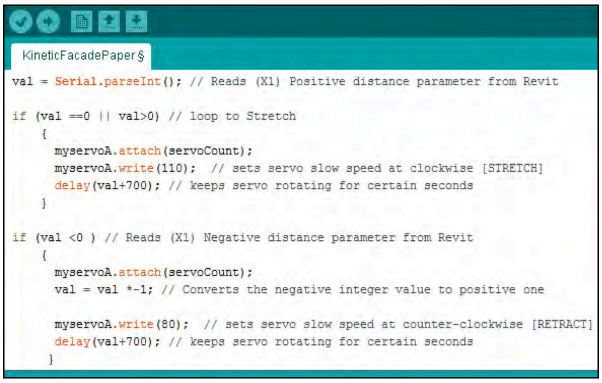


Figure 5. Sketch of the joint assembly idea with the motorized actuation parts.

3.1.1. PART (2) – Physical Façade Prototype Assembly

A sketch illustration of the physical prototype parts is shown in figure (5, b) below. It is constructed from affordable materials suitable for experimenting with responsive facade design. The materials such as wood support frame and flexible low-cost tensile fabric are adapted in the prototype to mimic the structural/mechanical system. The stretch/retract motion mechanism consist of motorized actuation assembly attached to the façade panels. The combination of the tensile-fabric panels, wood frame, strings, cords, gear head, actuating beams and the servos are arranged so that the panels can easily make a linear kinetic by actuating the servos.

Each façade panel relies on two joint assemblies to ensure the actuation assembly fitted within the prototype as an adjustable shading device. These panels can be adjusted and reconfigured to achieve the goal of "Self-Updating-Loop" responsive façade feature. The clockwise/counter-clockwise movement of the kinetic panel was based on an actuation mechanism by rolling gear beam attached to full-rotation servo motors (See figure 5, a). Through exploration while constructing this prototype, we introduced a pocket hole to house every kinetic joint of this prototype. This allowed us to achieve a stable movement with reduced vibration due to the actuation mechanism.


KineticFacadePaper §

```
val = Serial.parseInt(); // Reads (X1) Positive distance parameter from Revit

if (val ==0 || val>0) // loop to Stretch
    {
      myservoA.attach(servoCount);
      myservoA.write(110);  // sets servo slow speed at clockwise [STRETCH]
      delay(val+700); // keeps servo rotating for certain seconds
    }

if (val <0 ) // Reads (X1) Negative distance parameter from Revit
    {
      myservoA.attach(servoCount);
      val = val *-1; // Converts the negative integer value to positive one

      myservoA.write(80);  // sets servo slow speed at counter-clockwise [RETRACT]
      delay(val+700); // keeps servo rotating for certain seconds
     }
```

Figure 6. Arduino script defining conditions for stretch or retract mechanism.

Each façade panel is controlled by two full-rotation servos and in turn each servo is identified by the Arduino programmable board thru digital pins. Every pin represents a channel of communication between the computer ports where input information is sent to the servos connected to the Arduino board using jumper wires to transfer signals to the microprocessor. The linear actuating arm maximum and minimum ranges positions are defined for each servo. The Aduino programming script translates an electrical pulse delay to control the continuity of rotation and speed of servos. We experimented with this delay thru trial and errors to figure out the conversion of rotation cycles to translate to certain stretch/retract distances. We attempted a medium speed rotation in order to observe the kinetic movement and the notion that some servos can get damaged in high speeds rotations.

3.1.1. PART (3) – Digital and Physical Kinetic Computation

This is a core part of the project system environment development in which we created an Arduino script to execute the kinetic response and also a simple C# Graphical User Interface (GUI) in Revit API that accepts actions made by users. As mentioned previously in this paper, currently we are only discussing phase one of this on-ongoing research which is the kinetic system from Digital to Physical. This will be discussed in the following while describing the data-flow process.

- ***Arduino Script:*** evaluates two possible scenarios for a positive or negative (X1) parametric integer values sent from Revit to Arduino via USB serial communication port connected to the computer. This connection is the key part in this study of sending/receiving data between the Revit BIM prototype and the physical one. The general structure of the script is shown in the figure 6 above where the control occurs for actuation direction, speed of actuation and assigned servo motor pin number. As the servo motor rotates, it will drive the tooth-beam either to stretch or retract a certain calculated distance. It is important to mention that each servo motor operates after the following one sequentially and not at the same time as. This development realized such drawback issue due to the maximum voltage required to supply each servo motor.

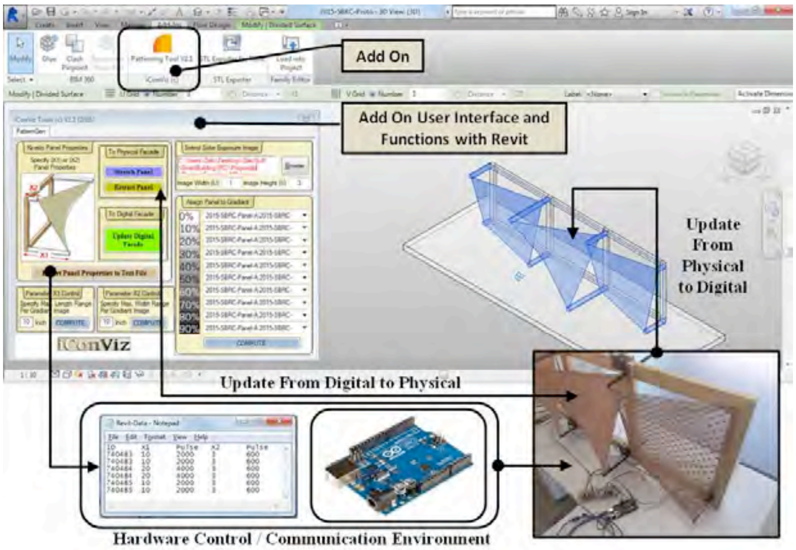


Figure 7. The Revit custom add-on and graphical user interface for kinetic façade.

- ***Custom Built Revit Add-On:*** designed in our work using the Revit API C# programming in order to achieve the translation from digital to physical (and the opposite). In terms of achieving the first phase of this research, it defines the behavior with logic to manipulate/read "X1" parametric panel input values. As illustrated in figure (7), the way of communicating the digital/physical façade properties is thru sending digital analog pulse to the physical façade prototype. The add-on makes use of a custom DLL file as communicating the actuation configuration of the digital façade properties mapped onto the physical prototype. This integration involved automating data transfer from the digital to the physical façade by means of exporting façade panel parametric properties "X1" formatted to their relative analog pulse rate. The calculation of the solar radiation variation occurred at different scenarios was real-time solar image exported from the Revit Solar Radiation add-on. The physical façade panel configuration is updated constantly using the custom add-on according to different solar radiation studies. As mentioned before, the physical prototype as controlled by the digital analog pulse sent for the custom add-on to Arduino board as a kinetic response for either increase/decrease of "X1" parameter.

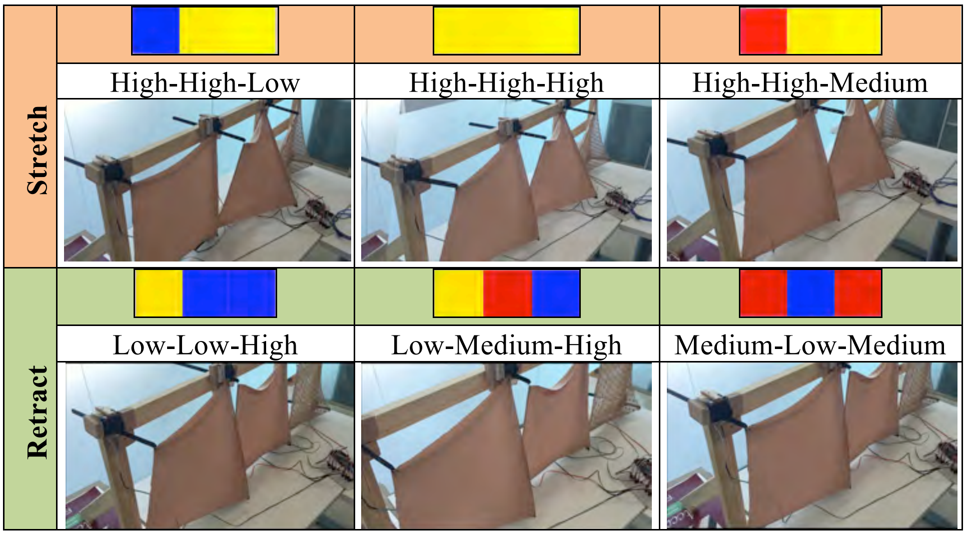


Figure 8. Small prototype parts and assessment of stretch/retract mechanism.

4. Preliminary Experiment Outcomes *(Digital to Physical)*

A series of six test-runs experiments have been initiated to illustrate the application and evaluate our proof-of-concept kinetic facade prototype during the early stage of façade design. Our aim is to simulate a real world environmental condition using simple solar exposure range values such as: low, medium and high. For each stretch/retract test-run, variations in the resulting façade panel movement were mapped from the digital to the physical based on input from four solar exposure analysis image. The resulting façade responsiveness was evaluated and compared in terms of: motor rotation movement, form/shape flexibility, and digital to physical design similarity. The test-runs outcome comparisons are shown in figure 8.

In all test-runs scenarios, we used the physical wood prototype frame structure and attached to it three panels made of light tensile-fabric to represent an exterior building façade. The main aim, at this stage of the research, was to examine the efficiency and suitability of the kinetic mechanisms. The three assessments are shown in the table of Figure 8 and described below.

- **Assessment (1) – Motor Rotation Movement:** as the user initiated a stretch/retract action, the servo motors rotate according to needed directions (i.e. clockwise or counterclockwise) and in a uniform set of speed. The increase/decrease change in the size of the opening is updated slowly. There were some minor issues with a delay in movement of some servos in less than a second time which caused variation in the rotation speed. This issue is attributed to material-to-material friction interaction which affects the repetitive rotation movement. The servo motor achieved the necessary 360° rotation and in turns the tooth-beam actuates to enables the panel to attain a Low/Medium/High position. Allowing the users to change the speed of motor rotation was not primary objective in this experiment because it depends on the speed of response needed, prototype cost, panel size and weight. In general, the overall reliability on the servo motor within the suggested kinetic arm joint remained stable for a period of time.

- **Assessment (2) – Form/Shape Flexibility:** is a major challenge in constructing kinetic façade prototype as it reacts to input/ data acquisition to create their flexible movement. The experiment led to permit the single panels movement of panels and thus allow for flexibility and interactive transformation. The tensile fabric-material utilized showed various responsive kinetic transformations for use in the kinetic façade. As the changing shape of the façade panels occurs, the panels demonstrated an elastic and flexible surface structure movement with few mechanical problems. Most importantly, the problem of friction during operating kinetic facade prototype is reduced as result of using the low-weight panel material and slow actuation speed reducing dependence on heavy mechanical components. Since facade responsiveness in this experiment needn't be in real time, it has been calibrated to respond in larger time scales like every hour at best. If high flexibility is needed then more electricity is necessary.

- **Assessment (3) – Digital to Physical Design Similarity:** through this exploration, we observed the visual similarities between a parametric façade model and behavior of the physical façade. This exercise consisted of manipulating the digital façade geometry from solar exposure image input and mapping the visual effect on the physical prototype panels. The observed results showed that the design similarity between digital and physical have a capacity to create matching facade patterns configuration. This effort on mapping visual similarities is noticeably generated by the kinetic actuation actions. The essence of simplest pairing of façade panels can generate interesting design alternatives with dynamic façade pattern. Specifically, the custom add-on employed here could quickly generate different versions of the facade geometry for different purposes. In this way, designers can interact with the digital form of the façade geometry and the density of its pattern and obtain visual feedback. Also, one can use the resulting parametric model properties to validate the design with more accurate kinetic exploration of visual and appearance.

5. Conclusion:

Since digital design technology is becoming more empowering to the design process, we were able to implement them to create a responsive facade in a different way than was previously possible. In doing so, we took advantage of the rich parametric information in a BIM facade model to understand the kinetic translation process to a physical facade prototype. For this purpose, this small project explored the principles and mechanism in the design workflow through a mixed digital-physical prototyping. Many practitioners and architecture educators consider “Creating-Making” a critical approach of learning environment as part of providing the user with knowledge and practical skills. It should allow the users to concentrate on DDC as a comprehensive process from the beginning of initial design concepts and ending with high quality design product.

A main aspect of this proposed system framework has seen the development of a custom add-on tool with algorithm to drive the kinetic façade generation and exploration. In this regards, the add-on controlled the digital/physical kinetic parts to simulate the surface of the façade under different conditions. One of the things we learned from exploring digital versus physical realm is that manually constructing prototypes are also necessary. The user interaction and sharing of digital information between software, hardware and kinetic building components is a whole challenging process that requires physical prototyping. The custom add-on was necessary to push the development of the experiment in kinetic architecture forward.

The presented experiment here is considered completion of our first phase of design and development (digital to physical). Although the second phase (physical to digital) of research is an unfinished feature, we believe that the underlying system framework and add-on are adequately developed to achieve our goals. The system framework implemented in this work is a starting point of our efforts to develop a connection to the BIM model from the physical model.

Acknowledgements

This work is developed as part of an ongoing research program of the category “Small Grant” supported by the Deanship of Graduate Studies and Research at Effat University, under grant

ID [UC#4/29.NOV.2015/10.3-2-1]. Special thanks to: Dr. Mohammed Asmatullah Khan for his valuable guidance, discussion, and input.

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3D PRINTED ARCHITECTURE

A New Practical Frontier in Construction Methods.

MAGDY M. IBRAHIM
Abu Dhabi University, College of Engineering
magdy.ibrahim@adu.ac.ae

Abstract. It is important to discuss and compare the rationale behind the success of the additive manufacturing technology in particular industries and at a particular scale versus full-scale building construction. The comparison should include structural qualities of the possible used materials, the cost effectiveness of the process, the time factor and its value in the construction process, the mass customization potential of the technology and its effect on building forms. The current state of technology in architecture, despite huge potential, has not produced new architectural forms.

1. Introduction

There is much literature regarding the benefits of additive manufacturing, or AM for short. While the adding of layer-upon-layer approach appears to be simple; there are many applications of AM technology with different degrees of sophistication that would meet several diverse needs. This includes design visualization, the creation of highly customized products for consumers and professionals, industrial tooling, construction in difficult environments, and one day the production of human organs. However, the strong potential behind the technology lies in its mass customization ability; that there is no more need for mass production to cut the cost of parts (Gibson *et al.*, 2015). Lately, the possibility of utilizing the technology to produce full-scale architecture has been seriously tested.

In May 2016, the city of Dubai launched the world's first “functional” 3D printed office building of 250 square meters. A structure of a single floor with all amenities printed in 17 days, and “assembled” on site in two days (Figure 1). The goal behind the project, as mentioned by officials, was to push the envelope on technological development, innovation and creativity. The machine responsible for printing out the office building was a massive warehouse-size printer that stands at about 6 meters tall, 40 meters long and 13 meters wide. The resultant building form, despite being slightly unconventional, still respects the traditional building shapes of vertical walls and horizontal slabs.

Figure 1. Dubai's first 3D printed office building.

Another company in China in January 2015, has produced a 5-storey residential house and the world's first 3D printed villa. The villa measures 1,100 square meters and comes complete with internal and external decorations (Figure 2).

Figure 2. 3D printed villa in China (3ders.org).

Moreover, back in 2014, ten 3D printed houses, each measuring 200 square meters, were produced in Shanghai, China. The buildings were created entirely out of concrete using 3D printing technology. The machines responsible for printing out these buildings are massive warehouse-size printers that stand at about 6 meters tall, 40 meters long and 12 meters wide.

However, the parts that were generated using the technology qualify as having been produced with alternative production methods. In the case of the Dubai office building, many repetitive similar looking parts were produced using 3D printing, then transferred to the site for assembly, a process that is very similar to precasting. The form of all the resultant building examples was not unique to the production method. The units making the parts for the roof are reinforced to create possible horizontal elements.

In fact, it is a replica of regular everyday architecture. The form of the produced buildings did not require mass customization. The only gain was time and cost.

On the other hand, to answer the question of the form, a Thai cement maker showcased in 2016 a small pavilion that adheres in form to the structural possibilities of the new medium (Figure 3). The resultant form is the only possible form without reinforcement. Despite the aesthetic qualities of the produced solution, the pavilion only qualifies as a piece of art rather than usable architecture. No meaningful spaces or horizontal planes are created.

Figure 3. A 3D printed pavilion with very interesting spaces and volumes by SCG Thai cement maker.

With this trend gaining momentum, many questions are raised about the logic and feasibility of utilizing such technology to produce full-scale buildings. Moreover, more questions about architecture aesthetics are raised: Would the 3D printing techniques produce different architecture?

2. Form follows Building Technology

The architectural form across history has always been affected by the technology producing it. Throughout history, we can pinpoint certain examples that can showcase the effect of building material and building technologies on the architectural product. Since caves of the caveman, spaces were shaped following the used technological tools and the structural properties of the natural stones in natural settings. Stone has been the dominant building materials throughout history with distinct structural qualities that enabled certain shapes only. The use of wood as a building material resulted in some different architectural forms as well (Figure 3).

Figure 3. Left: The Parthenon is the most important surviving building of Classical Greece. *Right:* The Thorncrown Chapel in Eureka Springs, Arkansas, 1980 by E. Fay Jones.

Hadrian's Villa, a large palace built near Rome on A.D. 125, used plain concrete extensively for its dome structure. The building materials are bricks, lime and pozzolana.

Frank Lloyd Wright was one of the designers who explored the possibilities of using concrete in a very creative way both reinforced and unreinforced creating many master pieces such as the 1920 the Millard House, the home Wright lovingly referred to as "La Miniatura". (Figure 4)

Figure 4. Hadrian Villa 125 BC and the 1920 the Millard House. Different ways concrete is used and its effect on form.

High rise buildings of the 20th century are clear evidence of how architectural form follows building technology. The invention of reinforced concrete has changed the profession and what it can achieve.

Additive manufacturing technology has the potential to be as interruptive as the introduction of reinforced concrete when formwork can be eliminated and any shape can be, potentially, produced with cost effectiveness and in a timely manner.

3. What Is Additive Manufacturing?

Additive manufacturing is the formalized term for what used to be called rapid prototyping and what is popularly called 3D Printing. The term rapid prototyping (RP) is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization. In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived. Gibson *et al.* 2016)

3.1 MASS PRODUCTION VS. MASS CUSTOMIZATION

Since the industrial revolution, mass production was the process with which manufacturers were able to significantly reduce the price of production, making products cost very competitive to consumers. The 20th century development was marked mainly by the mass production market.

Architecture as everything else has benefited from this trend which easily availed parts that contributed to the construction industry from construction equipment to assembly lines of doors and windows.

However, this did not change the form of the produced architecture. The building technology that shaped the form in the turn of the 20^{th} century did not change in an interruptive way to change the main lines of the architecture form.

By the nineties, the introduction of computers in the construction process and form shaping started casting its shadow on the form of architecture. Marked by the computer generated forms, that decade was a culmination of several advancements which enabled unprecedented architectural forms.

The ability to structurally analyze very sophisticated forms by computers, combined with the power of detailing parts that are not all mass produced, has started a new revolution. Mass customization of steel members, curtain panels and glass sheets began a brand new movement.

Mass customization is “the new frontier in business for both manufacturing and service industries. At its core is a tremendous increase in variety and customization without a corresponding increase in cost.” (Wikipedia, n.d.)

However, everything is still limited by the structural properties of the used materials. In the case of Additive Manufacturing, concrete, or more accurately, cement mix, is the most common material used to produce architectural solutions. As per the current technology development, the shown examples are all made of some type of concrete. It is not very clear how the horizontal elements of the buildings were solved structurally though, some have showed steel reinforcement being used in the process.

3.2 CONCRETE

Concrete is a universal low cost, extremely versatile construction material and it is the most feasible and suitable material for additive manufacturing in architecture, yet it does not have the qualities required to achieve desired structural qualities. As interruptive a technology as it can be, it is still limited to replacing precasting techniques. The examples previously showcased did not result in new architectural forms.

Concrete is also the only major structural material commonly manufactured on site, it has no form of its own, and more importantly has no useful tensile strength. Reinforced concrete in which steel bars are embedded to resist tensile forces, was developed in the 1850s by several people simultaneously.

3.3 THE CONCEPT OF REINFORCING

Concrete has no useful tensile strength. Historically, its structural uses were limited until the concept of steel reinforcing was developed. The compatibility of steel and concrete is a fortuitous accident. The two materials have similar coefficients of thermal expansion, and the two materials are chemically compatible. Also, concrete adheres and bonds strongly to steel surface providing a convenient means of adapting brittle concrete to structural elements that must resist not only compression, but tension, shear and bending as well. (Allen & Iano, 2016)

3.4 THE HORIZONTAL SURFACE STRUCTURAL PROBLEM

Without reinforcement, and due to the binding moment, it would be technically difficult to achieve horizontal elements out of concrete. This calls for other solutions that should affect the architectural form significantly.

The bridge project, which began by the Joris Laarman Studio and Petr Novikov and Saša Jokić from the Institute for Advanced Architecture of Catalonia (IAAC) to be placed across the Oudezijds Achterburgwal canal proposed for Amsterdam is one clear example of how to optimize the structure to achieve the desired form (Figure 5) and obtain horizontal usable surface; however, the material used had to be metal.

Figure 5. The bridge project, by Joris Laarman Studio proposed for Amsterdam (Source: 3D Printing Industry 2015)

4. Discussion

Despite the novelty and potential of the technology, no new meaningful and usable building form has been produced by it yet.

It is very exciting to imagine the future structures 3D printed out of steel or concrete, or maybe both of them combined, as a solution to the issue of structural stresses. A 3D printing machine that is capable of printing two materials intertwined together to make stronger members would enable much more diverse form to be achieved. A new material such as carbon fiber reinforced concrete or similar might fill the gap for the appropriate structural qualities.

The choice is either to adhere to current technologies and add traditional reinforcement to the material in order to achieve usable horizontal surfaces, or accept the generated form with less than efficient material usage and possibly less efficient spaces and volumes.

In order to describe what has been produced at the moment, it is safe to say that it is a traditional form that is produced with a new technology which would cut the production cost and time, but will not, in its current state, produce the possibilities envisioned by the technology.

Possibilities are endless if we can close the gap between the technology and the structural properties of the materials used. (Figure 6)

Figure 6. 3D printed buildings for Mars (Source: www.marscitydesign.com).

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COMPUTER AIDED ANALYSIS TO UNDERSTAND THE BEHAVIOR OF A MODULAR CHAINED BLOCK

Towards an intentional control of a transformable architecture

HARUNA OKAWA
Keio University, Tokyo, Japan
s13162ho@sfc.keio.ac.jp
harunaokawa214@gmail.com

Abstract. This paper reports on the outcome of several tests that are run to examine the behavior of virtual and physical models of a chained block. Correlations between parameters of the component and the global geometry are studied using parametric modeling and physical model. Studies are limited to proportional and non-proportional relations according to the direction of the force. Further experiments are expected in the future to explore other forces. These computer-aided analyses offer a deeper understanding of the behavior of the system towards an intentional control of the global geometry.

1. Introduction

The research investigates the behavior of a transformable structure that consists of discrete identical modular objects in order to obtain more controllability of the structure in the future. The structure consists of hexagonal hollow blocks with three legs (Figure 1). One component is connected to six adjacent components with ribs that keep them from falling apart. The range of movement is similar to that of a cloth and at specific point, it becomes a stable structure. On one hand, it overcomes the limitation of conventional compression structure that is built by joining blocks one by one using a substructure, on the other, it offers another strategy in transforming a global geometry for interactive architecture.

In most recent research, applications of computational design to the compression structure enabled architects to design and materialize complex geometry. For instance, interlocking structure (Tessmann, 2012) and vault structure (Varela & Merritt, 2016) gained free forms. In these examples, target geometries were designed first and then they were divided into processable unique components. During the construction, a substructure that serves to hold and support the blocks up until the last piece is assembled were built, and objects were laded on top of it. This results in needless consumption of time and materials, since the formwork eventually turns into waste.

Figure 1. A full picture of the mock-up.

Precedents in research for interactive architecture includes adaptive roof structure, that has individual unit controlled by a computer (Hotta & Hotta, 2016), which requires heavy wiring and soft acoustic tiles that deform but cannot bear the load (Decker, 2015). Transformation by shifting components' configuration is the alternative strategy for controlling a shape of a transformable architecture. The form will be changed neither by material deformation nor by an individual actuator attached to the each component.

In the proposed structural system, one can lay the component in any shape with any number and once the force is applied, it supports itself. Thus, this chained block system exhibits two interesting properties: incremental modularity as a discrete material and uniformity of transformation as a continuous material.

2. Aim and Problem Statement

The work attempts to understand the behavior of this structural system in order to establish a simulation methodology. If the accurate simulation is achieved, then it follows that the global geometry is predictable and thus can be intentionally controlled. This paper attempts to reveal how an example of modular design of components affects a global geometry. Parametric modeling was used to produce variations of the physical model.

As is often the case with physical phenomena, simulation of physical environment often comes with difficulties. In the proposed case, each component has six degrees of freedom and collides with neighboring six components (Figure 2). Although author built the previous mock-up, the actual mechanism of how each component transfers pressure and get stabilized, is not fully understood yet.

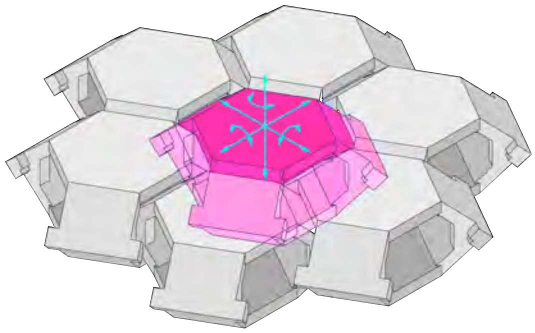

Figure 2. Relationships between components.

3. Methodology

Physical models were used to understand the behavior as “only synthesized information sets from both analog and digital realms can render a granular behavior comprehensively (Dierichs & Menges, 2013).” Two parameters, leg length and height, were changed to examine the correlation with a global geometry. Table 1 shows parameters used for this experiment. Models were 3d-printed with 0.4mm of layer height and the thickness of the surface was 1.5mm.

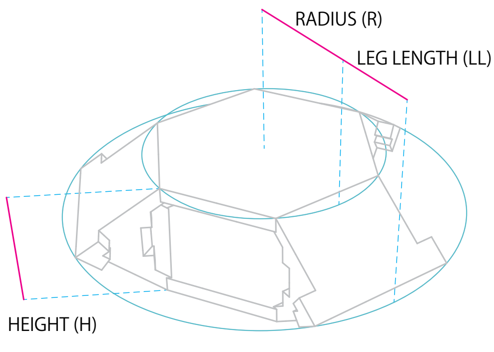

Figure 3. Three main parameters.

TABLE 1. Five models with different parameters.

Version (No.)	1	2	3	4	5
Radius [R] (mm)	8	8	8	8	8
Leg Length [LL] (mm)	5.5	4	7	5.5	5.5
Height [H] (mm)	5	5	5	4	6

For each version, two cases, A and B, were studied (Figure 4). In both cases, a force of 20N was applied to the sheet of components by pushing through a spring balance. Five variables were measured through this experiment.

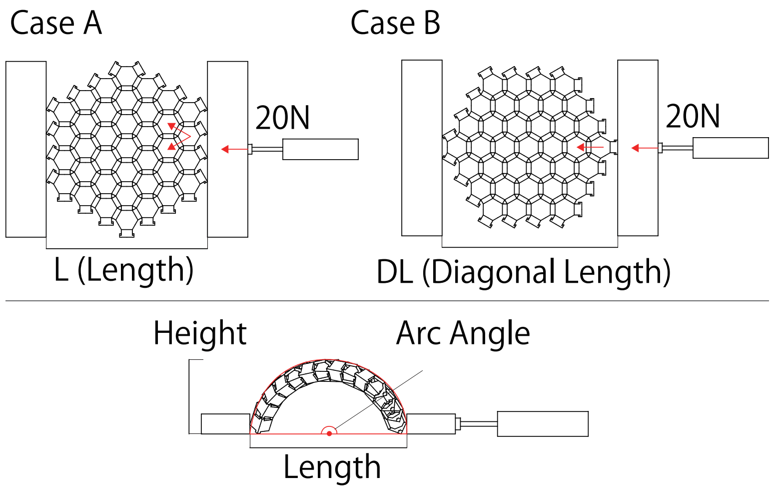

Figure 4. Definitions of measured variables.

4. Results

When certain amount of force is applied until model gets stable, the variables were measured (Table 2). The information on the angle of the arc that a group of components can afford is utilized in the future work for restraining a range of global geometry so that it does not locally collapse.

The mean angle of version 1, 2, and 3 in case A and B were compared to see how a difference in leg length affects global geometry (Figure 5). Similarly, the mean angle of version 1, 4, and 5 in Case A and B were compared to see how a difference in height affects global geometry. In Case A, proportional relations can be observed. On the other hand, in Case B, the value of version 1 is relatively high and hence, the relation is non-proportional.

TABLE 2. Properties of the physical models.

		Standard				Leg Length								Height							
R : LL : H		Version 1 8 : 5.5 : 5 L: 110, DL:120				Version 2 8 : 4 : 5 L: 105, DL: 112				Version 3 8 : 7 : 5 L: 117, DL: 121				Version 4 8 : 5.5 : 4 L: 111, DL: 120				Version 5 8 : 5.5 : 6 L: 110, DL: 117			
Case A																					
		Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7
	1st	32	90	140	20	25	98	98	14	54	77	204	29	11	107	60	9	50	76	199	28
	2nd	33	94	132	19	20	97	87	12	49	78	196	28	8	110	56	8	48	78	194	28
	3rd	35	91	133	19	20	97	76	11	55	75	202	29	8	108	56	8	49	77	198	28
	Mean	35	91	133	19.3	20	97	76	12.3	55	75	202	28.7	8	108	56	8.3	49	77	198	28
Case B																					
		Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7	Height	Length	Arc Angle (X)	X*1/7
	1st	50	83	187	27	19	107	78	11	65	77	217	31	19	117	58	8	60	75	218	31
	2nd	52	79	199	28	23	104	88	13	65	76	228	33	17	118	67	10	58	71	227	32
	3rd	51	81	196	28	21	105	81	12	55	79	201	28	16	116	63	9	58	73	226	32
	Mean	51	81	196	27.7	21	105	81	12	55	79	201	30.7	16	116	63	9	58	73	226	31.7

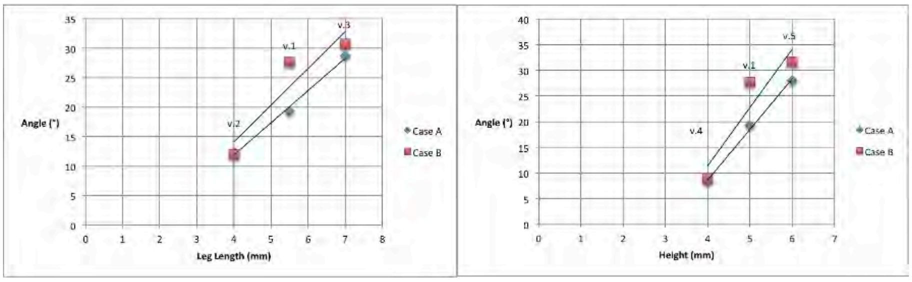

Figure 5. Correlations between parameters.

5. Conclusion

The behavior of the modular chained block was studied by a combination of digital and physical models. The correlation of parameters of a component and a global geometry was proportional in Case A and non-proportional in Case B. Further investigation has to be conducted to clarify what governs the angle between components. These findings and properties of a global geometry will be imported into a computational model in order to simulate the behavior for establishing a controlling system of a transformable architecture in the future work.

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Section

III

BIM, VISUALISATION & SIMULATION

MANAGING ACTORS AND BUILDING INFORMATION FOR SUPPLY CHAIN INTEGRATION

ELENI PAPADONIKOLAKI
Bartlett School of Construction and Project Management, University College London, London,, UK
e.papadonikolaki@ucl.ac.uk

Abstract. Supply Chain (SC) integration has been a long-standing issue. With the advent of Building Information Modelling (BIM) and its influence on inter-organisational relations, SC integration is again highly relevant. This study explores the conditions for SC integration from deploying BIM and SC management (SCM) philosophy. A set of topics from literature, pertinent to BIM and SCM, are confronted with the experiences of experts from the industry during a workshop. The *bottom-up* BIM initiatives and relational management were deemed more decisive than adhering to *top-down* BIM policies and operational SCM for managing actors and information and inciting SC integration.

1. Introduction

Supply Chain (SC) integration has been considered the cornerstone of Supply Chain Management (SCM) philosophy. Across various sectors, the concept of SCM focuses primarily on managing the information and material flows (Vaidyanathan, 2009). In construction, it has been suggested by London & Kenley (2001) that the discussions on SCM and SC integration should move away from the dogma of simply enhancing logistics towards a holistic consideration and particularly under the lens of a network approach. The concept of SC integration in construction in the literature of the United Kingdom (UK) has been a highly disputable concept as it has at times been considered either a precursor of innovation and process improvement (Pryke, 2009) or a hindrance to competitiveness (Fernie & Tennant, 2013).

Recently, with the proliferation of Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) industry, the discussions about SCM and SC integration are again relevant. For example, the McGraw-Hill Construction market report (2012) states that

SCM is key activity for leveraging from BIM. In the UK, the ‘intelligent’ information flow, derived from BIM models, has been considered as an enabler for SC integration from government reports (CIC, 2011). Thus, the management of the digital information flows could be supported from the set of technologies, applications, and processes that fall under the umbrella of BIM.

Whereas BIM has been mainly associated with design management, it is increasingly acknowledged that it affects many actors in the SC. This study explores the aspects under which BIM could be aligned with SCM and SC partnering, to induce SC integration in AEC. Through an expert workshop in the Netherlands the study discussed the management of actors and building information. The paper is structured as follows. In the ensuing section, the background that leads to the research gap is presented. The methodology and the results are presented next. Finally, the discussion confronts the findings with relevant scientific literature and the concluding section offers a summary of the study and implications for practitioners and researchers.

2. Related Work, Background and Research Gap

2.1. ANTECEDENTS FOR SC INTEGRATION

SC integration has been a long-standing issue in AEC. While it has been an enduring and undoubtedly fruitful approach for its financial rewards in the manufacturing industry (Christopher, 2011), it is not uniformly pursued in AEC. For example, in the literature from the UK, SCM, partnering and efforts for SC integration have been mainly considered a hindrance to competitiveness and the rules of the free market (Fernie & Tennant, 2013). Exceptions include considering SCM and partnering as extra governance structures, e.g. SC framework agreements (Pryke, 2009), to simplify the traditional contracts. After all, originally, the Egan’s Report (1998) had envisaged a less formally contractual and a more collaborative industry.

According to London and Kenley (2001) there are two schools of thought for SCM and SC integration in construction; one focusing on the material flows and the optimisation of logistics, and another focusing on holistic approaches to manage the inter-firm relations, e.g. partnering (Lambert *et al*, 1996). Leuschner *et al* (2013) differentiate between operational and relational views of SC integration in SCM research. The operational view of SCM entails activities, such as early involvement of the supplying parties and processual optimisations by applying lean practices, such as co-locations. On the other hand, the relational view of SCM implies some ‘soft’ aspects, such as increasing the level of trust that inevitably affects how the various inter-organisational actors align. The SC framework agreements are a prerequisite for SCM, as the contracts imply an absence of opportunism (Williamson, 1985), and could help trust building. Based on the above, managing the actors of the SC implies the deployment of both operational activities, e.g. early (contractual) actor involvement and co-locations, as well as the development of intangible antecedents, such as trust and increased collaboration, which are difficult to be achieved solely by operational means.

2.2. THE PROMISE OF BIM FOR INTEGRATION

BIM has lately been considered a paradigm shift for the AEC. As it is a promising set of technologies for generating, managing and sharing building information among various project actors, it could undoubtedly improve the information flows in projects. BIM offers benefits in design management (Elmualim & Gilder, 2014) and project management, i.e. time reduction, communication, and coordination improvement (Azhar, 2011), lower costs and fewer returns for information (Bryde *et al*, 2013). However, the varying capabilities and BIM readiness among the firms result in misunderstandings and poor information management (Mondrup *et al*, 2012). The collaboration and coordination in BIM-based projects is still a hot topic for the industry, which is approached either from 'bottom-up' or 'top-down' initiatives.

Various 'bottom-up' collaboration approaches have been reported about how the actors engage in BIM. The Open BIM initiative to collaborative design is based on open standards. According to that the actors exchange open rather than native formats under the concept of 'reference models' to coordinate the design (Berlo *et al*, 2015). Deploying BIM in projects requires increased communications and close collaboration among actors. Any pre-existing trust and close collaboration could, in turn, support better communication. The 'top-down' approaches to regulate BIM collaboration are National initiatives and mandates for controlling BIM features across project phases and prescribe BIM implementation. These initiatives entail quasi-contractual BIM documents among the actors, such as the pre-contract 'BIM Execution Plan' (CPIc, 2013) from the UK, and 'BIM Norm' issued by the Dutch Government Building Agency (GBA) (Rijksgebouwendienst, 2012), both of which are inspired from the Norwegian 'BIM Manual' (Statsbygg, 2011). However, whereas the BIM-related mandates increase across countries, they cannot fully capture the increasing advancements of the BIM technologies and there is a lack of feedback on their performance.

2.3. RESEARCH GAPS AND CONCEPTUAL FRAMEWORK

Based on the above literature, managing the SC actors takes place either via operational or relational approaches. Simultaneously, managing the BIM-derived building information takes place either ‘bottom-up’ or ‘top-down’. Thus, some key concepts for SC integration pertinent to SCM and BIM are:

- Trust (SCM, relational aspect)
- Early involvement (SCM, operational aspect)
- Co-locations (SCM, operational aspect)
- BIM readiness (BIM, ‘bottom-up’ aspect)
- BIM collaboration (BIM, ‘bottom-up’ aspect)
- BIM protocols (BIM, ‘top-down’ aspect)

The study explores next how these concepts could manage the various multi-disciplinary actors and building information to incite SC integration.

3. Methodology

A qualitative exploratory study was used to discuss the topics emerged from the conceptual model of the previous section, and confront them with the experiences of experts from the industry. The study took place in the Netherlands, where both SCM and BIM concepts have gained a lot of traction the last decade. The idiosyncrasy of the Dutch market could allow for a potential generalisation. As the Dutch AEC has been proactive and consensus-seeking, any lessons learned from this small market could reflect future trends to larger markets. After all, the Dutch BIM level of maturity is well advanced, without been subjected to mandatory policies from the Dutch Government Building Agency (GBA), but from ‘bottom-up’ initiatives.

The study drew data from discussions made during a workshop with a group of seven experts. These experts had diverse backgrounds, from both SCM and BIM. Five of them were practitioners from the industry, from which three had more than 25 years of experience in the construction sector. Two of the experts had a research background, but with many years of engagement in ‘consultative research’. The experts welcomed the use of their input for research, but preferred to stay anonymous. The experts and the abbreviations for quick reference (shown in parentheses) are:

- Senior Researcher in SC in Construction (SC Researcher);
- Senior Researcher in BIM (BIM Researcher);
- Regional Director at a large contractor A (Contractor-Director);
- Project Leader at a large contractor B (Contractor-Leader);
- Senior Consultant in Supply Chain integration (SC Consultant);
- Business Manager at a Software Vendor (Software-Manager);
- Senior Engineer at a large consulting firm (Structural Engineer).

The expert workshop lasted about three hours and had the following structure. First, a short presentation of the conceptual model and the six topics were presented (see Section 2). Second, the experts reflected on the aforedescribed topics based on their experience from practice. During the discussion, the experts discussed how these topics could be deployed to achieve SC integration. The discussions were recorded and the recordings were transcribed. The results were analysed qualitatively and are presented next clustered around the main topics, using quotations of the experts.

4. Results and Analysis

4.1. EARLY ACTORS' INVOLVEMENT

There were two contradictory views about how early supplier involvement could induce SC integration. The SC consultant and the BIM Researcher agreed that it could lead to integration and improve the project if the supplier is treated as 'co-designer'. The Contractor-Director was of the opinion that "*the early involvement is good for the design phase and the engineers*", but not for the realisation phase, as in his company, they "*separate the design from the realisation phase*". Another condition for engaging in early involvement was the alignment of BIM with the project scope, as "*if the project does not fit to one particular SC, they could adjust either the design or change the SC*" (Contractor-Leader). The SC consultant highlighted that early involvement is applicable to "*mature strategic partnerships, where they have to pay the suppliers for their advice under an incentive scheme*."

4.2. CO-LOCATION PRACTICES, BIM INVESTMENT AND BIM VISION

Overall, the co-location practices were deemed supportive of SC integration from the experts. However, the experts disagreed about whether it was more applicable to mature or young SC partnerships. For the Contractor-Leader, the co-location practices would be supportive of SC integration in all projects and pointed out that the interactions had to be genuinely reciprocal among the actors, otherwise "*some people sit together but do not work together*". The Structural Engineer brought up another important aspect of this strategy, which related to the strategy about BIM investment, and particularly because "*usually the architects do not have a laptop, who pays for those and the rent for the location of the co-locations? […] In a digital setting, you do not have 'small talk'. I think the co-locations can be useful in all projects, but it is most beneficial to practice those in small projects first*".

4.3. COMMUNICATIONS AND TRUST

The discussions about trust were contradictory. On the one hand, for the Contractor-Leader and the Software-Manager, all types of intra- and inter-firm communications (also post-project) under complete transparency could incite trust. The Contractor-Director highlighted that "*we should not talk only about the bad things. We forgot to do talk about the good things, like our shared vision*" (Contractor- Director). On the other hand, for the SC Consultant, not all communications could support SC integration, e.g. "*discussion about price, contracts, and (poor) quality of work do not help to build trust. Discussing the interpretations around a bad contract is bad*" (SC Consultant). The Structural Engineer underlined that the increased communications "*in the early stage are more important to set common BIM goals and planning […] then you see from the beginning the gaps that you face, and then you can resolve them half-way* (Structural Engineer).

4.4. BIM READINESS AND STRATEGIC PARTNERS' SELECTION

The experts discussed how the exclusive alignment among firms with similar levels of BIM readiness could induce SC integration. The Contractor-Director stated that for firms with an under-developed BIM level, this alignment could also be beneficial, because it could improve from BIM peer-learning and training. They stated that: "*theoretically, it could be the best option*" (Software-Manager) but "*the aligned SC on the same level is utopia, and this alignment has to take place beyond a project-level*" (Contractor-Leader). The BIM Researcher strongly opposed the alignment of firms based on BIM readiness, as some companies, e.g. the "*concrete supplying companies do not need the same criteria to collaborate with BIM as other actors*". The SC Consultant instead proposed that the "*SC will be weak if the strategic partners are not well advanced in BIM, so the BIM alignment of strategic partners is very important for the integration*" (SC Consultant).

4.5. BIM PROTOCOLS AND SCOPE

In principle, all experts agreed that having BIM protocols could induce SC integration. However, not all experts agreed on the definition of the 'BIM protocols', issued by the Dutch GBA. For example, for the Contractor-Director, the BIM protocol was more a file format and information exchange specifications, while the Structural Engineer viewed them as process prescriptions. The Contractor-Leader emphasised that the BIM protocol "*is more than exchanging files*" and it relates to scope. In practice the BIM protocol "*has nothing to do with the project management plan, because it is not drafted by the person who manages the project*" (Contractor-Leader). Thus, they "*usually do not discuss the protocol properly. […] First, we should plan the logistics, decide if BIM can help, and then have a protocol*" (Contractor-Leader). The BIM Researcher agreed that the "*protocols are made from people who do not know anything about the SC*". To support these discussions the Structural Engineer stated that as the project phase boundaries are obscure at the project start, the BIM protocol should be flexible, and they should "*update the BIM protocol along the way*". The BIM Researcher also emphasised that "*we probably need different protocols for each project*" (BIM Researcher). The Software-Manager added that the BIM protocols could be a way to communicate the firms' BIM visions. The SC Consultant agreed that "*agreeing on a strategic level about the BIM protocols could reduce costs*" and a "*joint industry protocol would be ideal […] from the agreements of big companies coming together*".

4.6. BIM-BASED COLLABORATION

The experts agreed that there are many ways to collaborate with BIM. However, not all ways could "*be beneficial for SC integration*" (Software-Manager). The Contractor-Director suggested that "*with BIM it is all or nothing. You cannot choose to do it 'little BIM', like you can do with SCM*". The Software-Manager emphasised that collaboration with the exchange of reference models with either open or proprietary formats on a Common Data Environment (CDE) could support SC integration. The Contractor-Leader admitted that for BIM: *"we have to learn to work with all the parties. Maybe we should now do things differently. BIM needs to redesign the processes. It takes a long time, and everyone has to be very transparent about what we mean with BIM and how to be efficient"* (Contractor-Leader). Finally, the SC Consultant underscored that similarly with SCM "*there is a lot of opportunistic behaviour in the construction industry about BIM, and many say they are mature, whereas they are very traditional*" (SC Consultant).

5. Discussion

The data suggested two routes for inducing SC integration: managing (a) actors and (b) building information from both operational and relational standpoints. First, for managing the actors, the deployment of operational incentive schemes was deemed important to engage in early actors' involvement (Lambert *et al*, 1996). Simultaneously, the deployment of relational means, such as increased informal communications, that incite trust, could integrate the actors beyond organisational boundaries (Leuschner *et al*, 2013). Regarding BIM, the experts agreed that diffusing BIM-related knowledge from various projects across the firms could instigate BIM learning in the SC partnerships, which could in turn support SC integration.

Second, for managing the building information, both 'bottom-up' and 'top-down' approaches were deemed necessary. Consciously aligning the BIM-related investment, such as for digital (CDE) or physical infrastructure, e.g. co-locations with the scope of the SC and the project could increase the aforedescribed learning experiences of the SC within and beyond projects. However, these ‘bottom-up’ means to SC integration naturally require a process redesign and rechannelling of the existing information flows. This redesign could accordingly be partially supported by National ‘top-down’ policies, such as agreements about BIM protocols and BIM Execution Plans.

During the discussion, the nature and use of the ‘BIM protocols’ emerged as a key aspect for SC integration. The experts stated that such documents are preeminent for managing the projects; however, the protocols could also act as a firm-based BIM vision of the involved firms. This in accordance with the current approach in the UK, where the BIM Execution Plans (CPIc, 2013) are more project-oriented, whereas the CIC BIM Protocols are firm-based and focus on how the various organisations have adopted BIM. That could potentially also be applicable to the Netherlands, where the firms could benefit from separating their BIM visions and the operationalisation of those visions in SC partnerships and projects, within their BIM protocols.

6. Conclusion

The study challenged theoretically and practically concepts derived from literature on BIM and SCM for SC integration. By means of a workshop, industrial experts shared their experiences on BIM and SCM implementation and discussed how the ‘top-down’ and ‘bottom-up’ BIM initiatives could support both the project and SC partnerships’ scope. From the data, it was deduced that while operational and transactional means for SC integration are imperative, e.g. contractual relations and financial incentives, additional relational considerations, e.g. trust-building, increased communication, and joint BIM learning are crucial for integrating the actors. These suggestions for managing both actors and building information flows show a balanced way forward for achieving SC integration. As this study has set up new points for discussion, further research on the prioritisation and fine-tuning of these aspects could focus on BIM process redesign for SC integration.

Acknowledgements

The authors thank the experts of the workshop for their openness. This study would not have been possible without their generosity to offer new insights into the topic.

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DYNAMIC SIMULATION OF NEIGHBORHOOD WATER USE

A case study of Emirati neighborhoods in Abu Dhabi, UAE

DAVID BIRGE, SNEHA MANDHAN AND ALAN BERGER
Center for Advanced Urbanism, Cambridge MA, USA
sneham@mit.edu | dpbirge@mit.edu | aberger@mit.edu

Abstract. Being located in a hot, humid and arid bioregion, as well as having a unique religious and social context, the Gulf Cooperation Council cities pose significant challenges to the achievement of sustainable urban development. Using native neighborhoods in Abu Dhabi as a case study, this ongoing research aims to develop a design methodology which utilizes both qualitative and quantitative analysis towards the holistic, feedback driven design of new neighborhood typologies for the native population. This paper focuses on the methodology and application of a water use module which measures neighborhood scale indoor and outdoor water use, an area of simulation critical to developing sustainable neighborhoods for Arab cities, yet underrepresented within the literature. The water module comprises one part of a larger toolkit that aims to measure both environmental sustainability as well as social and cultural factors unique to the context of Abu Dhabi and the gulf region.

1. Introduction

This paper introduces a computational module for measuring and simulating neighborhood scale water use and management in hot arid climates. This module is being developed in Python and C# as part of a larger toolkit for the Rhinoceros and Grasshopper software platforms, and is co-developed with similar modules that address land use, infrastructure, building energy and mobility, as well as economic and socio-cultural factors. When combined, the entire toolkit will provide a comprehensive and integrated analysis of holistic sustainability. This research uses Emirati villa neighborhoods in Abu Dhabi as a case study to examine the potential effects of new housing and neighborhood typologies on all factors of sustainability.

Abu Dhabi is the capital and largest of the seven emirates that form the UAE. It covers an area of 67 340 km^2 and has population of 2.65 million, 19% of whom are native Emiratis (Abu Dhabi e-Government, 2016). However, despite forming such a small proportion of the total population, Emirati neighborhoods comprise roughly 55% of the total urban landscape (per GIS spatial data calculations). Neighborhoods are constructed in which houses are allocated to Emirati families at no or minimal cost through a government program facilitated by the Abu Dhabi Housing Authority (ADHA). Being based on the villa housing type, these neighborhoods are low-rise and low-density. Many have claimed these neighborhoods are environmentally unsustainable due to the high volumes of water demanded by their residents, demand driven in large part by the use of non-native vegetation and turf grasses as well as the low cost of water which the government subsidizes (Bahaman, 1998). Studies have shown that many villa-based neighborhoods in Abu Dhabi consume three to nine times more water per capita than other neighborhoods with similar climatic and socio-economic conditions (Chowdhury & Rajput, 2015; Melbourne Water, 2015; *United Arab Emirates Water Conservation Strategy*, 2010; Waterwise, 2016).

Furthermore, the UAE is burdened with the second lowest supply of renewable freshwater in the world. As a result, the Abu Dhabi government must desalinate 99% of the municipal water supply, which it acquires from eight independent desalination plants (Degnan, 2010; Paul *et al.*, 2016; Randall Hackley, n.d.). These plants are energy and capital intensive, (Dubreuil *et al*., 2013; Yu *et al*., 2015) and their operation results in multiple environmental externalities such as carbon emissions and high-salinity discharge (Assaf & Nour, 2014; Dawoud, 2012; Miller *et al.*, 2015). Additionally, because these plants predominantly use multi-stage thermal co-generation, they are vulnerable to natural gas shortages, oil spills and algae blooms, the latter two events occurring in 1998 and 2008 respectively (Lowell, 1998; McDonnell, 2014; Villacorte *et al.*, 2015). Because Abu Dhabi currently only has three days of potable water storage, any such disruptions to the desalinated water supply becomes an immediate health hazard to the general population, a hazard made more acute during the increasingly frequent and severe summer heat waves (Lelieveld *et al*., 2016; Pal & Eltahir, 2016). The potential crisis from a supply shortage, current strain on existing capacity by increasing populations and environmental externalities of desalination, all emphasize the urgent need for the more efficient use of limited and costly water supplies in Abu Dhabi.

2. Water Algorithm: Introduction

In order to increase water use efficiency in arid regions, both academics and government officials have begun looking more intensely at domestic water use and the potential reuse of treated wastewater flows (Bazza, 2003; Dawoud *et al*., 2012; Murad *et al*., 2006; Shanableh *et al*., 2012). These studies have demonstrated that both treated graywater and treated blackwater offer financial and environmental benefits relative to using desalinated water alone, and that larger graywater systems perform up to three times better than smaller, household scale, systems (Gurung *et al*., 2016; Jabornig, 2014; Malinowski *et al*., 2015; Memon *et al*., 2005; Stec & Kordana, 2015; Yu *et al*., 2015). Within the Emirate of Abu Dhabi specifically, a study in the city of Al Ain showed there is considerable potential for graywater reuse as roughly 70% of potable water use in the houses observed resulted in light graywater, which requires only minimal treatment before being reused (Chowdhury *et al*., 2015). Currently, however, all domestic outflows in Al Ain and Abu Dhabi in general are combined and treated together in wastewater plants. Therefore, when considering the development of a water measurement toolkit for this region, accurately measuring the potential for recycled water use is crucial.

A potential challenge in using recycled graywater and blackwater in this region, however, is the unique socio-cultural and religious context. Islamic society requires stringent regulation of human contact with waterborne contaminants due to concerns for human health. In the past, these requirements have slowed the transition towards using recycled water sources. Recent scholars have concluded that when adequately processed the use of recycled water (whether gray or black) is not only safe enough to be permitted by Shari'a law, but in fact aligns with its precepts towards the “reclamation… rehabilitation and purification of the soil, air, and water” (Al-Jayyousi, 2010; Farooq & Ansari, 1981).

Due to the absence of an existing tool1 which allows urban and architectural designers to measure and understand the complex interdependencies between each water flow type, while parametrically testing and optimizing the overall water balance within a designated area, this paper proposes a Python-based, neighborhood-scale water analysis module for the Rhinoceros software platform. This tool will calculate daily average volumes and costs (when possible) for all indoor and outdoor potable water demands, their resulting light and heavy greywater and blackwater waste flows, percentages of graywater and blackwater recycling, all potential demands for recycled water, including toilet flushing, outdoor water cleaning, and vegetation, as well as final over and under supply

1 To the authors’ knowledge no stand-alone software package nor plug-in for the major design software platforms (Revit, Rhinoceros, SketchUp, and Envision Tomorrow) currently exists which offers the necessary combination of neighborhood scale analysis, multiple water type simulation and balancing, detailed parametric control over all demand producing parameters, and multi-factor optimization.

volumes. The module provides users parametric control over all critical input metrics, including behavioral changes (e.g., shorter bathing times), technological advancements (e.g., more efficient dishwashers or sprinkler systems), and new system configurations (e.g., presence of graywater system). An abstract representation of this model and its linear simulation process is shown in Figure 1.

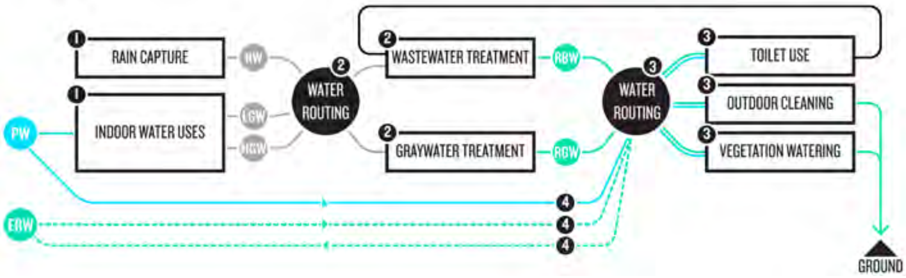

Figure 1. Proposed Simulation Process (ERW = External Recycled Water; PW = Potable Water; LGW = Light Graywater; HGW = Heavy Graywater; RGW = Recycled Graywater; RBW = Recycled Blackwater)

It is important to note that while research shows the potential benefits of recycled water use under many conditions, the water module itself does not assume nor prescribe any one system. All potential factors and water system configurations are open to testing and subject to design decisions or numeric optimizations which may weigh various aspects of social, environmental, and economic factors differently. As such, the final optimal water schema will change depending on which factors are weighted most heavily. This capability is driven by a novel water routing functionality (Figure 1: 3, 4) which abstracts and differentiates between water inflow demands and their resulting outflow streams.

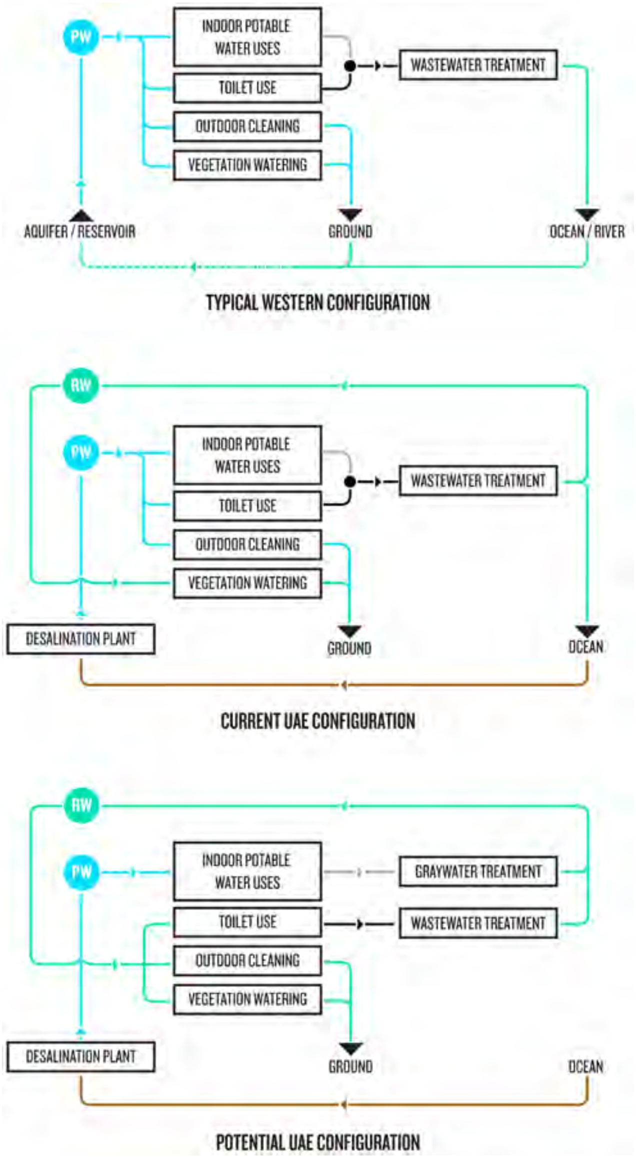

Figure 2. Municipal Water Schemas

2.1 WATER MANAGEMENT ALGORITHM: METHODOLOGY

2.1.1. Potable Water Demand and Graywater Production

The first step in the water management algorithm calculates the neighborhood scale potable water demand and resulting light and heavy graywater outflow arising from all indoor water uses, except toilets.

Typically, light graywater is defined as drain flows coming from showers, bathroom faucets, and clothes washers, while heavy graywater results from kitchen sinks and dishwashers (Cohen, 2009). Flow rates are determined by multiplying previously calculated demographic data for the neighborhood by averaged per person use rates, which in turn is multiplied by averaged appliance/faucet flow rates. Each factor is parametrically controllable. As stated above, the algorithm's calculation of graywater outflows does not presume its use as such, but nevertheless provides a critical data point towards understanding the relative costs and benefits of all potential system configurations.

Parallel to this step, potential rainwater capture is calculated from monthly averages or daily totals (if available), and multiplied by the total area of selected impervious surfaces and a loss coefficient simulating evaporation and other losses (Preul, 1994).

2.1.2. Water Treatment and Recycled Water Production

Once rainwater, light graywater and heavy graywater outflows are calculated, the next step allows users to simulate where each type of outflow is sent, whether to a neighborhood (or city) scale graywater treatment facility, or to the municipal wastewater treatment plant. This will be a Boolean parameter designating the presence or absence of a graywater recycling plant. The algorithm calculates graywater and blackwater recycling volumes at the neighborhood scale because graywater treatment, historically done at the household scale, is more efficient, better regulated and less costly at larger scales (Memon *et al.*, 2005), and because differences in supply and demand can be potentially balanced internally within the neighborhood system boundary without needing costly city-scale storage and treatment.

2.1.3. Recycled Water Use and Make-up Demand from Desalination

The next step simulates the return of treated graywater and blackwater from their respective facilities as useable, recycled water flows. Each flow type remains separated in the algorithm so it can be applied to the most appropriate uses and deployed according to use hierarchies depending on the relative quality of the recycled water flows. For example, recycled blackwater may still contain a high enough level of biological contaminants that is should be used for edible plants only as a last resort, or not at all. Boolean logics and if/else statements allow for the modelling of complex scenarios and decision making for which recycled flow is used for which use type and when. The four major categories of recycled water use the algorithm models for are toilet flushing, outdoor cleaning (including car washing), both edible and non-edible vegetation, and turf grasses. Other uses, such as district cooling and industrial processes, could easily be appended to the algorithm later as needed.

Water demand for landscaping is determined by multiplying the number of instances of trees and shrubs, and total area of turf grasses modelled by the designer in Rhinoceros, by each species regional yearly watering schedules. These schedules are typically available from local municipalities or universities. Future work on the algorithm could add a more precise calculation of watering needs of each species based on hourly or daily environmental factors including rainfall, humidity, radiation, wind, and ambient temperature. Water flows for vegetation and other outdoor uses is assumed to be fully lost through evaporation or permeation into the ground. Water used for toilet flushing (regardless of source) is designated as blackwater and fed into the stream of municipal waste water for treatment and recycling. It is worth noting that toilet water can become a nearly infinite loop of use, treatment, and recycling, minus losses to evaporation and leakage.

2.1.4. Unmatched Demand and Supply Balancing

The last step in the algorithm calculates any over- or undersupply of recycled water. In the former case, an economic multiplier can be applied to estimate the net benefit of this scenario. In the latter case, user inputs determine how much of the needed make-up supply is from other sources of recycled water (industry for example), and how much is from the desalinated potable water supply. The latter also helps designers and public agencies diagnose factors leading to increased water demand, and develop strategies for reducing it.

2.2 WATER MANAGEMENT: APPLICATION

The final output parameters from the water use algorithm include per day and per capita flow rates of all water types (desalinated, graywater, blackwater, recycled water) through the neighborhood, the amount of available graywater and blackwater, the percentage of those streams that is recycled and percentage reused, the amount of water permeated into the ground, and finally, the costs associated with each flow type. The parametric nature of the algorithm allows the user to adjust and test the relative effects of different values for each input parameter. These parameters quantify human behaviors, shifts in technological efficiencies, and larger-scale system configurations. It allows designers, therefore, to use the water module to explore and understand the trade-offs each scheme produces between environmental, economic and social costs. Finally, the tool normalizes these costs on a per capita and per area basis which in turn allows comparison between the designed neighborhood typology within the Rhinoceros program, and preexisting local, regional, and global neighborhood typologies. As such, the tool provides governments, academics, developers and designers alike with critical metrics to examine which configurations, technologies, and behavioral modifications are most effective in providing an efficient, resilient and sustainable supply of water to local populations.

3. Conclusion

This paper outlines an algorithm for simulating and analyzing water metabolism for an inputted neighborhood design in the Rhinoceros and Grasshopper software environments. When situated within the larger sustainability toolkit, planners and designers will be able to dynamically model, simulate and compare multiple environmental, economic, and social factors. Because the other environmental modules will share many of the same input parameters, such as vegetation and built form, the completed toolkit will allow for complex feedback loops and interdependencies not only within the water use module itself, but also among all the modules. This will provide designers a robust understanding of the trade-offs between various design input parameters including built and natural form, transportation infrastructure and networks, demographic patterns, system configurations and technologies.

Even though this toolkit is being designed specifically for Emirati neighborhoods in Abu Dhabi, it is anticipated that the toolkit will have broader applicability due to the inherent parametric nature of the existing modules, as well as the expandability of the toolkit through the addition of regionally or city-specific modules as needed.

The potential impact of the water module is significant given the current lack of existing tools which allow for the fast inputting of multiple design scenarios and attending data at the schematic phase, the disaggregated assessment of all potential water flow types and their environmental and economic costs, and the interdependency of water flows upon other, equally critical factors of environmental and social sustainability.

Acknowledgements

This work was funded by the Cooperative Agreement between the Masdar Institute of Science and Technology (Masdar Institute), Abu Dhabi, UAE and the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA. We would like to thank the Masdar team for their thoughtful conversation and useful insights about Emirati communities.

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ASSOCIATIVE PARAMETRIC URBANISM:

A Computational Approach to Parameterization of Conceptual Design Phase

MOHAMMED AYOUB
Arab Academy for Science and Technology and Maritime Transport
Alexandria, Egypt
dr.ayoub@aast.edu

Abstract. Urban planning projects usually comprise a complex set of objectives that needs to be addressed by developing a number of proposals. This requires a lot of repetitive steps resulting in fewer and slowly-developed design alternatives. To address the limitations of the existing system, this research introduces the merge of associative parametric design tools with the conceptual design phase of urban planning process to propose a Parameterized Conceptual Design Phase. The developed Associative Algorithm within the proposed phase represents a computational approach that translates a site's settings into local attractors to define urban fabric, and provide the designer with variations for optimal solutions. The Informal Settlement of Ezbet El Matar, Alexandria, is selected as the case study of this approach.

1. Introduction

Urban planning lays the foundation for the new buildings and public spaces that shape our lives. Traditionally, urban planning process consists of a sequence of phases that may vary or overlap to suit the project nature. During the conceptual design phase, a complex set of objectives and requirements are addressed regarding certain factors such as land use, site considerations, circulation, and environmental issues. To respond to these complexities, a number of design alternatives is needed to be developed and assessed against certain criteria. However, designers normally develop only few alternatives that may not be able to give the optimum design solution, as they are considered static tools. Moreover, the amount of time spent in generating and evaluating alternatives using traditional design models and tools, such as CAD systems, forces many designers to use these methods only for validating a selected alternative rather than exploring multiple scenarios (Shea *et al*., 2005: pp. 253-264). Urban planning now finds itself at the mid-point of an ongoing cycle of adaptation to comply with the demand for an increased level of complexities. To address the limitations of the existing system, it is essential to consider new methodologies of design techniques at a higher level of understanding. Among new ones is the Parametric approach, which is a novel trend that utilizes the computational technologies to model geometries based on multiple parameters, and can offer explorations during the conceptual phase of design process.

In response to the above-mentioned challenges, this research will aim at merging parametric approach with urban planning process for developing urban planning projects and their alternatives during the conceptual design phase. The research methodological objectives are realized through two main steps. The first step is to define the parametric approach in design, and to delineate the parametric urbanism and review its current approaches, in addition to merging the parametric approach with urban planning process. Secondly, the Parameterized Conceptual Design Phase will be developed, with the application of a case study, to support this computational approach.

2. Parametric Approach in Design: Parametric Urbanism

Given the digital nature of the contemporary design, parametric approach is becoming an essential tool for architecture, and urban planning. It has its roots in the digital techniques since the mid-1990s, though it only fully emerged over the last fifteen years with the development of computational tools (Schumacher, 2009: pp. 14-23; Stavric & Marina, 2011). It has become clear that parametric tools could bring similar benefits to architectural design projects, having even effectiveness in higher scale of urban planning (Nagy, 2009: p.14; Leach, 2009: p.19). The design is controlled by fixed or variable relations, either numerical or geometrical (Kilian, 2006: pp. 54-55). New forms and ideas can emerge when the designer converts all his concepts and design guidelines into a parametric environment (Hernandez, 2006: p.38). Parametric approach also allows setting rules and relations to the design to minimize the time consumed in modifications during the design process (Araya, 2006: p.11). In short, parametric approach is the process of modeling and designing with geometrical sets that hold fixed and variable attributes, in a computational environment where variations are effortless (Ayoub, 2012: p.86).

Many researchers developed new urban planning techniques to enable a more flexible and faster design developments parametrically (Batty, 2013; Beirão *et al*., 2011; Stavric & Marina, 2011; Oxman, 2008; Saleh, 2012).

Parametric Urbanism is a new trend in urban planning that uses advanced computational technologies to plan geometrical urban spaces, and by variating their parameters values, different geometrical configurations could be generated (Canuto & Amorim, 2012; Schneider *et al*., 2011; Schumacher, 2009: pp.14-23). It is defined as the ways in which associative design systems can control dynamic information and design components to affect and adjust design process by embedding intelligence into the formation, organization, and performance of urban spaces, uses, and activities (Stavric & Marina, 2011).

2.1. APPROACHES OF PARAMETRIC URBANISM

The computational processes of form transformations are referred to computational architectures. Using these technologies in design has established new approaches. Kolarevic stated a number of architectural subcategories that emerged from studies with different computational techniques: topological space, isomorphic surfaces, motion dynamics, parametric design, and genetic algorithms (Kolarevic, 2005: p.251; Stavric & Marina, 2011; Saleh, 2012: p.8). On the other hand, Oxman proposed that the computational approach provides a medium for the structure of design models according to various relationships of the designer, his concept, the design processes, and the design object itself. She identified the approaches of computational design: CAD models, formation models, generative models, performance models, and integrated compound models (Oxman, 2006; Saleh, 2012: p.8). However, not all of these approaches can be related to the urban planning domain. Some of them have made a notable impact on the development of urban planning methods and techniques, moving from the traditional methodology to a more dynamic one. The correlation between these approaches and the urban planning has led to the emergence of four parametric urbanism approaches [FIGURE 1]:

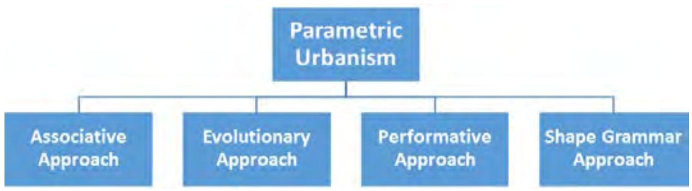

Figure 1. Approaches of Parametric Urbanism

2.2. PHASES OF PARAMETRIC APPROACH

Parametric design process integrates new way of thinking into the design process through the ability to control variables, and to adapt the designs, which allows the formulation of more precise, and even complex solutions

(Gane, 2004: p.14). The idea is that the designer first establishes rules and relations by which design components are connected to minimize the time and effort consumed in modifications, and to provide multiple solutions that could not be reachable by traditional methods. The parametric approach has been studied and analyzed by numerous academics and designers (Araya, 2006: pp.11-12; Gane, 2004: p.54; Hudson, 2008: pp.18-19; Llabres & Rico, 2016). Most of them coincide describing it as a series of phases, which increase in the level of detail and precision, as they involve from preliminary concept to construction. Herein, the parametric design process starts with *Design Exploration*, in which background data and design problems are determined, including the design objectives, variables, and constraints. The second phase, *Design Development*, includes possible solutions for design problems and manipulations of design instances. Generation of alternative solutions are reviewed and evaluated in the *Simulation / Evaluation* phase, to satisfy project goals, and previously built constraints. After these explorations, a development is considered one single direction in the *Manufacturing / Construction* phase (Araya, 2006: p.12; Gane, 2004: p.54).

3. Parameterization of Conceptual Design Phase, Case Study: An Informal Settlement in Alexandria (Ezbet El Matar)

The proposed Parameterized Conceptual Design Phase (PCD) comprises the merge of the parametric approach with the conceptual design phase of the urban planning process. It can help the designer by embedding intelligent computational tools in terms of using the parametric approach in urban planning. It conceives site qualities that represent unique character and scale of a project in a way that would eventually shape its character. Relations and dependencies of the design components are developed and linked together by suitable rules and definitions. Grasshopper (a visual programming language developed by David Rutten at Robert McNeel & Associates) will be the modeling platform used in this research, in which, geometric models will be integrated with these rules to generate project variations parametrically. The following application will focus on the proposed process of PCD, which consists of three main stages [FIGURE 2]:

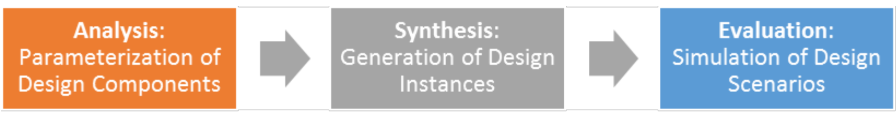

Figure 2. Parameterized Conceptual Design Phase (PCD) Process

Regarding the case study, Smouha Area is one of the most diverse parts of the City of Alexandria, Egypt's second largest city and main port. However, the impact of settlements unplanned-process has become unmistakable towards the city's urban border. Ezbet El Matar is one of the informal settlements localized in Smouha Area near the El Nozha Airport. The 0.163 km^2 site stretches between the Alexandria Agriculture Road, and Airport Lake waterfront. It is surrounded by formal housing units and industrial warehouses from the north, Airport Lake waterfront from the south, agriculture land and German Company for Sewage System from the east, and El Nozha Airport from the west. The original development was planned to be an industrial and warehouses area near Alexandria's borders. However, informal housing units were sustained there, and became cohesive to the urban fabric as the city expanded decades ago. Ezbet El Matar is characterized by very narrow streets with varied widths, poor environmental conditions, and absence of open spaces and green areas.

3.1. ANALYSIS: PARAMETERIZATION OF DESIGN COMPONENTS

Parameterization of Design Components is the first stage of PCD process. It starts with *Exploration of Generators* step. A number of Grasshopper definitions is carried out during this research. These definitions focus on translating of the site's settings into local attractors with range domains as main drivers for geometric variations of a site's urban fabric within certain boundary. The current step begins with identifying all available generator nodes on the site (Alexandria Agriculture Road, Airport Lake, formal housing units, and El Nozha Airport), which vary in magnitude and response. Then, an exploratory point cloud is represented on the site with regard to generators that dominate the preliminary settings for point cloud population by manipulating their coordinates. The generator nodes act as local attractors for the propagation rules affecting surrounding points to generate a unique range domain for each one [FIGURE 3].

Figure 3. An Exploratory Point Cloud (Left), Preliminary Settings for Point Cloud Population (Middle), Point Cloud Population after Applying Propagation Rules (Right)

The second step is *Parameterization of Generators*, in which the designer assigns parametric attributes (dependent, independent, fixed, or variable) to the previously stated generators and point cloud to convert the static site model into a parametric one. Independent fixed attribute is applied to the generators, which are considered geometrical entities that control the behavior of other components. Dependent variable attribute is assigned to the point cloud, then, a set of transformations is applied on every point to be attracted towards the closest generator point. In order to create contextual urban subdivisions, a series of Voronoi tessellations is created, which divide the site into polygons based on the dependent variable locations (point cloud) after applying the propagation rules. A linkage correlation is then developed for the tessellations to establish contextual urban relationships between them (to be converted into triangulation subdivisions) [FIGURE 4]. It is noted that all the above mentioned parameterized design components are dictated by the input location of the generators in the parametric model.

Figure 4. Voronoi Tessellations (Left), Linkage Correlation Development for Establishing Contextual Urban Relationships (Right)

3.2. SYNTHESIS: GENERATION OF DESIGN INSTANCES

Synthesis: Generation of Design Instances is the second stage of PCD process. *Rules Setting* is its first step that is concerned with applying the rules and conditions in which the previously parameterized design components combine together. Within the developed linkage correlation, each triangulation subdivision varies depending on its polygonal area and the number of connections. Then, certain rules strategies can be derived from subdivision variations, which will define urban settings of open spaces as voids, and building masses as solids. Based on the subdivision variations of triangulation subdivisions, a set of geometrical responses, which correlate with the tessellations density change, is developed to define different urban settings of open spaces and building masses. External geometrical responses are applied to triangulation subdivisions for extruding building masses.

Other internal geometrical responses are set to these subdivisions to develop variable internal layouts. These variations are created to incorporate the linkage correlation with the site's urban fabric to produce a more coherent solid-void relationship [FIGURE 5]. The *Associative Algorithm* is the second step of this stage. It focuses on creating the Associative Algorithm and its computational definitions for different urban settings to acquire particular rules strategy of parametric urbanism, and eventually, provide the designer with explorations about the project to search for optimal design solutions. The implementation of this algorithm is developed using the associative approach in Grasshopper environment [FIGURE 6].

Figure 5. External Geometrical Setting to Voronoi Tessellations (Top Left), Creation of Internal Polygonal Spacing (Top Right), Proposal 3D External Shots (Down)

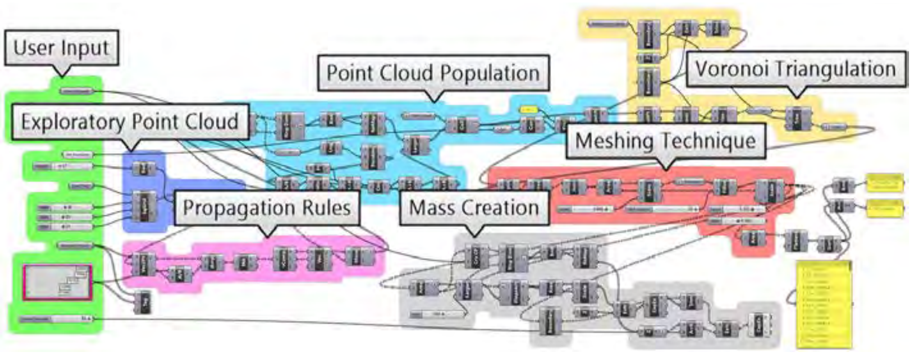

Figure 6. The Developed Associative Algorithm and its Computational Definitions

3.3. EVALUATION: SIMULATION OF DESIGN SCENARIOS

In the past, the only simulation method was to create, test, and evaluate physical prototypes. With the rapid growth of computational systems and numerical methods, recently, better simulation techniques can be achieved computationally. *Simulation of Design Scenarios* is the final stage of PCD phase, in which the generated design instances are evaluated and tested. Algorithms can be established for simulation purposes to make decisions about proposals against specific design criteria. However, this research will not emphasize on these issues due to the limitations of its scope.

Discussion

Recent decades witnessed a paradigm shift on how new techniques of parametric urbanism are utilized to facilitate viable developments, which are becoming an essential part of contemporary urban planning standards. This research aimed at merging parametric approach with the conceptual design phase of urban planning process to propose a PCD phase. The work within this research reveals the power of the parametric associative approach as a suitable tool to support and expand the development of urban planning projects. By applying the proposed PCD, designers can increase their understanding and creativity outcomes by assembling more dynamic components, exploring variable solid-void relationships, and guiding development through modular computational environment. This is valuable in high density cities like Alexandria, especially in informal settlements, to explore possible multidirectional solutions to design problems. Although the developed associative algorithm within the proposed PCD still in an early development stage, it has potentials to translate a given site's settings into design generators to define urban fabric and generate geometric variations for continuous urban development. Undoubtedly, there are more variables and considerations of conceptual design phase that could be considered, such as visual qualities, pedestrian services, land uses, etc. However, for a first experiment, this tool is sufficient. As for recommendations, PCD phase can be applied to parametric systems, which are widely used by designers.

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USING TIME AS A SUSTAINABLE TOOL TO CONTROL DAYLIGHT IN SPACE

Creating the Chronoform

SAMER EL SAYARY
Beirut Arab University and Alexandria University, Egypt
samer.elsayary@alexu.edu.eg

Abstract. Just as Einstein's own Relativity Theory led Einstein to reject time, Feynman’s Sum over histories theory led him to describe time simply as a direction in space. Many artists tried to visualize time as Étienne-Jules Marey when he invented the chronophotography. While the wheel of development of chronophotography in the Victorian era had ended in inventing the motion picture, a lot of research is still in its earlier stages regarding the time as a shaping media for the architectural form. Using computer animation now enables us to use time as a flexible tool to be stretched and contracted to visualize the time dilation of the Einstein's special relativity. The presented work suggests using time as a sustainable tool to shape the generated form in response to the sun movement to control the amount of daylighting entering the space by stretching the time duration and contracting time frames at certain locations of the sun trajectory along a summer day to control the amount of daylighting in the morning and afternoon versus the noon time.

INTRODUCTION

According to most dictionaries (Oxford, 2011; Collins, 2011; Merriam-Webster, 2015) Time is defined as a nonspatial continued progress of unlimited duration of existence and events that succeed one another ordered in the past, present, and future regarded as a whole measured in units such as minutes, hours, days, months, or years. As time is considered to be one of the seven fundamental physical quantities in both the International System of Units and International System of Quantities but it was not used to define the geometry of the architectural form. Time is used to define other quantities—such as velocity of the user inside the building —so defining time in terms of such quantities would result in a new formation that considers time as a parameter that shapes the architectural form. (Duff *et al*., 2002).

Fig. 1. Etienne-Jules Marey (1830-1904), Analysis of the Flight of a Seagull, 1887, Bronze, 16.4 x 58.5 x 25.7 cm, Dépot du Collège de France, Musée Marey, Beaune, France.

An operational definition of time that defines time in terms of a process needed to determine its existence, duration, and quantity would be more convenient to observe a certain number of repetitions of a standard motion event that constitutes one standard unit such as the second, is highly useful when it relates to architectural form that might be constructed on a grid module.

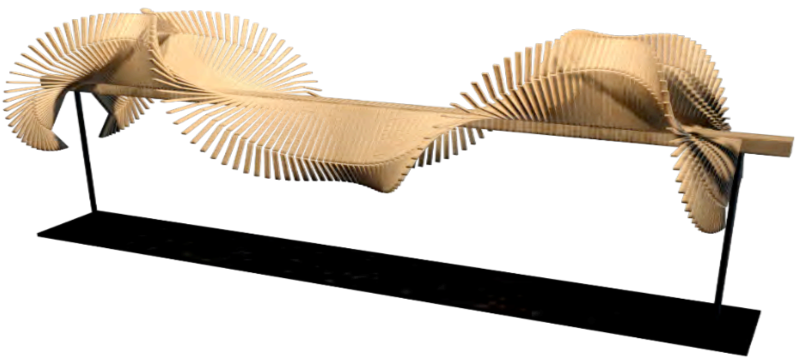

Fig. 2. A chronoform model inspired from Marey analysis of the flight of a seagull, Researcher.

Based on the previous concept we used the standard motion event unit of time to place arrays of hierarchal events in sequence one after the other, and we use time to compare how long events last to make time visually perceived relating our work more to Minkowski spacetime which combined the Euclidean space and time into a four-dimensional manifold where the spacetime interval between any two events is independent of the inertial frame of reference in which they are recorded.

As agreed also by the working definition offered by Adolf Grünbaum who defined time in the contemporary mathematical theory of continuity to physical processes, and he says time is a linear continuum of instants and is a distinguished one-dimensional sub-space of four-dimensional spacetime.

Now it is possible to warp or loop time or get back in time as if time is a linear entity after mapping the sequence of events using the proposed animation timed array model.

1. Background

1.1 BRIDGING THE GAP BETWEEN CHRONOPHOTOGRAPHY AND CHRONOFORM

"Time is nature's way to keep everything from happening all at once."

John Archibald Wheeler.

As Chronophotography was developed, at the end of the nineteenth century by Marey, Demenÿ and later Gilbreth and used as a tool for investigating motion. At the beginning of the twentieth century chronophotography's potential in other fields as in research for example was ignored as aspects of chronophotography were developed into cinema. Now, in what many call the post-cinematic era as expressed by Manovich (2001: p 296), artists and researchers are beginning to return to chronophotography to continue some of its unfinished stories. A chronophotograph contains information about interval, duration, speed and other derivatives of space and time. This information can and has been used to answer questions about spacetime perception. Movement is the physical act of traversing through space as performed by a body and is in contrast to the static nature of architecture. Bernard Tschumi stated, "There is no architecture without program, no architecture without movement." (Tschumi, 2000). Through his definition the measure of architecture lies in the relationship of the user and his experience of space, which emerges from the dynamic interaction of their activities. Marey's graphic method, with which he provides highly abstract representations of bodily movements to solve the problem of the tension between space and time, to principles of the quantum mechanics to result in what we called the spacetime model (Chronoform) where we explored the potentials of the synchronized arrays (decomposed frames of time) to define the geometrical shape of the model. Continuing this metaphor, the studies that Marey conducted in the early part of his career of decomposing movement, some of which we shall now describe, may be construed as devices for translating invisible phases of motion into the spatial code of graphic notation. His effort to refine graphic display of bodily movement, and eventually time itself, thoroughly dominated his work, including his innovative experiments with chronophotography. Marey experimented with several techniques of photographic representation the motion of natural phenomena like wind as well as human kinetics in various phases of motion. His aim was to decompose bodily motion into the smallest temporal and spatial segments possible within the limits set by representational techniques (Muybridge,1979). As Marey pointed out in this method of photographic analysis the two elements of movement, time and space, cannot be both estimated in a perfect manner. Knowledge of the positions the body occupies in space presumes that complete and distinct images are possessed; yet to have such images a relatively long temporal interval must be had between two successive photographs. But if it is the notion of time one desires to bring to perfection, the only way of doing so is to greatly augment the frequency of images, and this forces each of them to be reduced to lines (Marey, 1883). In other words, to make it possible to visualize time, he had to reduce photographs to diagrams. Photographs capture a plethora of detail that Marey believed was irrelevant to, and interfered with, the representation of time. Marey wanted to construct a pure geometry of time. The result was a pure, synchronized timed geometry of motion. Marey used chronophotography to decompose time into its 'elements'. In effect, he created an empirical geometry that could, he thought, show how continuous motion can be built up out of discontinuous series of fractional movements.

2. Application & methods

2.1 CREATING THE SPACETIME MODEL (CHRONOFORM):

Our spatiotemporal model simply fuses space and time into the single same interwoven continuum that involves gradual quantitative transitions without abrupt changes or discontinuities of the overall form in consistency to the Minkowski spacetime and developed as a descendant of chronophotography with the help of computer animation technology with representation of time contraction and dilation. It is the unfolding of series of moments visualizing the narrative of a certain event, picturing it through moments lined up in a controlled array defined by a geometrical path trajectory. The user stepping inside the chronoform will be defining his now moment by every step perceiving a new instance of the arrayed elements, where user motion will slow or speeds the motion of time depending on his velocity. Defining the geometry and length of trajectory path allowed the viewer to conceive it as an overall continuous spacetime model. And according to Einstein, whenever you do something to space, you also affect time. Physically you could walk through time as you walk through space with visual reading to its events where we freeze the events duration allowing the user to pass by them. As where Einstein explained that in order to travel through time you have to reach the light speed we on the contrary had frozen time in consecutive sections throughout the space to enable the user to walk through frozen time to achieve the same experience.

As a developed concept of Muybridge chronophotography, Chronophotography, is the photographic capture of movement over time. the chronoform is a model that enables the users to move backwards or forwards to observe different points in spacetime. The suggested name was derived from the Greek *chronos* (time) and the word (form) to suggest a form that tells a linear narrative based on its gradual quantitative transitions of modular structure synchronized by time unit. The new chronoform model is defined by the following parameters:

P: Trajectory path
T: Timing
N: Number of synchronized arrays
M: Motion typology

2.1.1 Trajectory path

The trajectory path is considered to be the main geometry spine of the chronoform timeline where it is the path that a moving object follows through space as a function of time. The object might be arrayed synchronized objects and hence will be the same path of the user inside the chronoform. In consistence with control theory which indicated that the trajectory path is a time-ordered set of states of a dynamical system, the trajectory path is the circulation line displaying a list of events in chronological order (See the fig. 3).

It is what defines the direction of the motion and creates a vector motion.

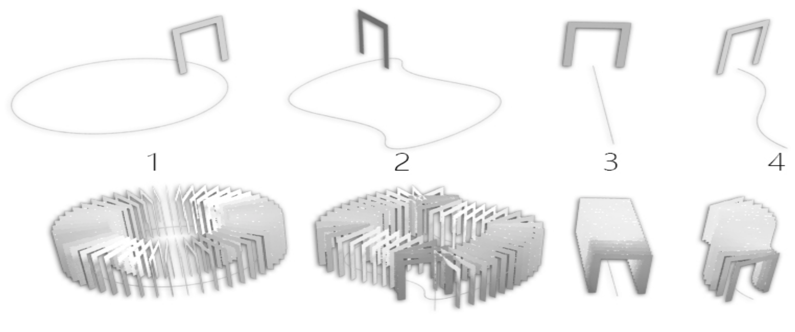

Fig. 3. Different trajectory paths resulting in different geometry of chronoforms, (Source: researcher).

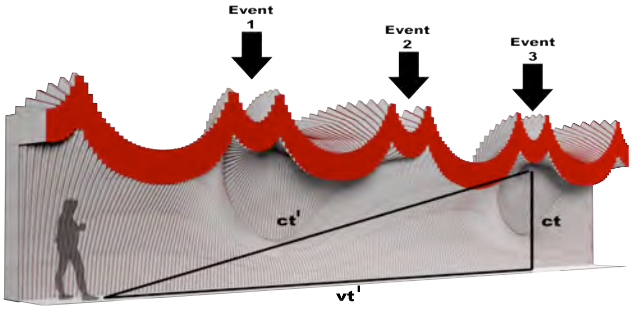

Fig. 4. Diagram showing the user inside the chronoform calculations, (Source: researcher).

2.1.2 Timing

Based on the theory of relativity, the user can move inside the chronoform timeline as a graphical representation of a period of time, on which important events are marked with the black heavy arrows.

Applying the same time dilation rule of chronoform and according to the Pythagoras equation

$(ct^i)^2 = (vt^i)^2 + (ct)^2$
$c^2(t^i)^2 = v^2(t^i)^2 + c^2t^2$
$(t^i)^2 = v^2/c^2\,(t^i)^2 + t^2$
$t^2 = (t^i)^2 - v^2/c^2\,(t^i)^2$
$t^2 = (t^i)^2\,(1-(v^2/c^2))$
$t = t^i\,\sqrt{1-(v^2/c^2)}$
$t^i = t\,/\,\sqrt{1-(v^2\,/\,c^2)}$

Where:

(t^i) is the time of the user inside the chronoform
(t) is the time of the clock perceived by a stationary user outside the chronoform at the place of the event.
(c) is the time of light where the event takes place by the perception of the user.
(v) is the velocity of the user inside the chronoform

If we assumed that we had frozen the time due to the static chronoform that mapped the time frames.So this means that the user will be moving with a speed near to the speed of light

So practically when c = v, it means that time had frozen

$t^i = t\,/\,\sqrt{1-(v^2\,/\,c^2)}$
$t^i = t\,/\,\sqrt{1-\,(v^2\,/\,v^2)}$
$t^i = t\,/\,0$
$t^i = \infty$

This is the same principles of time dilation theory but on the contrary of traveling the user with the speed of light we frozen the time to decrease the speed of c till it reaches the speed of user v.
Metaphorically the user can travel through time forward and backward.

2.1.3 Number of synchronized arrays

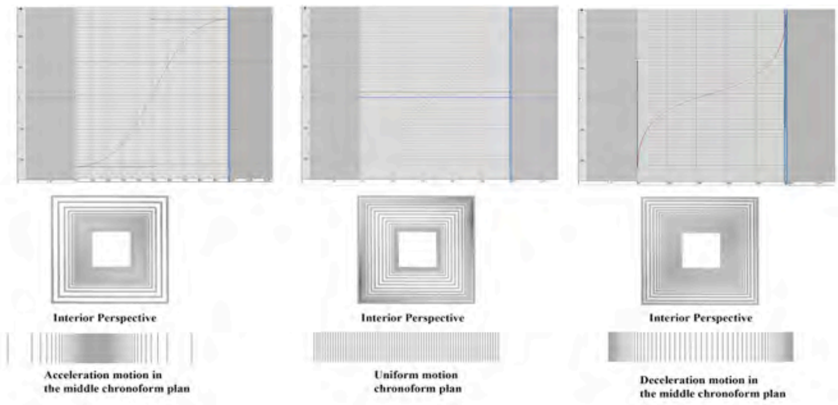

Fig. 5. Studies of Spatial and Temporal Sequence, (Source: researcher).

It is the array of a modular systematic range of a particular type of items in ordered arrangement with gradual transition and synchronized with a time measuring unit. The arrayed elements create the modular grid of the architectural form. Modular design is rooted deep in design theory and has been used by a number of architects for a long time. Transforming and growing according to the needs of the transition in spacetime is a key characteristic of modular nature of chronoform. The Modular nature of chronoform allowed it to grow by adding to or reducing in size by adding or removing the arrayed components. This can be done without altering larger portions of the chronoform. It can also undergo changes in functionality using the same process of adding or removing modular arrayed components.

2.2 APPLICATION

Greg Lynn indicated that architecture's relationship to time is typically posed in terms of the representation of motion (1999). The representation of time and motion in architecture has been a persistent theme throughout its history. The proposed application is a direct application of the previously discussed model. It is about engaging the time dilation and contraction technique of openings arrayed on timespace trajectory of sun path where the time contraction openings accelerating array will be performed in the morning and afternoon period and time dilation decelerating array on the noon period to maximize the sun rays entering at morning and afternoon period while minimize sun arrays from entering the space at noon. Time contraction here in this paper is considered to be the decrease in time of the openings array traveling on the same trajectory of sun path as measured relative to the observer. Whereas time dilation is achieved by a difference of elapsed time between two periods *(morning and afternoon)* as measured by users observing the openings arrayed at a non-uniform time pace.

2.2.1 Building the Chronoform:

Since the time of Vitruvius architects have described architectural space as a static construct. Computer animation nowadays provides an alternative description to the architectural form. Animation to analysis of space and form through time can have a significant role in the generation of architectural form resulting in a new structuring of the architectural design process. Since we defined the parameters controlling the geometry formation of the chronoform earlier in this paper, the same four parameters were taken into consideration while generating the suggested model. The key feature used in this technique is computer animation as referred by Greg Lynn (1999) the term virtual has recently been so debased that it often simply refers to the digital space of computer aided design. But while Lynn (1999) believed that Architecture has historically modeled time in terms of models of procession where architectural form is typically conceived as a modulating frame through which a mobile eye moves. The nature and complexity of the modulating frame has been the primary factor in discussions of temporal procession. In processional models of time, architecture is the immobile frame through which motion passes. We visualized time frames in our chronoform to draw the whole motion path in the user movement memory in consistency to Lynn's concept that processional time depends on static frames, formal time indexes time through the multiplication and sequencing of static frames. The following sequential steps were taken to build the chronoform:

2.2.2.1 (P): Trajectory path

Representing time as linear entity offers a way to describe spatial organizations through the objects arrayed changing profile and trajectory. Broken into fragments of arrayed objects along trajectories that might have meaning lines may act as descriptive linguistic elements. The trajectory path was generated from the sun path extracted with the help of the software algorithm after defining date by first of June 2016 and the geographic location of Zurich. However, the concept of the chronoform is designed to be a generic model that could be applied in anywhere else but for the particularities of the experiment we had to specify a date and geographical location

2.2.2.2 (T): Timing

Computer animation now days gives us the privilege to control time visually using motion graphs which enables us to accelerate or decelerate motion as required. That will result in a narrow rhythmic array or wide rhythmic array as will be shown later in this research.

2.2.2.3 (N): Number of synchronized arrays

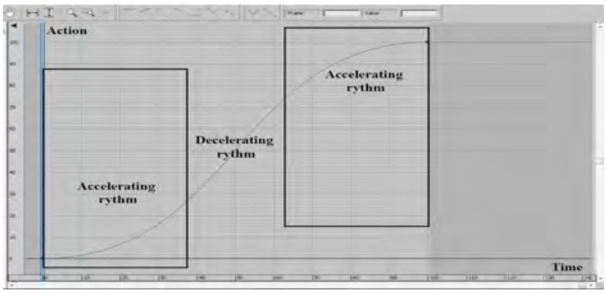

Fig. 6. Accelerating and decelerating action vs. time graph, (Source: researcher).

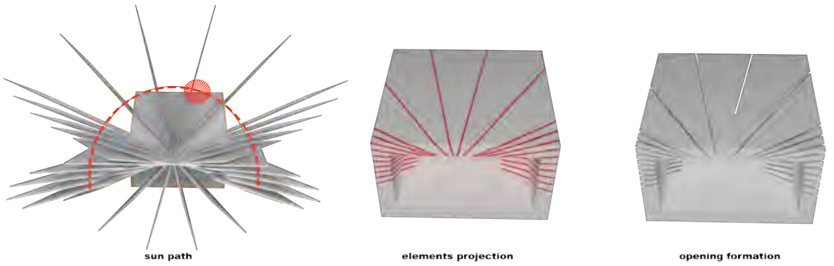

Fig. 7. Final process of arraying the openings along sun path trajectory, (Source: researcher).

Depending on the last principle of time control through the visual graphs the continuity of motion is divided and proportioned based on the number of arrays that is to be generated. Fig.(6)

3. Results and reflection

This paper is considered to be the meeting ground between art and science as the original definition of architecture itself claimed. Art represented as a developed descendant of chronophotography using latest computer animation techniques and science in rethinking the application of spacetime in the architecture. Chronoform is a fusion of time and space unfolding a series of decomposed moments visualizing a space narrative in a vectorial linear continuum.

4. Conclusion

We explored the potentials of spacetime through a scientific and artistic perspective using computer animation. Animation in architecture is traditionally used as post-design exercise in service to the representation and visualization of a project. The role of this paper was to rethink animation to explore new possibilities to achieve sustainability using the animation techniques Although a large amount of work has been done in space time modeling by physicts and mathematicians, many issues are still open and deserve for architects, further research needs to be conducted, especially in the following areas:

4.1 SUSTAINABLE ARCHITECTURE APPLICATIONS

How can the chronoform inform a design problem in response to wind and sun movement pattern to create passive design using Kinetic architecture.

4.2 INTERFACE BETWEEN ARCHITECTURE AND QUANTUM MECHANICS

Studying the relationship between quantum mechanics theories like Lorenz attractor for example and user behavior inside the chronoform to observe its impact on sustainable design.

4.2 DIGITAL FABRICATION AND PARAMETRIC DESIGN

Parametric design has a great potential in liking modern physics and architecture form finding and testing these theories as a generative medium for design to visualize phenomena like gravity and wind forces.

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PARAMETRIC ISLAMIC GEOMETRIC PATTERN FOR EFFICIENT DAYLIGHT AND ENERGY PERFORMANCE

Façade retrofit of educational space in hot arid climate

MAHMOUD F. MOHAMADIN[1], AHMED A. ABOUAIANA[2] AND HALA H. WAGIH[3]
[1]*Future University in Egypt (FUE), Cairo, Egypt*
[2]*Cairo University, Egypt*
[3]*Arab Academy for Science & Technology, and Maritime Transport (AASTMT), Cairo, Egypt*
[1]*mahmoud.mohamadin@fue.edu.eg* | [2]*a-malek@mau-eg.com* | [3]*wagih.hala@gmail.com*

Abstract. The purpose of this paper is to reach an optimal Islamic geometric pattern (IGP) shading screen design in terms of daylight and energy performance in an existing educational design studio (EDS) using generative design and simulation techniques. The study was carried out in a hot arid climate, in a typical EDS in 6th October University, located in Cairo, Egypt, and the study focused on the north-east oriented façade. Grasshopper for Rhino was utilized to generate the IGP parametric variations. Diva-For-Rhino which performs daylight analysis using Radiance / DAYSIM, and Design Builder which performs thermal load simulations using EnergyPlus were utilized in simulation. The results of the study achieved the required daylight levels with significant reduction of energy consumption levels of cooling load. This shows the affordance of the parametric IGP shading screens in façade treatment for achieving both efficient daylight and energy performance in educational design studio in hot arid climates.

1. Introduction

Natural light is beneficial to human working performance in terms of both visual quality and psychological well-being (Altamonte, 2009). In educational spaces, it improves students' mood, concentration, behaviour & their learning process in general (Che-Ani *et al*, 2012). Increasing the transparent parts of the building envelope can help harvest daylight, however, in hot arid climates this solution would cause some issues such as the lack of the ability to control daylight uniformity, and the increase of heat gain when exposed to direct sunlight, which leads to higher energy consumption levels of cooling load. This led the research team to search for a solution to these issues proposing the IGP shading screen.

Shading screens are efficient architectural elements for reducing the thermal loads inside buildings (David *et al*, 2011). IGP shading screens have been widely used in ancient Islamic architecture in many hot arid climate regions, and the use of IGPs in shading screens has shown great effectiveness for decades as an environmental solution in terms of both daylight performance and reduction of thermal loads.

2. Literature Review

Barrios and Alani (2015) were able to make a complete parametric analysis of the IGP. They used traditional Islamic geometry as a starting point and performed an analysis of pattern's fundamental units and cells. Consequently, they were able to do a metamorphosis operation based on parametric variations of geometry and colour. This resulted in generating new geometries through a guided exploration of Islamic geometry (Barrios, & Alani, 2015).

Samaan (2016) investigated the impact of envelope design variables (shading – WWR – construction layers) on achieving the balance between efficient daylight with minimal cooling loads in the EDS with various orientations and dimensions in a public university in Egypt using digital simulation tools. The study showed that East & west orientations increased the energy consumption of cooling load by 47% more than optimum orientation (North). They achieved significant reduction in energy consumption using (overhangs, louvers & Low-E glass) but with poor daylighting performance. Their optimum solution has been achieved by using skylight in roof with 8% opening ratio.

In a similar context, Wagdy *et al* studied the influence of the parametric Kaleidocycle in a double skin envelope that is south oriented to optimize day lighting with efficient energy consumption for cooling loads, heating loads, and artificial lighting in a typical office building located in hot arid climate. It showed that using many Kaleidocycle units with less perforation ratios and open angles reduced energy consumption by 23% reduction and achieved appealing day lighting levels more than LEED V.4 requirements (Wagdy *et al*, 2016).

3. Methodology

This paper investigates the application of IGP shading screen as an environmental solution to solve daylight usability issues in relation to energy consumption levels of cooling load in an EDS in [..] University, located in [..], which was modeled using Rhinoceros to be investigated as shown in figure 1.

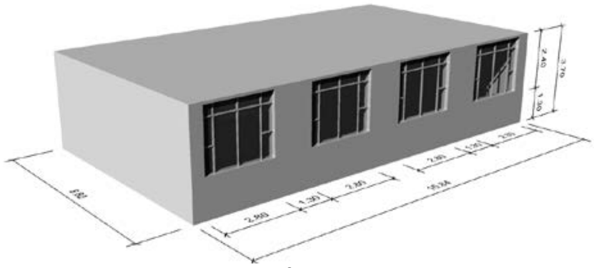


Figure 1. Model of the case study

3.1. ISLAMIC GEOMETRIC PATTERN

A six-point star IGP shading screen was selected to be tested parametrically, and the fixed topology approach (Barrios & Alani, 2015) was adopted in this study where the new geometry should always be topologically identical to the starting point of the variations.

The cell is the basic unit for the pattern, and the fundamental unit in the cell is the group of geometrical elements with non-repeating components (Alani, 2015).

Selected pattern Cell Fundamental Unit

Figure 2. Pattern, cell, and fundamental unit

Fixed Topology: (Barrios & Alani, 2015) proposed this method in which the total number of points and edges of the IGP remain identical at every stage in the parametric variation. While the geometry changes, any parametric variation shouldn't result in a topological transformation. The geometry of the new designs can be generated by adhering to the following rules, for all the points within the fundamental region: 1) Point overlap is not allowed; 2) line overlap is not allowed; 3) Intersections are allowed; and 4) Points should not leave the fundamental region. Fig. 3. shows the 4 cases of the parametric variations of the IGP Fundamental Unit chosen for this study; F1, F2, F3, F4.

Figure 3. Fixed topology parametric variations on a six point star IGP

A total number of 12 cases were tested under the fixed topology method as follows:
IGP cell grid: diameter = 35 cm (fixed)
IGP fundamental unit (F): 4 cases (variable)
Thickness (T): T1 = 2.5 cm , and T2 = 5.0 cm (variable)
Depth (D):D1 = 2.5 cm, and D2 = 5.0 cm (variable)

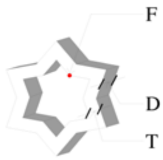


Figure 4. IGP parametric variables F, T, D

3.2. THE PROCESS

In a first stage, Grasshopper-For-Rhino was utilized to generate the parametric variations of the IGP. Diva-For-Rhino was used to test the cases for an optimum solution in terms of daylight performance. In the second stage Design Builder (DB) was used to test the outcome of the first stage in terms of thermal performance so as to achieve the best solution with the lowest energy consumption of cooling load.

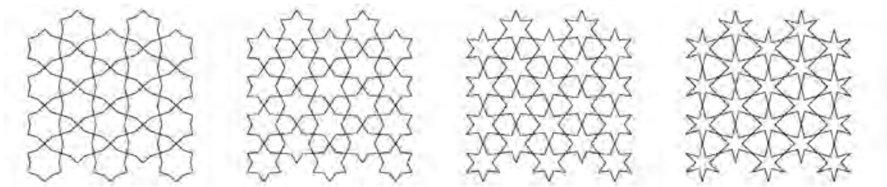


Figure 5. Grasshopper generated variations for the IGP fundamental unit

3.2.1. The first stage

Daylight simulation was conducted using Diva-for-Rhino 3.0 to measure Daylight Autonomy (Da), Daylight Factor (DF), and Useful Daylight Illuminance (UDI). Daylight Autonomy (DA) is represented as a percentage of annual daytime hours that a given point in a space is above a specified illuminance level (Reinhart 2001). We selected a Daylight Autonomy threshold of 500 lux (DA500). The daylit area is the area of space at which the Spatial Daylight Autonomy corresponds to at least 50% of the occupied time of one year in which the daylight levels are above the target illuminance. Daylight Factor DF is the mean ratio between the interior illuminance level and the exterior illuminance level under overcast sky conditions.

Zach Rogers (2006) proposed Continuous Daylight Autonomy (cDA) as a basic modification of Daylight Autonomy. Continuous Daylight Autonomy awards partial credit to values below the target threshold. If a sensor point exceeded 500 lux 50% of the time on an annual basis, then the cDA500 might result in a value of approximately 55-60% or more.

Useful Daylight Illuminance (UDI) is a modification of Daylight Autonomy proposed by Mardaljevic and Nabil in (2005). It provides full credit only to values between 100 lux and 2,000 lux suggesting that horizontal illuminance levels outside of this range are not useful.

3.2.2. The second stage

Thermal model was built using Design Builder 4.7 which works on accurate details related to building design, construction layers & internal loads, climatic weather file data was selected and the building air condition. The current study assumed that no natural ventilation was set, and neglected artificial lighting and system loads. The study focused on energy consumption of cooling load.

3.2.3. Base case simulation results

Daylit Area : 64% of floor area .
(DA): 68% of time occupied .
Mean Daylight Factor (DF): 2.5% .
(cDA): 87% for active occupant behaviour
(UDI): 89% for active occupant behaviour.
Annual energy consumption level of cooling load: 6485 kWh .

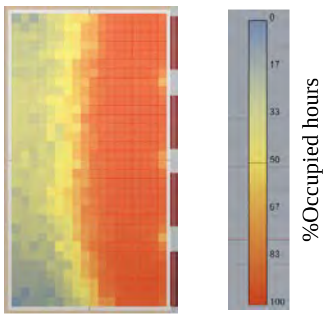


Figure 6. Daylight simulation results for the base case, occupancy 1680 hours per year

4. The Investigation

The tested EDS in the faculty of engineering building of [..] university, in [..] is climatically located in a hot arid climate based on Koppen classification. The façade of the EDS is oriented towards north-east with a Window-to-wall ratio (WWR) equal to 43%. The dimensions of the EDS are 16m X 8.6m, and its clear height is 3.6m, with a total area of 138 m2. The selected EDS is settled in the second floor of a four story building in the University.

Daylight model parameters (DIVA for Rhino) were set as follows:
Target illuminance for the EDS is 500 lux, Inner walls: Reflectance 50%, floor: Reflectance 20%, Ceiling: Reflectance 70%, Glazing: VLT = 80%
A Daylight Autonomy (DA) simulation was run on the 12 cases shown in table 1 where (F) refers to the different variations of the fundamental unit, (T) refers to the thickness; T1 = 2.5 cm, and T2 = 5.0 cm, and (D) to the Depth; D1 = 2.5 cm, and D2 = 5.0 cm.

The windows consist of a single layer of blue glass 6mm thickness with total solar transmission (SHGC) 0.62 and U-value 5.778 W/m2.K. The opaque wall consists from 0.02 m plaster, 0.25 m & 0.02 m plaster with U-value is 1.826 W/m2.K and all Ceiling, flooring & internal walls are set adiabatic. Natural ventilation & Lighting template are set off. Air condition default setting software were used where set point 23 °C m The occupancy is (3.40 m2/person), 12 cases were tested for an energy consumption kWh on an annual basis.

TABLE 1. The 12 cases tested

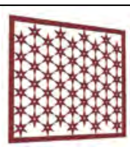
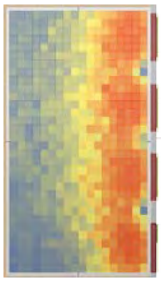
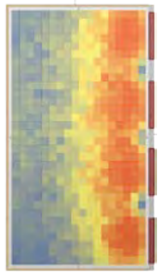
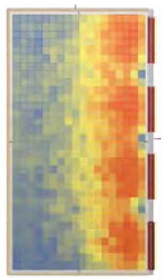
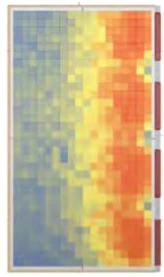
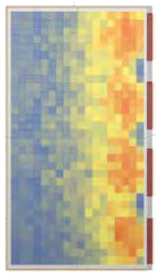
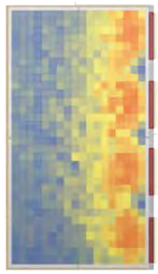
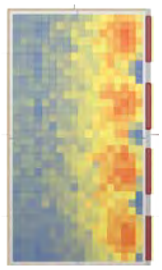
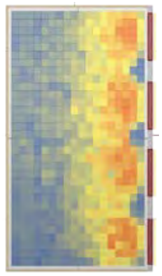
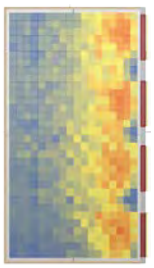
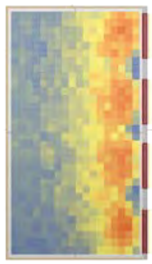
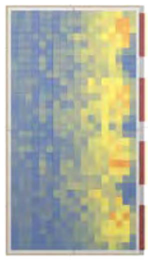
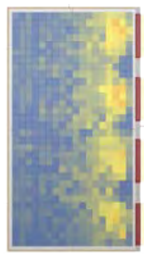
					
Case1 F1 - T1 - D1	Case2 F2 - T1 - D1	Case3 F3 - T1- D1	Case4 F4 - T1 - D1	Case5 F1 - T2 - D1	Case6 F2 - T2 - D1
					
Case7 F1 - T1 - D2	Case8 F2 - T1 - D2	Case9 F3 - T1 - D2	Case10 F4 - T1 - D2	Case11 F1 - T2 - D2	Case12 F2 - T2 - D2

TABLE 2. Daylight Autonomy (DA) & Annual Cooling Load simulation results

			
Case 1 Daylit Area :42% DA: 45%,DF: 1.3% cDA:73%, UDI:100% Cooling load:5533kWh	**Case 2** Daylit Area :41% DA: 44%,DF: 1.3% cDA: 73%,UDI:100% Cooling load:5326kWh	**Case 3** Daylit Area :40% DA:42%, DF: 1.2% cDA: 71%,UDI: 99% Cooling load:5389kWh	**Case 4** Daylit Area :41% DA: 45%,DF: 1.3% cDA: 73%,UDI:100% Cooling load:5392kWh
			
Case 5 Daylit Area : 26% DA: 31%,DF: 0.9% cDA: 62%, UDI: 95% Cooling load:5177kWh	**Case 6** Daylit Area :26% DA: 31%, DF: 0.9% cDA: 62%, UDI: 95% Cooling load:5201kWh	**Case 7** Daylit Area : 28% DA: 34%, DF: 1 cDA: 66%, UDI: 99% Cooling load:4959kWh	**Case 8** Daylit Area :24% DA: 32%, DF: 0.9% cDA: 65% ,UDI: 99% Cooling load:5443kWh
			
Case 9 Daylit Area : 24% DA: 32%, DF: 0.9% cDA: 64%,UDI: 98% Cooling load:5301kWh	**Case 10** Daylit Area :28% DA: 34%,DF: 1% cDA: 66%,UDI: 99% Cooling load:5332kWh	**Case 11** Daylit Area : 7% DA: 20%, DF: 0.6% cDA: 52%,UDI: 88% Cooling load:4750kWh	**Case 12** Daylit Area : 3% DA: 16% ,DF: 0.5% cDA: 46%,UDI: 77% Cooling load4603 kWh

5. Discussion of Results

The results showed that Case 1 provided the best daylight performance, as it includes the widest perforation ratio the pattern provides (F1) with the least depth and thickness values (D1 and T1), however, it had the highest energy consumption levels with 14% reduction than Base case. On the other hand, Case 12 had the lowest energy consumption levels 29% reduction, as the amount of shading in the space increased with the increase of the values of T and D (T2 and D2), and with using the lowest perforation ratio the pattern provides (F4), but had very low daylight levels. The case that provided a sufficient daylight level of DA 45% of occupied time, with 41% daylit area, and at the same time achieved a notable reduction in energy consumption levels of 17% less than the base case was Case 4. Though this case includes the lowest value of F for the star pattern (F4), meaning having the narrowest perforation inside the star geometry, it appears that it widens the perforation outside the star geometry to an extent that balances the whole perforation ratio of the pattern, providing sufficient daylight and at the same time significant reduction in energy consumption. This is also shown in Case 10, where using F4 provided the best daylighting values among the four cases that used the variables T1 and D2 (Cases 7, 8, 9 &10).

The study also showed that the slightest change in pattern geometry affects the daylighting and energy consumption levels. The differences between the four pattern variations is a few centimetres, however, each F value corresponded to a slight change in the daylighting and energy consumption results. On the other hand, the change in thickness and depth had a major effect on the results. As shown in Table (2), switching from D1 and T1 to D2 and T2 took the results to another level of both daylighting and energy performance.

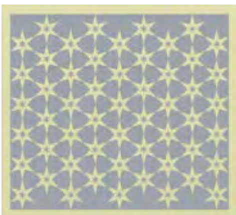


Figure 7. Case 4, IGP pattern the best case for retrofit

Figure 8. 3D model of the retrofitted façade

6. Conclusion

This study presented a retrofitting method to achieve sufficient daylighting levels and increase energy efficiency in an educational space. It showed the significance of using IGP shading screens for better daylighting and energy performances. Through a parametric setup for modelling and simulation, the study revealed the affordance of the geometry variations of the islamic geometric 6-point star pattern to affect daylighting and energy performances. It also showed the effect of the thickness and depth parameters over daylight and energy consumption values and the significance of balancing between those variables and the geometry itself. This has opened the way for further exploration of more complex IGPs with more geometry variations. We suggest that by the analysis of more complex geometries and consequently generating new ones, along with balancing the dimensional variables of the material used as thickness and depth, we can generate effective IGP formulas for facade retrofitting meant to enhance daylighting and energy performances of the space.

Acknowledgements

We thank everyone who contributed to this research with advice or help, and we thank our professors and colleagues who provided scientific guidance that gave great support to the research. We appreciate their help without which this research couldn’t be completed in a satisfactory way.

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IMPLICATIONS OF INCLUDING FULLY PARTICIPATING FURNITURE AND FITTINGS IN NUMERICAL SIMULATION MODELS

JON HAND
University of Strathclyde, Glasgow, Scotland, UK
jon@esru.strath.ac.uk

Abstract. Many simulation teams create models of empty buildings, e.g. without furnishings and fittings. Such virtual worlds lack many of the thermal and visual artefacts by which we make thermal and visual judgements and some numerical tools only abstractly treat the physics of furnishing and fittings. This paper explores what happens if sunlight actually falls on desks and chairs and filing cabinets rather than the floor as well as what happens if interior artefacts were treated with the same rigour as facades by the simulation engine and are available for use in visual assessments. Typically increasing model resolution is a tedious process and added detail if included, may not be fully utilised. To explore removing such barriers, a data store of pre-defined entities, which include provenance, visual form, explicit thermophysical composition, light distributions and mass flow attributes has been introduced in ESP-r. ESP-r facilities for calculating view-factors and insolation distributions have been updated to include this extended data model. Issues related to creating and managing such entities is discussed and the impacts of their use is quantified.

1. Introduction

The form and composition of buildings we use in numerical representations of buildings are abstractions of what we observe in real spaces. There are many valid reasons to limit what we include in our models. And our choices are also influenced by the beliefs and conventions of the architectural and engineering professions as well as the tool facilities on offer. For whole building simulation the general pattern has been to largely ignore or highly abstract the interiors of buildings. In decades of simulation conferences, the author has observed a majority of practitioners who believe that thermophysical clutter has a minimal impact on the assessments they undertake and certainly not worth being literal about.

Numerical engines that solve the virtual physics of light, heat, moisture, power and mass flows within such virtual worlds also employ abstractions of the physics. Surveys (Crawley & Hand, 2008) indicate numerical tools provide a range of abstract and explicit representations of building entities as well as a range of solution techniques. Abstract representations of internal thermal mass are widely available (Waddell & Kaserekar, 2010). The EnergyPlus Engineering Reference DoE (2016) reflects a common consensus: "Furniture in a zone has the effect of increasing the amount of surface area that can participate in the radiation and convection heat exchanges. It also adds participating thermal mass to the zone. These two changes both affect the response to temperature changes in the zone and also affect the heat extraction characteristics. The proper modeling of furniture is an area that **needs further research**".

Longwave radiation transfer between surfaces in rooms in many simulation tools is also problematic. The EnergyPlus DoE (2016) approach is, again, typical: "In the case of building rooms and zones, there are several complicating factors…—the main one being that the location of surfaces representing furniture and partitions are not known. The other limitation is that the exact calculation of direct view factors is computationally very intensive even if the positions of all surfaces are known. Accordingly, EnergyPlus uses a procedure to approximate the direct view factors."

Despite such simplifications, the physics that apply to building facades and within rooms also apply at the scale of the thermophysical clutter that surrounds us and which we directly interact with. All have measurable form and composition and interact with their surroundings in ways that could be included in the visual and thermophysical assessments. For example, our models routinely track the influence of facades on heat transfer but ignore hot desk surfaces near facades. Being close to warm or cold surfaces is a classic source of discomfort and detailed metrics are needed to track local discomfort. Tools sometimes offer more robust treatments of the underlying physics, but only if the user requests this or is willing to import information from third-party software Bigladder (2016). A recent ASHRAE project RP 1383 ASHRAE (2015) resulted in a comfort toolkit but detailed metrics tend not to be available in whole-building simulation tools.

2. The Study

The core question for this paper is: What is the difference in the thermal and visual performance of an empty building (Figure 1) and one which is populated with furniture and fittings and where these are treated at the same level of thermophysical resolution as the facade? The impact of different levels of abstraction is worthy of testing and this paper explores whether excluding or including what might be termed *thermophysical clutter* either abstractly or explicitly matters. It asks whether there is new information to be gained from more comprehensive virtual worlds? In earlier studies, Hand (2015 and 2016) provides additional background as well as reporting on the implications in residential buildings.

Figure 1. Empty buildings as commonly modelled.

The ESP-r simulation tool Hand (2015) has been used as a test bed:

- It is open source and can be adapted to support this study
- It already includes entities for explicit thermal mass and visual entities.
- It calculates surface view-factors in rooms of arbitrary complexity.
- It supports local comfort assessments with radiant sensor bodies.
- It supports insolation calculations in rooms of arbitrary complexity.
- It supports exports to Radiance (incremental changes only).

Indeed, researchers and practitioners using ESP-r have been inserting mass surface pairs within zones for more than a decade. The drawback – ad-hoc creations are tedious, error-prone and far from ubiquitous.

The goal of pre-defined entities is to provide access to a diverse collection of objects that commonly populate buildings and support their insertion into the simulation model without specialist skills or the need for pedantic working practices. They should be visible within the model and included in the model contents reports to ensure clarity and reduce errors.

Each entity would include sufficient attribution to support multi-domain assessments with little or no additional interaction from the user (beyond selection and placement directives). They should have a clear provenance, documentation as to their intended use as well as subsequent actions required by the user. Each would include directives to be interpreted by the simulation tool to ensure dependencies are resolved.

3. Implementation

Pre-defined entities have been implemented as a database within the ESP-r suite. The data structure is a subset of that used by ESP-r for thermal zones and surfaces but the work has also extended the concepts which ESP-r deals with. Each pre-defined entity includes the following:

- Header: object name, menu entry, documentation, provenance, geometric origin, bounding box and merge-into-model directives.
- List of vertices
- Mass surface pairs (name, composition, optics, usage, list of edges)
- Boundary surfaces (name, composition, optics, usage, list of edges)
- Visuals (name, composition, type, origin, rotations, list of vertices)

The author of an entity would need to ensure it is a reasonable thermal and visual abstraction using the available primitives and attributes. For example, a computer monitor is a mix of visual shapes and thermal entities representing the case of the monitor as well as the electronics it contains. Its documentation provides the provenance as well as its electrical characteristics.

Populating the database requires gathering dimensional and composition attributes via tape measure, callipers and digital scales. Establishing typical weights of a bookcase or filing cabinet is straightforward if somewhat tedious. Sometimes disassembly is necessary. Typical objects include:

- swivel office chair, wood office desk, four drawer file cabinet, dell monitor…
- TV 53 cm wide, coffee table, Ikea book case, double bed with solid head and foot, wooden chair with arms …
- Honeywell thermostat, radiator 1.1 x 0.5 m, radiator 0.6 x 0.5 m…
- PVC framed window, five section bay window…
- suspended 1.25 x 0.15 m LED lighting fixture…

Once selected those viewing the model get visual clues as well as entity details. Figure 2 shows an office chair and a bookcase. The mass of the seat and the back are represented but the mass of the legs and the armrests have been omitted. The bookcase visual hints are low resolution but in the context of room views is recognisable. A variant could easily be created with greater visual detail.

After inclusion in the model, the thermophysical portion of a predefined object are treated no differently than any other surface in the model within the solution process. ESP-r detects the change in complexity and offers to recalculate view factors as well as update shading/insolation patterns.

Some elements of buildings such as stairs and facade assemblies are ubiquitous but geometrically complex to the point of being ignored or highly abstracted. The challenge of hosting such complex objects and allowing them to be merged into a model did much to generalise the facility.

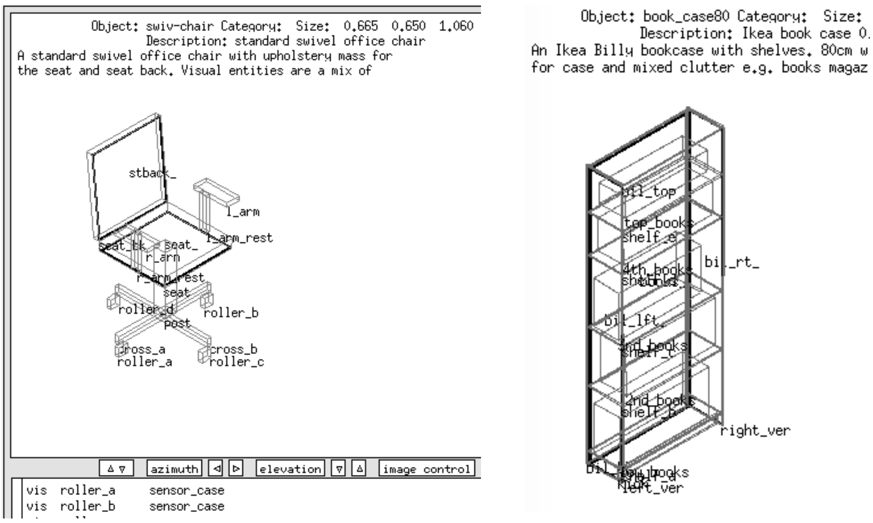

Figure 2. Office chair and bookcase visual/thermal objects.

4. Visual assessments

ESP-r has long had a Radiance export facility. One of the workflow complications of doing mixed thermal and visual assessments has been the expertise (and time) needed to edit Radiance files. Consider the empty residential model on the left Figure 3 and the populated model in the middle. With the fully populated residence model a glare assessment (lower left) is straightforward requiring only the specification of the viewing position and the specific time of the assessment.

ESP-r's insolation calculation bookkeeping has also updated to display insolation calculations as they are computed. The lower right of the figure shows grids of insolation points (blue dots) on the desk, adjacent wall and floor from a source window (red dots)) during an isolation calculation for the office discussed in the next section. This is particularly attractive if we want a quick appraisal of solar insolation over the whole year. Animating the patterns at each hour through the year or on specific days at ~2 frames per second, patterns quickly emerge.

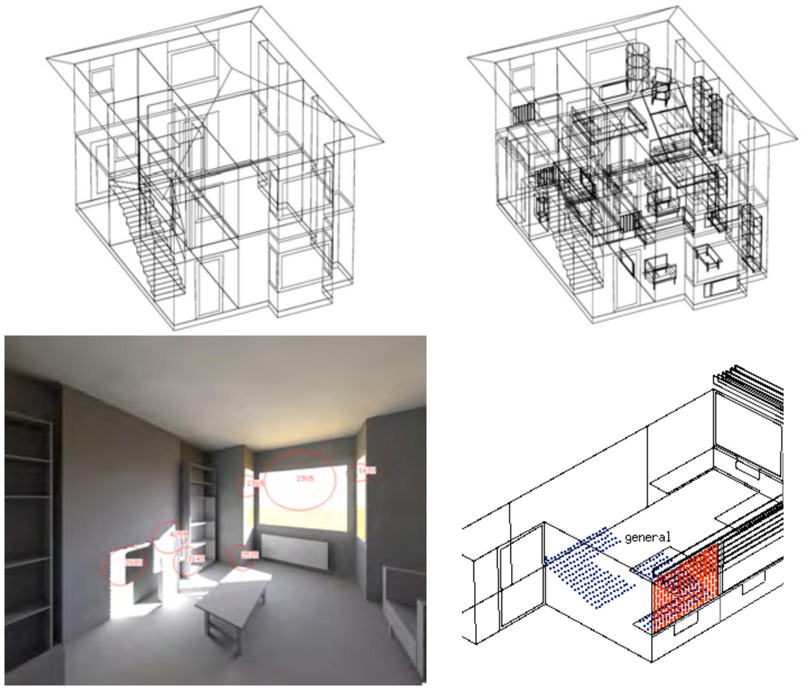

Figure 3. Empty residence, populated residence and glare study.

5. Office Example

To explore the implications an office block in Ottawa which initially included an abstract representation of furniture has been used (Figure 4 left). The intent was both to improve the clients' understanding of the model as well as account for some of the thermal impacts of internal mass. It preserves overall surface area, mass and placement of the desks, but results in a single temperature at the upper face and lower face of the desk in each room. It took roughly 15 minutes to implement this in the original model.

For this study, model variants also included an empty building and one fully populated (Figure 4 right). Radiance views are shown below the wireframes. What is interesting is that the ad-hoc representation on the left turned out to be a poor representation of furniture placement – desks were low and there was insufficient space for seating. Using objects clarified where occupants were likely to be located so that comfort sensors could be placed accordingly.

The assessment includes explicit surface-to-surface view factors, MRT sensor bodies as well as an insolation analysis. The initial model includes 125 surfaces and the model with predefined entities includes 311 surfaces and 446 visual blocks. The largest room went from 35 to 93 surfaces as a result. Although crude in the context of CAD models this level of detail pushes boundaries for zonal complexity within whole-building simulation.

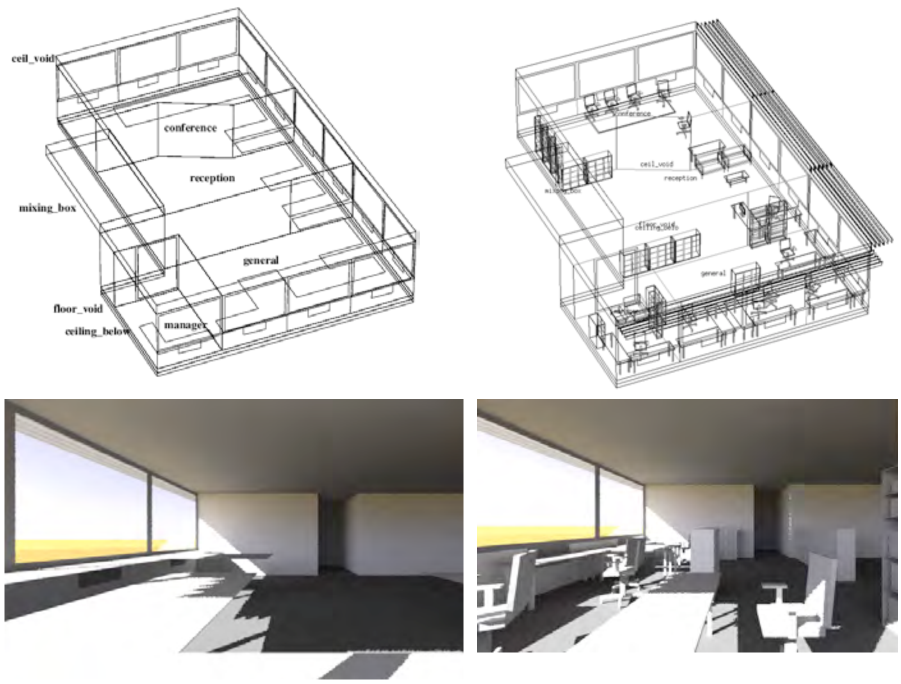

Figure 4. Abstract (left) vs fully populated (right) office model, thermally active surfaces in an office (lower left) and a Radiance view (lower right).

In Figure 5 shows the cellular office in the lower left of the office model. The active thermophysical surfaces which fully participate in the solution of the model on the left and on the right are the visuals which are passed to Radiance. We are not used to being able to track the evolving temperatures of seat-backs and desktops but we might get used to having a larger collection of virtual sensors in our design assessments.

What does this cost in terms of computing resources? An annual run at 15-minute time steps on a Lenovo X220 laptop took ~25 seconds for the abstract model and ~4 minute for the populated model. Radiance images of the abstract comprised 45 million rays took 5 minutes 1 second (Figure 4 lower left) and the view with pre-defined objects was 70 million rays and 9 minutes 1 second (Figure 4 lower right). Insolation calculations and view factors require a few additional seconds to calculate in comparison with an empty model.

Is this a sufficient computational burden to preclude the use of populated models? Certainly there are many workflow and hardware choices that would mitigate much of this overhead. Is is useful to spend an additional minute or two when creating the zone in terms of new performance information or clarity for other members of the design team?

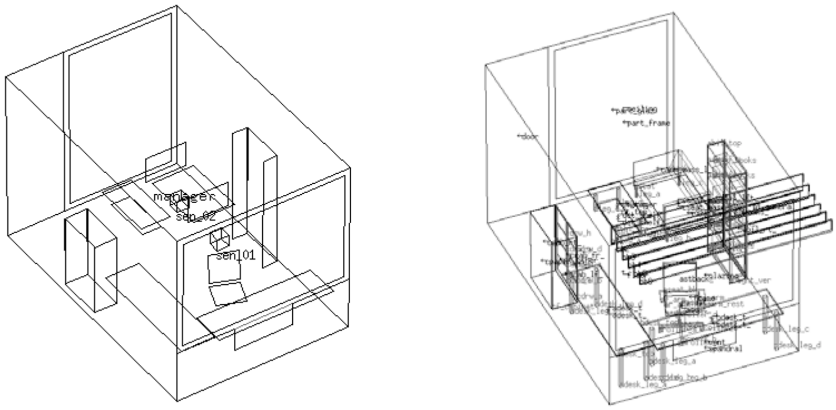

Figure 5. Active thermal surfaces (left) vs thermal + visual entities (right) office.

Focusing on this office during a spring thermal assessment we find the floor in the empty room is 1.2 °C and the abstract room floor 0.5 °C warmer than in the populated model. The abstract desk peaks at ~31 °C while the more explicit desks peaks at ~29 °C and ~33 °C. We do not know the risk of elevated desk temperatures in the empty model. While the abstract desk is energetically correct the use of objects provides additional information on the temporal characteristics and spatial risks. We also find the additional inertia alters the patterns of heating and cooling demands.

On the last day of the assessment the peak solar on the floor is 41.2 W/m^2 in the empty room, 21.4 W/m^2 in the abstract desk room and 19.8 W/m^2 in the populated room. The aggregate solar on the floor that day is 3.44 kWhrs, 1.94 kWhrs and 1.64 kWhrs respectively. In terms of heating and cooling capacity there are minimal differences between the office model variants. Annual heating and cooling demands are within a few 100 kWhrs but there are hundreds of hours where heating and cooling demands are shifted or eliminated in the fully populated model. Exploring such temporal variance is beyond the scope of this conference paper but would be of interest to control engineers.

7. Conclusion

This paper provides an overview of a facility for hosting common objects with attributions supporting multi-domain assessments and increased model resolution. An office has been presented with different levels of resolution. Observations from the use of the pre-defined object store as opposed to empty rooms and ad-hoc manual insertion of internal details indicate a savings in time, greater diversity in internal mass types and model error.

The change in simulation workflow was seen to remove barriers to the creation of higher resolution models. Especially in the case of joint thermal and lighting assessments this provides scope for enhanced modelling deliverables with lower resource requirements.

Images often are more easily interpreted than phrases in reports. The ease of populating models for clarity and animating the patterns of insolation would be, for some, a valid use of the facility.

The ability to track local discomfort is a useful option in some simulation studies. Simulation work flows and planning activities will need to change to identify the degree to which additional resolution is useful and whether relevant common entities exist for use or adaptation.

In the case of the office, there was a ~3 minute computational time penalty during an annual assessment on a five-year-old desktop. Increasing model complexity results in larger predictions files and has minor impacts on data mining tasks.

Initial indications are that the use of the facility to populate models has minor impacts on peak and overall heating and cooling demands. We observe that the distribution of heat gains within rooms changes. Lightweight components close to facades alter the response characteristics of the room just as the inertia of filing cabinets dampens changes. These temporal patterns of environmental control actions may be of interest to control engineers and for assessments where local comfort is an issue.

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Section IV

DESIGN INTELLIGENCE, COGNITION & COLLABORATION

“TIME” IN ADAPTABLE ARCHITECTURE

Deployable emergency intelligent membrane

ANA COCHO-BERMEJO
Genetic Architectures Research Cluster. School of Architecture, UIC. Barcelona. Spain
acocho@uic.es

Abstract. The term "Parametricism" widespread mainly by Patrick Schumacher (SCHUMACHER, 2008)is worthy of study. Developing the concept of Human Oriented Parametric Architecture, the need of implementing time as the lost parameter in current adaptive design techniques will be discussed. Morphogenetic processes ideas will be discussed through the principle of an adaptable membrane as a case study. A model implementing a unique Arduino[i] on the façade will control its patterns performance through an Artificial Neural Network that will understand the kind of scenario the building is in, activating a Genetic Algorithm that will optimize the insulation performance of the ETFE pillows. The system will work with a global behavior for façade pattern performance and with a local one for each pillow, giving the option of individual sun-shading control. Machine learning implementation will give the façade the possibility to learn from the efficacy of its decisions through time, eliminating the need of a general on-off behavior.

1. Introduction

A new global movement discussing the new definitions of matter, materiality and material within Architecture has arisen due to the importance Digital has acquired in those field discourses definition.

Meanwhile is worthy of study the reception, critical fortune and critical acclaim of the now ubiquitous term “Parametricism”, widespread mainly by Patrik Schumacher. This term was already immediately contested when Bernard Cache was invited to publish about the obsolescence of the parametric reflected in “After Parametrics” (CACHE, 2009).

But, approaches have demonstrated to be as many as experts. It is within the architectural disciplinary debate where non-conclusive and non-allied ideas on post-humanism, matter, materiality and material are occurring, knowing that new materialism and post-humanism has demonstrated to be trans-disciplinary fields.

"Digital technologies have changed architecture—the way it is taught, practiced, managed, and regulated. But if the digital has created a "paradigm shift" for architecture, which paradigm is shifting?" (CARPO, 2011)

In that sense the idea of complex systems with intelligent components with emergent behaviours was proposed then as the base for form studies. It appears then to be a consensus about the requirements in design: continuous variation and intelligent emergence.

Post-human minds: The aesthetics of hybridization.

Being all digitally fabricated variable; this variability can be studied trough computation. This variability produced with emergent form finding methods implies new formal languages. At this point it enters the debate the idea of a natural adaptive "intelligence" with no consciousness awareness: But, should we study the nature adaptive "intelligence" processes instead of simulating artificially human mind processes? process that are the ones non related to human cells.

Human Oriented Parametricism (HOP)

Based on the study of the current implications of the Parametricism term, the current study considers *Dynamic Parametric Architecture* as an architecture which basic design inputs might vary during the building lifetime. It is defended the concept of Human Oriented Parametricism, HOP, which considers the idea of "Time" as the lost parameter in Adaptive Complex Architecture as the obvious evolution of the Parametricism idea. The current study will develop an example for this kind of design process implementation introducing the idea of buildings with morphogenetic behaviors.

2. The Emergency Health Deployable System, EmDeplo. Complex Systems. Morphogenetic Processes.

EmDeplo is a parametrically designed health system composed of an Intelligent Deployable Membrane. Morphogenesis (from the Greek *morphê* meaning "shape" and *genesis* meaning "creation") is the biological process that causes an organism to develop its shape. Artificial Intelligence is currently proposing processes based on biology as a solution for intelligent performance even in Architecture.

2.1. EMDEPLO SYSTEM DESIGN

The "body" of the system will be a multilayer deployable membrane with a factory interface customized fabrication. Its "brain" will be developed with an Arduino and its "mind" through an AI Algorithm.

Bottom-up robotics and evolutionary processes allow the existence of Artificial Intelligent Systems with quasi-intelligent behavior. That is, systems that simulate emergent and generative properties of natural processes, obtaining well-adapted and efficient forms.

Through an abstract model for the system and the presence/absence of behaviors the complex system that will configured.

3.3.1 The Emergency Customized Deployable Intelligent System.

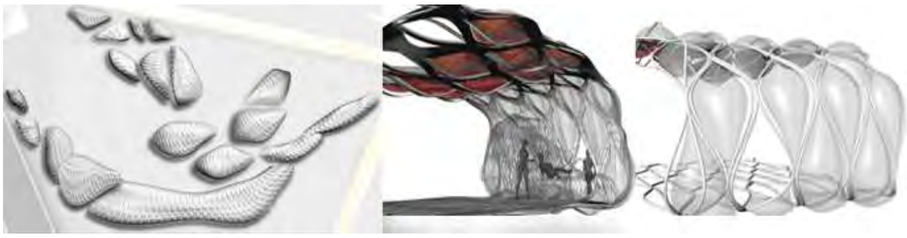

Figure 1. System deployability sample and triage sections.

WHO[ii] states that natural disaster and other unpredictable events are so common that it urges that architects to develop new kinds of high adaptable and rapidly deployable spaces for different emergency scenarios. The system proposed will be able to satisfy most medical needs in the shortest time in any scenario. (Figure 1) Deployable 3D structure from a flat surface, able to arrive directly from the factory to site, it is perfectly packed and ready for easy and quick employment. A multi-layered membrane will be designed so a 2D patterned deployable surface expands into a complete 3D space.

The factory interface[iii]

In recent decades the notion of time-based design has increased the architectural practice's interest to explore new kinds of design processes more linked to biology, philosophy and other disciplines.

When an emergency occurs, WHO will work through the interface at the factory that will fabricate the membrane system perfectly customized for the emergency scenario ready for deployment. The interface will design some compulsory parts for every particular scenario but also will offer to the client the option of some non-compulsory parts and units. This membrane customization through the interface will be the main strength of the efficiency of the Emergency Units. The clear properties of the material and some basic real controlled parameters will perform the unit, helping us to create a real transformable, transportable and customizable space.

Membrane Material System

The patterns of the different layers, controlled in four different scales, will hold all the design's weight (Figure 3|4).

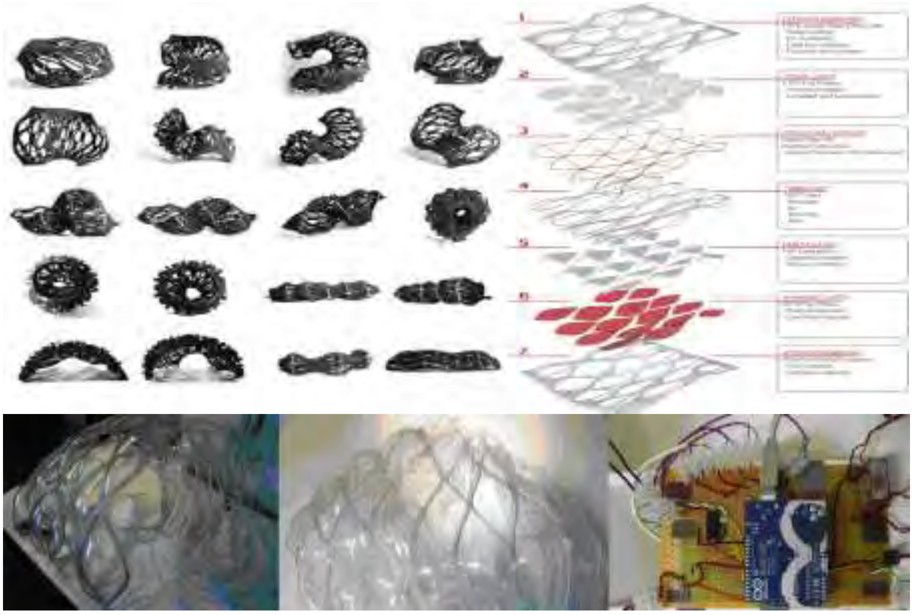

Figure 4. (a) Static models scale 1/20. (b) Circuit used for dynamic models 1/5
Figure 3. System layers and samples of performance.

3.3.2. System's mind algorithm: AI & ML Algorithms search

The Artificial Intelligence approach that will be used in the current study will be the one in which, in a continuous loop, an intelligent agent will receive data from the environment through some sensors, and will change or not its state, interacting with the environment through some actuators. It will be a perception-action circle benefiting the adaptability property of the system. AI will be studied as a method for uncertainty management and the aim will be finding actions for an agent (1).

$$\text{act} = \text{AgentFn}(\text{percept}) \tag{1}$$

Problem Solving vs. Planning

It was not considered as a valid method for developing the understanding and decisions related to the learning of the climate in which the system was in as the intention of the current study was to develop the system in a partially observable environment.

Markov Models
A Markov model will be still memory less but will provide more options in the next state to the goal calculation. In the case, Markov models were discarded, as they are not good algorithms for training memory.

Machine Learning Algorithms
Making the system learn from existing, artificial or new environmental data models will be the main goal of the system's mind.

Reinforced Learning.
Even though agent analysis has been a very effective learning technique, the idea of using EmDeplo as an agent, inside an unknown environment that has to take decisions for a goal and a reward, is clearly different to the learning process that our system must have, as the concept of reward function and goal might vary trough time during the existence of the building.

Unsupervised Learning algorithms: - Network; -k-means; - Spectral cluster.
After a study of the most common Clustering Algorithms unsupervised learning algorithms, it was concluded that unsupervised learning might not be the appropriate learning behavior for system's initial mind.

Supervised Learning algorithms: Linear Regression, Logistic Regression
Both models use Gradient Descent algorithm to find local optima. The problem with these algorithms appears when the size of the features array gets really big. The probability of over fitting increases and we will be dealing with an extraordinary number of parameters that makes this process clearly unreachable even if we are using only subsets of the training set.

Support Vector Machines (SVMs)
As non-probabilistic linear classifiers, they are a kind of algorithm that can be taken into account for the decision of EmDeplo's mind configurations. SVMs propose a much better error minimization as they are trained on the worst classified examples.

A Neural Network, on the other hand, will be likely to work well for most of these settings, but may be slower to train. Considering that real building implementation will be not developed at this stage, slow training speed was not considered a basic disadvantage. In this way an Artificial Neural Network seemed appropriate to start making the system work, not having to worry about the number of features and training set sizes.

Artificial Neural Networks (ANNs)

A Multilayer Perceptron will be able to deal with initially non-linear separable operations. In this way, inputs that were not linearly separable in the beginning became able to be mapped and classified. Therefore, loop networks with feedback and the idea of back propagation are the definitive alternative for adaptability. This kind of Machine Learning algorithm gives EmDeplo's mind the ability to distinguish between different kinds of environments and situations.

3.3.3. System's algorithm: Definition of the ANN & GA.

The process desired for the deployable system learning has to be a mixed one. It will need the power of neural processes for choosing and decision situations, and the performance of a genetic algorithm for optimizing the pillows pattern and adaptability. The combination of both sub-processes will generate a global behavior, where, since the very first day after deployment, the system will perform properly.

The system will be composed of: (a) An ANN for classifying and deciding the kind of situation we are in, which will learn through a series of labeled sets of situations for training. (Global Behavior) (b). A Genetic Algorithm optimizing the performance of the whole set of pillows creating a pattern for adaptability and improvement. Phenotype, genotype, fitness and mutation will decide and teach EmDeplo how to act in each situation. (Global Behavior) (c). An off/on behavior, for sunshade control, through the intermediate layer of a patterned ETFE Membrane not allowing the solar factor to be higher than FS 10. (Local Behavior)

Scenarios approach. Labeling Situations.

An analysis was therefore done of all the earth's climates and possible scenarios based on the three parameters that were able to be evaluated by the membrane: temperature, humidity and sunlight.

The Artificial Neural Network.

A supervised learning process will be developed consisting of learning training data based, data classified appropriately with known classifying patterns. We will consider ten different possible scenario situations for the system during its lifetime in a particular climate. These situations will be the outputs to decide and to choose by classification.

The proposed ANN, will have 100 neurons, (100 pillows), in the input layer, 150 neurons in the hidden layer, each one of these 100 neurons corresponding to the behavior and temperature of one pillow of the façade. The proposed outputs will be 10 different performances of the façade. So, depending on the output, one GA's behavior or another will start. Testing the system with less than one hundred trainings was demonstrated unsuccessful.

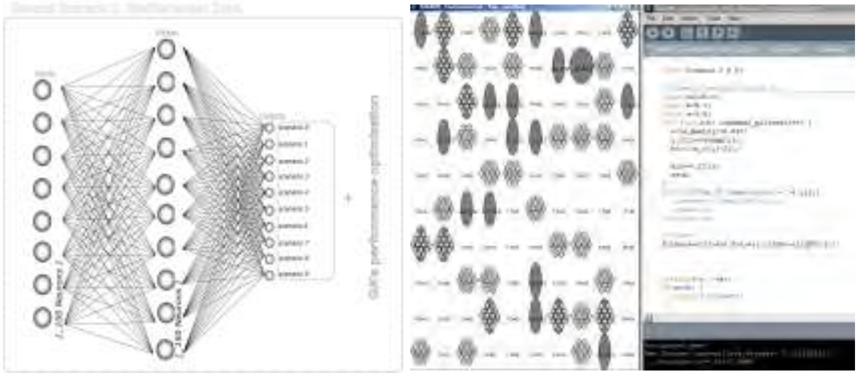

Figure 5. (a) Proposed ANN. (b) Digital model sample

The Genetic Algorithm.
Once EmDeplo has decided trough the ANN in which scenario it is located, it will generate the chromosome of the façade through an array that will be a sequence of all opening and closing possibilities for the 100 ETFE pillows. In that way, the genotype, will be an array of 100 elements that indicates the initial position of the pillows the system is starting with. The positions considered will be: closed, open or half-open.

Genes = new [100]; Genes [i]= [open/ close status] (2) (3)

Façade genotype = [c, o, c, h, c, c, h, o, c...] (4)

The general idea was to optimize the genes array of the façade for obtaining a desired temperature of 22º. Several simple fitness functions were implemented with a percentage of mutations between 0.01-0.05%.

Phenotype Definition
The thermal relationship between the pillows' degree of openness and temperature variability was implemented as the fitness function. For the system, this environment in which our phenotype exists is the thermal relationship environment-material. After implementing the new relation genotype-phenotype, a new fitness function was included to avoid premature convergence and stagnation. This function will also be related to thermal behavior and it will be implemented in the phenotype for the pillows:

Δ Temp = (Q * thickness)/λ ; t_f[i]-temps[i] = G* genes[i]/ λ (5a) (5b)

This gene array will be the data needed to implement when the optimized result is sent to the Arduino. Starting with fitness smaller than -2000, stagnation appears with a fitness of -727 around evolution number 1000.

Selection method.
The method implemented initially was the Alasdair Tuner interpretation of the Rank Selection(TURNER, 2009). Maximum fitness obtained, -727 will try to be improved with different combinations. Roulette Wheel Selection will not be implemented due to the danger of premature convergence it generates if a clearly dominant individual exists. The implementation of the Tournament selection method improves the algorithm performance but only proved to increment fitness 0,98 %. On the other hand, when Top Scaling selection implemented, fitness decreases 1%. Tournament selection will therefore be the method used.

Multi-objective optimization. Pareto frontier
Considering necessary the optimization of two values, Q, the thermal flux, and t_f, the final temperature, a multiobjective optimization will be implemented.

Obj. A: Thermal flux min Obj B: t_f = 22ºC Weights Wa =0,2 Wb =0,8

Fitness function: f(x)= 1/ (1+ Wa*A + Wb*B) (5)

The results obtained in this final experiment showed a maximum fitness of 0,016. But due to the thermal properties relationship implemented,

t_f [i]= Q* genes[i]/0.017 + Temp [i] (6)

and to the constrains on the degree of opening of the pillows, and that is,

genes [i] = 0, genes[i] = 0.5 or genes [i] = 1 (7)

That will be the maximum fitness that can be reached. Nevertheless, if we consider a free opening degree of possibilities, from thickness 0 to thickness 1, being all floats between 0 and 1 allowed as possible degrees of opening. A different code with a non-constrained genes array of opening was run. After a certain time working, the code reached the maximum fitness, a fitness of 1.

Conclusions, discussion & further research

The different façade patterns created by the learning of the system through the different scenarios and experiences, plus the local behavior for shading, optimizes the material insulation performance of the façade, maximizing material insulation properties. Even when a non-constrained opening of the pillows is allowed a maximum efficacy of the insulation properties of the façade is reached, the set of different layers proposed for the membrane configuration demonstrated not to be enough for a proper insulation and climate regulation.

A point that must be taken into account for further research must be a strict thermal calculus by proper environmental software taking into account the different curvature degrees of the pillows in each phase of the opening-closing procedures.

Considering the performance of the façade or the membrane as the performance of a set of autonomous agents improving its behaviour and adaptability in reaching their goal by practise and experience. Interpreting the possible behaviour of the system with a Q- Learning algorithm, look really a good approach for future developments. These agents, each of which, can be considered to be a pillow of the façade, can shape their behaviour according to the environmental context through the learning including a reward function. The proposed method will work in a diagram like the one proposed by Calderoni and Mancenac at the 12th Artificial Intelligent Conference in their paper *"MUTANT: A genetic learning system"*. The paper presented and demonstrated, in 1999, the efficacy of the application of Q- Learning to a similar situation that the one this thesis presented.

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[i] Arduino is an open-source electronics prototyping platform easy-to-use microcontroller.

[ii] The World Health Organization, WHO.

[iii] *Factory's Interface* is understood in this paper as the contact mechanism between the final customized physical system and the required needs for a particular emergency scenario. A factory integrated software that according to the different emergency scenarios, number of people involved or injured, will fabricate one physical system or another depending on the adequacy it considers for that particular emergency. Samples of that can be an extra foundation for strong winds, special designs for earthquake scenarios, desert special insulation layers, number of triage units or operating theatres, etc.

ADAPTIVE COLLABORATION IN PROJECT DELIVERY

ADAM MODESITT
New Jersey Institute of Technology, Newark, NJ, USA
modesitt@NJIT.edu

Abstract. Digital workflows in architectural design have upended traditional models of collaboration. As digitally networked tools further permeate the project delivery process, information and knowledge are increasingly distributed seamlessly across decentralized networks. While the seamless flow of information across digital networks can serve to augment traditional hierarchies of production, it can also change fundamentally the process by which architecture is produced, enabling modes of collaboration in which creation and production occur as decentralizing acts. This paper examines current models, methods and theories of decentralized collaboration in digitally networked architectural production, towards the goal of establishing a framework for understanding the meta-controls and standards that structure it. Particular emphasis is given to the emerging process of crowdsourcing, in which design intelligence emerges collectively from a decentralized network of actors and agents. This study serves as the foundation for a proposed model of 'adaptive collaboration,' in which an adaptive set of meta-controls and standards change in response to the evolving roles and scopes among individual actors and agents. An experiment in Adaptive Collaboration is described, taking place in a Solar Decathlon project at the New Jersey Institute of Technology.

1. Introduction

As digitally networked tools further permeate the project delivery process, information and knowledge are increasingly distributed seamlessly across digital networks. Diverse forms of information flow with little resistance through digital networks, blurring boundaries between disciplines and levelling out once pronounced distinctions between design and production (Garber, 2014). Design knowledge can be embedded, encapsulated and modularized. Digital networks absorb design information pliantly and adaptively, forgoing traditional cycles of redevelopment and redesign as new information is introduced to a process (Woodbury, 2010).

The seamlessness of digital networks has transformed how of design intelligence emerges among disciplines and actors (Kocatürk & Codinhoto, 2009). In traditional, top-down, hierarchical approaches, different types of design intelligence are bracketed by disciplines and scopes. As digital networks render traditional boundaries frictionless, digital workflows in architecture redistribute design intelligence, reconfiguring where it resides and how it is generated. No longer associated with individual actors, design intelligence can emerge as an outcome of a dynamic process among multiple actors, models, tools, representations and systems, linked by digital networks that seamlessly distribute project information (Kocatürk, 2013). This paper proposes the model of "adaptive collaboration" for generating design intelligence across a distributed digital network, in which an adaptive set of meta-controls and standards change in response to the evolving roles and scopes among individual actors and agents.

2. Established Models of Decentralized Collaboration

The forms of collaboration in architectural design and production are closely correlated with the medium through which information is exchanged. Digital workflows allow for systems of collaboration that retain design intelligence, through the creation of interconnected, networked modules of multi-disciplinary design information (Woodbury, 2010). This process is well-established in other industries, such as automotive and aerospace, famously characterized by Kieran and Timberlake (2004) as "framing" versus "quilting," distinguishing between a traditional, hierarchical, sequential approach, and a modular, networked approach. The types of information exchanged in both framing and quilting are substantially similar, but are distributed and redistributed through fundamentally different systems of collaboration. The information can be divided into three categories: social, model and logic-based. The structure of the medium of exchange among these sets of information can determine how collaboration occurs in a project, and how design intelligence emerges (Kocatürk, 2013).

Understanding how digital workflows are structured has increasingly become a subject of study for architects (Marble, 2012). As digital networks permeate the production process, they increasingly inform the emergence of design intelligence and digital workflows become design problems in and of themselves. Digital workflows structure the medium of exchange in digital networks and formulate how architecture is both conceptualized and produced. They increase the territory in which designers can operate, allowing diverse actors and agents to function seamlessly in a decentralized medium, fusing machine intelligence with human decision-making (Keough & Benjamin, 2010). Historically, drawing was the primary means of communication among the disciplines involved in the production of architecture, which simultaneously and correspondingly developed as the primary tool for conceptualizing design, drawings developed to both contain and generate design intelligence (Evans, 1986). As digitally networked tools permeate the production of architecture, digital workflows likewise increasingly become both a medium of communication and a means for generating design intelligence.

One well-established approach to cultivating design intelligence in digital networks is crowdsourcing. As demonstrated in both theory and in practice, crowdsourcing is a method for generating design intelligence across decentralized networks of actors and agents (Oxman & Gu, 2012; Nolte & Witt, 2014). In crowdsourcing, design intelligence and solutions emerge from the medium of the digital production environment. Crowdsourcing utilizes social digital networks, the primary medium for generating collective design intelligence. Decentralized collaboration across the network disseminates social, geometric and logical information. Collective intelligence emerges from distributed contributions, generating design knowledge across the digital network that would not otherwise be possible in a traditional, top down, hierarchical approach. Collaboration is structured by "command and control structures," through "standards, norms and shared language to support the 'interoperability' of collective knowledge" (Oxman & Gu, 2012). These meta-controls and standards mediate the exchange of social information, digital design models and parametric logic (Oxman, 2015).

Crowdsourcing has been proven to scale well in practice on large and complex projects. In one high-profile example, the implementation of Gehry Partners' the Fondation Louis Vuitton was enabled through crowdsourcing. To produce the elaborate, nonstandard architectural form of the building, geometrical complexity, organizational complexity, diversity of multidisciplinary scopes and hundreds of collaborators were integrated through a custom-made, web-based, building information model tool (Nolte & Witt, 2014). The platform incorporated social computing, data visualization, data mining and approval processes, as well as building simulation and near real-time optimization feedback loops. The result is a collapse of geometric, social and logical information into a single, distributed, digitally networked space (Shelden, 2013).

3. A Framework for Adaptive Collaboration

In the case of the Fondation Louis Vuitton, overall design intent was established at the onset of production, and experts from a full range of disciplines contributed to implementation, integrated through a web-based platform. The model of production however, relied on experts and disciplines that, while overlapping, were grounded within well-established and well-defined roles (Nolte & Witt, 2014).

In scenarios where roles and scopes are not well-resolved or still evolving, an alternative approach to crowdsourcing is required. These scenarios include situations in which the roles of collaborating actors and agents are subject to change, scheduling and staffing is variable, concept and fabrication processes must be developed as concurrent processes, or other conditions without well-established initial conditions. These scenarios require new command and control structures to generate distributed and collective intelligence and operate dynamically. To what extent can crowdsourcing be applied to networks in which the roles of actors and agents are dynamic and changing? In projects where the scopes of actors and agents are initially ill-defined, can an adaptive platform help resolve roles?

One approach to addressing these questions can be drawn from the disciplines of electrical and computer engineering, in which the concept of "adaptive control" is established to describe nonlinear operations that adapt to a dynamic set of circumstances (Krstic *et al*., 1995; Åström & Wittenmark, 1989). A classic example is flight control systems in airplanes, which can procedurally operate complex flight patterns for a single condition, but in unpredictable, unanticipated overlapping conditions, such as turbulence, change of weather or redistribution of airplane mass, a meta-controller must empirically evaluate outcomes, and reconfigure the operating parameters of the controller to adapt to new conditions. While adaptive control is generally applied to automated systems, the logic of adaptive control can be applied to the design and production of architecture by adapting meta-controls and standards, dynamically responding to unanticipated changes to the structure of collaboration among project actors and agents. Applying the logic of adaptive control to collaboration in architectural workflows, this paper proposes the process of "adaptive collaboration." Adaptive collaboration builds on the concept of crowdsourcing, and is defined as a system for incorporating adaptive meta-controls and standards to accommodate networks of actors and agents with dynamically evolving roles and scopes.

Like crowdsourcing, which requires a robust social network, adaptive collaboration requires a network that synthesizes social, model, and logic-based information into a single platform. A platform for adaptive collaboration must be able to engage in all modes of production, from conceptualization and design to fabrication and logistics. For these requirements, Cloud-Based Design and Manufacturing (CBDM) systems provide an ideal platform. CBDM systems are an emerging technology and represent a new paradigm for digital design and production (Wu *et al*, 2015). CBDM systems are software platforms that enable distributed collaboration across cloud-based digital networks, "an information communication technology system that facilitates design and manufacturing knowledge sharing between actors in the distributed and collaborative socio-technical network" (Wu *et al*., 2013). CBDM systems are typically distributed as a service, and are comprised of modular sets of applications designed for scalability, flexibility and re-configurability. And, because CBDM systems are an environment for facilitating manufacturing, digital mockups can be simulated for deferred production and feedback from the digital mockup can be incorporated into the design process.

4. Implementing Adaptive Collaboration

A Solar Decathlon studio at the New Jersey Institute of Technology (NJIT) has been deployed as a test case for an experiment in adaptive collaboration. Academic, virtual design studios have long played a role as incubators, testing grounds for experimental digital workflows, and are often case studies for exploring questions of how digital workflows change the nature of collaboration (Deamer, 2011; Shelden *et al*., 1995; Yee *et al*., 1998). Design studios offer a flexible, relatively risk-free environment in which to stage experiments. A Solar Decathlon studio also offers a test of multidisciplinary integration and a full-scale project delivery process, in which a series of studios conclude with the implementation of a built, zero-energy house. The Solar Decathlon studio at NJIT began with a group of 20 third-year professional degree undergraduate students, all in the formative stages of their education. The initial group of students had minimal prior experience in digital modeling, parametric design, architectural detailing or construction. The Solar Decathlon requires a wide range of specializations, from communications, to project management, to fabrication. In the earliest phases, these roles were undefined, but specializations emerged as the project evolved. For a CBDM system, the studio adopted Dassault Systèmes' 3DExperience platform, a successor to the CATIA platform. The 3DExperience platform integrates applications for social networking, blogs postings, wikis, instant messaging, tools for digital simulation, parametric modeling, direct-to-fabrication, logical-scripting, knowledge capture and visualization tools, including virtual reality. The platform operates entirely within a cloud-hosted database. All information is seamlessly integrated into the database, with multiple access points for viewing, editing, and generating content, including web and mobile applications. The design of the Solar Decathlon was informed by research, design discussions and other conventional approaches, but was from the onset developed through the 3DExperience platform.

The custom workflow developed for the studio centred around the concept of "components," which were defined for the studio as parametric modelling elements integrated with other information, such as documentation or associative fabrication drawings. Components were developed in a graphical user interface through constraint-based modelling. They sometimes included integrated scripting and procedural logic, but were intended to be primarily parametrically modelled encapsulations of design knowledge. Components were comprised of individual parts, assemblies of parts, or operations to be performed on other components. For example, a component may consist of framing connection details, a structural wireframe, a panelization system, massing geometry, set of operations for extracting quantity take-offs or fabrication simulations. Components were developed for modularity and interoperability with other components. Students were assigned to initial, seed components such as massing, structure, facade or roofing. The setup was designed to allow components to evolve in tandem with student roles. As components took shape and developed increased levels of resolution, information shifted in and out of different components. A close correlation exists between component development and student development, such that while components exist primarily as parametric geometry, they also serve to integrate various social, modelling and logical information.

For example, two prototypical components involve a facade panel parametric model and a wireframe parametric of overall facade form. Initially, both the panel model and the wireframe model develop independently and with minimal complexity. As the project developed and student skills and knowledge advanced, the components grew in complexity. Ultimately, the final facade form is driven by the relationship between the wireframe and the panel, but with multiple possible outcomes. In one possible scenario, the panel drives facade form by incorporating the logic of the relationships among panels, which aggregate to shape the facade form, in turn parametrically driving the facade wireframe. In an alternate scenario, the wireframe drives the form, and the panels parametrically host on the wireframe. Over time, the panel and wireframe components subdivide into sub-components, such as framing, exterior and interior panels. This subdivision process continues as the project progresses, splitting off into smaller subdivisions of components, or recombining into new hybrids.

The interoperability of parametric components was defined at the onset by sets of geometric inputs and outputs. These inputs and outputs functioned as standards for exchange. For example, the panel geometry may take as inputs four points, a plane and a depth parameter. This wireframe model will then be designed to output arrangements of grids of points, planes and parameters. The wireframe and panel components can be developed independently, without knowledge of the development of each other, with the expectation that the interoperability of the system will function so long as the inputs/output conditions are satisfied. The other form of collaboration standards involved specified input/output requirements. For example, a panel hosted on four points only functions if the points are not all coincident. This level of interoperability is communicated through written documentation embedded into the model database.

As components evolve over the course of the project, interoperability likewise evolves to accommodate new component relationships. Various social networking mediums were used in the platform to enable students to post work, receive markup from instructors, and for collaborator suggestions for new configurations of components. As a network of components is developed, design information begins to concentrate in some components over others. In some instances, components developed high levels of resolution while others remain underdeveloped. In other instances, components assumed functionality that superseded other components. For example, a framing component might begin to include substantial amounts of information for other components, in the form of geometric and parametric outputs. This framing component could drive a specific type of information, for example, outputting information for position, thickness, bolt locations, etc. As a result, the bracket component develops very little intelligence, and is merely the end result of the information embedded in the framing component. Redistributing design information requires identifying unbalanced conditions and making shifts to component information distribution, as well as to the meta-controls and standards that facilitate the exchange of information between them.

To control standards of exchange for this process, a system of automatic task assignment triggers was utilized, built into the scheduling system on the platform. The project schedule was linked to specific tasks, such the modelling of a parametric panel component, the completion of which would then trigger a new task assignment to another student. This task was developed as an item in the schedule that would trigger an announcement and assignment of the task to the student representing the panel. Assigned tasks remained active until they were completed, at which point the next task was assigned automatically by the schedule. The status of all tasks, completed and active, is viewable in a web-based dashboard in the platform. Schedule and 3D models in progress can likewise be viewed from the dashboard. Task assignments also include information about parametric input and output geometry, which can be revised as components develop. By actively reviewing the dashboard for progress, weak links in project development can be identified, and the schedule of task assignment correspondingly adapted.

As the project progressed, students developed strengths and specializations within specific areas of the project. Certain students became proficient in parametric modeling, for example, and were highly productive in generating new components, while other students focused on research and documentation that informed the components. Identifying trends and patterns in the evolution of roles was important to maintaining collective productivity and efficient collaboration. Individual discussion with students was a part of evaluating roles, but would not always reveal collective trends and patterns in advance or accurately characterize individual or group roles. Moreover, some necessary roles remained underdeveloped, such as a focus on specific building components or documentation production, and needed to be identified. To support an understanding of how design intelligence was emerging from the network, web-based dashboards in the platform that aggregate live production data were used by both instructors and students to assess trends and patterns in role development. Web-based dashboards were used to review live, collective statistics on data, such as how the production of component or documentation was occurring across the studio, the distribution of components types being created, and time spent by individual students on developing components.

5. Discussion

The evaluation of statistical data through web-based dashboards allowed meta-controls and standards to be adjusted both in response to evolving roles, and to manage and shape them. This included defining and redefining the exchange standards of geometric inputs and outputs for parametric model components, identifying and enabling student specialization, redistributing production time among components, defining and allocating new task assignments, adapting the schedule, and identifying gaps in production resources. The meta-controls and standards were part social, part model and part logical. Taken together, they allowed for collaboration to occur similar to crowdsourcing, as a decentralized system for generating design intelligence, but with a dynamic evolution of the roles of the actors within the project. The web-based dashboards and scheduling, as well as the web-based model viewer, allowed persistent review of project data and statistical trends from a granular level to an overview level. The information gathered from collective data, supplemented with individual review, offered a far more thorough understanding of the how design intelligence was emerging and being produced than in a typical studio process. This understanding allowed for a more efficient distribution of resources and time, as well as allowing for a more flexible and dynamic, adaptive approach to project development than could otherwise occur.

Deeper understanding of the extensive data revealed through the platform dashboards remains a site for further investigation. Trends in data did not always correlate with expected interpretations and the degree to which meta-controls and standard should be specific must be balanced with flexibility. Many opportunities exist to test adaptive collaboration in new projects. The incorporation of machine agents into the process is an additional area for further study. Workflows that integrate computational optimization have already proven to expand the territory in which designers operate (Keough & Benjamin, 2010). Can collaboration be adaptively controlled by procedural logic? As artificial intelligence increases in sophistication, could it play a role in structuring meta-controls and standards? The current study remains primarily a human-operated and -managed system of adaptive collaboration, but new territory exists to be explored with the application of procedural logic, optimization and machine learning.

6. Conclusion

The evaluation of data generated through CBDM platform-based workflows are well established in other industries, where they have enabled highly efficient practices and smart factories (Wu *et al*., 2013). Architectural workflows, as has been discussed above, have widely different methods, distribution of multidisciplinary expertise and requirements for adaptability in production. To maintain agency for design within a system tailored for efficiency, architects must understand how command and control structures influence collaboration, and take an active role in structuring how design intelligence is generated.

Acknowledgements

Many thanks to all the members of the Solar Decathlon China 2017 design studios at the NJIT, College of Architecture and Design (CoAD), for their hard work, dedication and enthusiasm for learning new ways of working, to Dassault Systèmes, for their generous time and engagement, and to the industry partners and sponsors of the studio. Special acknowledgements to CoAD Director Richard Garber, for his vision in implementing the studio, and to CoAD Dean Urs Gauchat, for his ongoing engagement and support.

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TRENDS AND PRACTICES USING 3D VISUALIZATIONS FOR LARGE-SCALE LANDSCAPE PROJECTS IN NORWAY

RAMZI HASSAN, FRODE SAETRE
Department of Landscape Architecture and Spatial Planning,
Norwegian University of Life Sciences, Norway
ramzi.hassan@nmbu.no
COWI, Oslo, Norway
frst@cowi.no

AND

KNUT ANDREAS OYVANG
Hjellnes Consult, Oslo, Norway
kao@hjellnesconsult.no

Abstract. New advances in 3D modelling and visualization tools for large-scale landscape and construction projects have been achieved recently. The introduction of the new 3D digital modelling and visualization tools, e.g. CAD, VR, GIS and BIM initiated a huge shift in the way planners and designers develop, communicate and present project scenarios. This paper outlines the challenges, new trends and workflows connected to the use of new tools and how it's been practiced and experienced by professionals and stakeholders as observed in Norway. The observation shows that the latest developments are providing new potentials for performing better communication and collaboration. Planners could now demonstrate many aspects of a project which exceed the usual minimum requirements. An important functionality is the capability to work with huge amount of data-sets for large-scale projects which were previously almost impossible to work with.

1. Introduction

The practice of planning and design in Norway is witnessing new transformations and challenges when dealing with planning for large-scale projects. There is an increased demand for planning tools that allow projects to be more sustainably and economically constructed. There are pressures to develop planning proposals that more accurately connect to their geographical context. Projects including multiple disciplines make it difficult to visualize project goals in ways that are comprehensible to all stakeholders. In the context of increasingly strong competition to secure a project, clarity of communication is key in making sure a proposal is selected over many. Furthermore, there is a struggle to engage community groups effectively into the planning process.

Advancements in the field of 3D modelling and visualization make it possible to present alternative planning and design scenarios with a high degree of realism and interactivity. Using these tools, it is now possible to explore many aspects of a design in real time. These new approaches can be helpful in streamlining workflows, fostering greater efficiency and incorporating feedback in the concept evaluation and approval phases. This in return can greatly enhance collaboration and communication in the design and planning process.

Considerable studies highlighted the importance of visualizations in planning, architecture, urban and landscape planning (Hanzl, 2007; Oh, 1994; Tress & Tress, 2003). Other studies found that 3D visualizations tools are able to convey experiential qualities better than traditional 2D representations and are especially beneficial for collaborations involving audiences with no training in spatial design disciplines (Lewis and Sheppard, 2006; Kwartler, 2005; Lindquist, 2010).

This paper explores an approach to implementing 3D modelling and visualizations tools starting from the conceptual stage of planning process for large-scale landscape and constructions projects. It focuses on the E-16 highway project in Norway by the planning and design firm COWI. The project was supported by researchers at the Virtual Reality Laboratory (VR-Lab) of the Norwegian University of Life Sciences (NMBU) in Aas. The study is part of a project aimed at strengthening research on digital applications in landscape architecture and planning. It aims to explore the potentials and complications associated with 3D digital tools and visualizations when applied to landscape, urban systems, architecture and construction projects.

2. Method

This study followed a two-track methodological approach. The focus for the first track is on studying and learning the technical capabilities and limitations of the latest commercially-available 3D digital applications. This involved work by planning students and professionals with intermediate digital modelling skills enrolled in courses offered at NMBU in 2013 and 2014. Through the courses, case studies were used to uncover the challenges working with large-scale projects. The courses made use of two recently launched software products: Infraworks from Autodesk and Lumion3D from ACT3D B.V. Autodesk Infraworks provided the possibility to collect various types of datasets in a 3D environment. The software supported a BIM approach for creating data-rich 3D models. In addition, the software was able to create various types of planning scenarios in a 3D environment and communicate them through the net using a special viewer. Lumion3D provided the functionality to produce real-time, realistic 3D visualizations compatible with the models produced by Autodesk InfraWorks. Participants to the courses were exposed to a learning methodology that forced them to use large data-sets which included GIS layers of roads, building layouts, water features, landscape contour lines, vegetation and aerial photography. The focus of the second track was to monitor and observe how planning and design professionals used these technologies in real projects, like the large-scale road construction E16 led by the planning and construction firm COWI.

2.1. E-16 HIGHWAY PROJECT BY COWI

The new E16 is a 4 lane, 32 km long highway planned in the eastern part of Norway, stretching from Nybakk in the south to Slomarka in the north. At the time of the announcement (2012) it was the single largest contract for a road project ever announced by the Norwegian Public Roads Administration. The project required three major deliverables: an area plan, technical plans and a BIM model. The E16-project was the first infrastructural project for which COWI used Autodesk InfraWorks. During the initial piloting of the software, COWI was especially impressed by the software`s ability to handle large datasets and by the intuitiveness and user-friendliness of the software when sketching conceptual designs. After deciding to utilize the software in the E16-project, the digital modeling efforts were divided into three parts: a model of the existing conditions, a conceptual design model and a detailed design model. The three stages of the model came to be the basis for the subsequent zoning plan and the project budgets.

In the first meeting with the client, three weeks after the contract was won, COWI showed a model with the basic existing conditions of the project area and a road that was planned in an earlier stage of the project. From the onset, the planning of the new road took place in a 3D environment, and different road concepts where discussed and modified during the meetings. After gathering and visualizing even data on existing conditions, the model evolved to become a conceptual design model. At meetings with the client, different proposals and concepts were presented, discussed and altered. New proposals and concept were also created at these meetings. This was possible because of InfraWorks`s ability to rapidly create new road concepts, by simply pointing and clicking on a computer. After the meetings the different proposals where communicated back to the rest of the design team through the cloud and refined before the client meetings that followed. After deciding which concept to evolve further, each discipline made their model in their preferred software, and then imported this into InfraWorks. The purpose of this was to make a model that would show the detailed design.

Interaction with the client and the public improved considerably. Proposals that in previous projects had been shown in 2D now were shown in a 3D environment. The 3D model COWI showed had never been at such a high level of detail at such an early stage in the planning process in former projects. This made the decision-making more precise and made both the client and the project team more confident that the right proposals were forwarded to the more detailed face. The high quality of the 3D visual information gave the stakeholders accessible and readable information at an early stage of planning, but also made it important for COWI and the client to emphasize towards the stakeholders that further changes in the design could apply later on in the planning process.

Figure 1. E-16 highway project. Analyzing flood situations (Source: COWI).

Figure 2. E-16 highway project. Detailed road design model (Source: COWI).

3. Reflections and Discussion

The use of 3D digital tools for large construction and landscape engineering projects has always been challenging because planners, architects, engineers, landscape architects and governmental institutions operate at different scales, using different data sources and working with digital tools that are not designed to work in sync. Our experimentation with 3D digital tools for developing planning scenarios in the context of NMBU courses shows that the learning process was relatively short and straightforward and also that planners and designers were able to visualize in 3D simply and in real time any changes and adaptations of every design concept. At a very early stage of the planning process, alternative proposals were visualized quickly, in greater detail and accuracy, and could thus be evaluated more accurately than 2D maps and illustrations.

Working with 3D visualizations increased the efficiency of the planning process, especially in the concept phase. The ability to create and edit proposals made it possible to visualize and examine different design proposals at a speed that the design team had never experienced before, often during live interaction with the client. In addition, the ability to share the different proposals through the cloud, made communication within the design team and towards the client more efficient than before.

Projects of the scale and complexity of our E16 case study involve many participants who often do not have either the motivation nor the time necessary to understand a project in sufficient depth. Engineers, project leaders, project owners and end users are mostly dependent on a complete

3D understanding of the project. This will enable them to do correct planning, to make well-informed decisions, or to give adequate and accurate feedback. The experience from E-16 highway project show that clients, community groups and experts felt engaged by the 3D visualizations used in project meetings and public presentations, greatly improving collaboration and communication at various levels in the planning process.

The technical capabilities of readily available commercial 3D digital applications could be utilized to establish a common 3D collaborative planning platform. It provides possibilities to create functional design models with enough details to better inform preliminary reviews of large-scale projects fully within a 3D environment. During interactive feedback sessions, professionals could evaluate and consider making *on the fly* adjustments to the models in response to other stakeholders' concerns. The case study also illustrates new capabilities for planners to work at different scales using a wide variety of datasets. An important functionality is the ability to work simultaneously and with greater than usual accuracy with large datasets, which was almost impossible prior to the recent advances in 3D visualization software and hardware.

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EXPERIMENTAL GEOMETRY

Redefining way of design by human factor

BÜŞRA GÜLER AND HÜLYA YASAK
Istanbul Technical University, Istanbul, Turkey
busra.bguler@gmail.com | *hulyaayasak@gmail.com*

Abstract. Designing by rules and limitations can minimize the variations of design generation. The paradigm demonstrates how design concepts could be formed and produced by humans as an experience. A system, both digitally and physically, built as a spatial environment offers a tool to compare possible design products by people themselves. At the same time, it offers an opportunity to understand the implications of user interface and to compare technologies that further bridge the digital and physical. We also discuss conceptual foundations of the design process, interaction, collaboration, gamification, in an attempt to explore geometry and its potentials.

1. Introduction

"All forms are reflected to concrete coordinates of Euclidian world. In the nature these coordinates are not exist, there is not a stabile world. This is an abstraction, an unreality." (Zamyatin, 1920) Geometry is a creation to perceive the world, "creation of human mind." (Phaedrus, 274) A complete science of mind needs account for subjectivity, and consciousness. "All consciousness is perceptual … *The perceived world* is the always presupposed foundation of all rationality, all value and all existence." (Merleau-Ponty, 1964: 13) Relation between mind and body is the key to understand the environment, which is human experience.

The aim of this study is to outline a new approach to geometry and its generation. What is presented, is a paradigm of how the human factor as fundamental parameter during design process in order to generate design or environment based on general approaches, which is based on regular geometric shapes as a starting point. In this experiment, both digital and analog phases of installation were created as a game and also these phases have similar layered surfaces that users may easily interact with, in addition to a tool connected to provide collaborative design opportunity to users.

2. Problem

Design is a process that is constructed with defined parameters and finalized with defined boundries by the designer. However it does not reflect the general instability of the real world and its situations and is built with just controllable parameters. In this age, human interaction is central to our experience and, in many ways, is redefining it. It may open up new possibilities and potential, to handle design itself with definitions that allow flexible, changable surfaces to people not just designer. Notification of “people” is significant to understand the reason of searching new areas in design. In experience age also design should allow humanity in itself.

Experimental Geometry project is a way of design. The project was developed with feedbacks by group of a course community. At the beginning, several systems were developed to illustrate the problem. Feedbacks were led to create environment, and a game to compare with each other.

3. Methodology

This experiment focuses on issues and approaches based on the physical interaction between human and digital interface by the help of game console and intervention to physical environment by human. Experiment has two phases, digital and analog based on same fundamentals and created as a game.

3.1. DIGITAL PHASE: RHINOCEROS/ GRASSHOPPER/ ARDUINO/ FIREFLY

We are surrounded by technologies, options, tools that both are very complex and basic, therewithal continue to change and evolve. Thus, this experiment is required effectively real-time intervention to digital interface. Yet, there is a need for a tool, which could provide users as if they are playing games, at the same time getting command from people. Arduino is the one that is used to design a game console, which allows getting data real time to grasshopper code and direct connection to computer.

3.2. ANALOG PHASE: PHYSICAL ENVIRONMENT MATERIAL SELECTION

Main idea about physical environment is a space that is formed vertical surfaces facing each other and surrounds human. "Design process as a function of knowledge and strategy."(Krishnamurti, 2006) The deeper the knowledge is, the more informed our design decisions become. And the richer a strategy is, the more alternative a design process generates. The notions of the rules and conceptual framework are the beginning structure of design process and human is the one who performs to produce unpredictable design outcomes. As a start, two steel rectangular, triangular grid surfaces are constructed. Specific, flexible rope is selected to make lines vertical, horizontal, diagonal to create patterns which is determined before for users. In this way, users could manipulate intersection points from one surface to other, then creates its own space.

4. Investigation

This study is started with curiosity for definition of geometry, its generations and interaction with human to produce designs.

4.1. GEOMETRY

Geometries are defined relationally with their points, sides, angles and relations. When geometries are defined with points, by overlooking sides, which are formed according to distance between points, and angles which are formed by two sides, it can be fundamentally defined.

With this way, just points in space, start to show different relations and with their coordinates, they start to define different types of geometries.

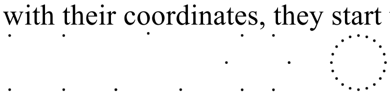

Figure 1. Point based definition.

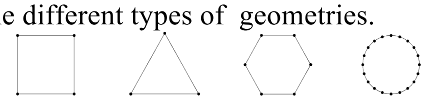

Figure 2. Sides created by points.

With defining points as nodes of geometries and taking ability of changing those coordinates and communicate with those points, new geometric definitions can be made and this can be called as “experimental geometry”.

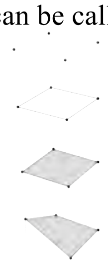

Figure 3. Transformation of geometrical definitions by point.

4.2. PATTERNS & EXPERIMENTAL GEOMETRY

With experimental geometry approach, layers of geometries are created but those layers are hidden and with human interaction the system can construct the layers. So the experience with nodes, geometry might started to be defined as lines, surfaces, environments or points again. In a different term, system offers different forms of geometries at the same time only the result is shaped with experience.

Figure 4. Pattern creations.

4.3. PROTOTYPE

For digital phase, game console is structured. It contains arduino circuit, between two acrylic glass. On front face of console, there are four bottoms, two potentiometers and one joystick. Console has usb connection to connect the computer.

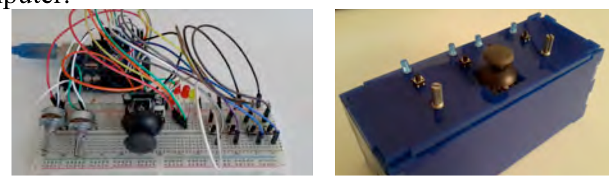

Figure 5. Console.

4.4. INSTALLATION & GAMIFICATION

The installation is prepared as a game that is experienced into two parts as digital interface and physical environment played as pairs.

Game has some basic rules: One of player use game console, the other interact with nodes of gridal surfaces in environment. Group players are selecting prepared cards that consist the commands, which players due to do their parts according to commands. But basically players start to pull and push the grid nodes according to commands. When the levels are done the geometrical environment that created by new nodes are analysed in grasshopper algorithm, and winner is determined by manipulation level. This way, it is considerable simple to compare, digital interface to physical environment with analog manipulation, also perceiving spatial to perceiving interface.

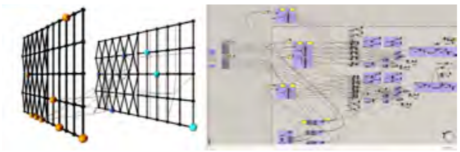

Figure 6. Grasshopper algorithm.

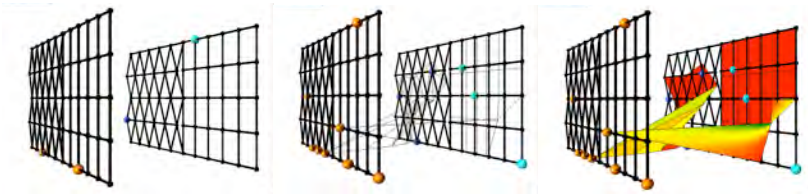

Figure 7. Game interface.

5. Discussion

In an experimental age, design approaches can also cover human experience; "humanity" under calculation system idea and it can generate possibilities from stabile definitions to possibilities of experiment. Parametric design is a calculation system and it directs designer to search deeply on possibilities of environment with coming terms; input, output, operation, programmability. However, we reached the end to design with controllable parameters. As designers it is time to shrink back and allow people to experience, produce, manipulate design itself. *Experimental Geometry* is a design approach that found with this idea and focus on flexible, changeable, uncontrollable design process in the center of humanity. With this approach, the aim was to illustrate a system with experiment approach with new questions to overall design process. What is designer factor in an experimental design process? How people can be included design process? Which ways can be used to design something with people who are not designers? Now design starts to change and try to get used to new unfamiliar paradigms and designers are in a possibilities age. With calculation system in design, tools, approaches made rich design term and people not just designer will start to communicate with design language in this experience age.

6. Conclusion

Most of designers have the ability to determine design problems and to propose productive concepts. Yet, not collaborate with users directly. Conceptual descriptions set at the early stages of the design process are used to frame some general design approach. Interpreting the process of the design by human offers more variety and belonging. This approach allows concepts and design artifacts to evolve in parallel. This study revealed some of clear results about forming design and comparison between digital and physical environment experiences. The success in the use of technology consequently leads to the exploration of saving time during process comparing to physically interaction to environment. To allow human interacts to design during process with initial rules and shapes, it is beneficial both designer and users. In brief, it is a computer supported interactive and collaborative design process and gamification of the process raises the progress.

The paper claims that defined geometry could be redefined and reproduced if creations begin with point, basic element of geometry. This way, new geometrical shapes and patterns could be formed.

Every research must get mature. Hence its first steps, creating more problems than it solves and increasing more question than it responses. Therefore, this researches answers some questions at the same time creates more for further works. Comparison between digital interface and physical environment, demonstrates both benefits and deficiencies. And interaction with people in an entertaining way, absolutely abridge the time, increases progress.

Acknowledgements

The starting this project is partly made possible by Architectural Design Computing Master Program at Istanbul Technical University. Also would like to thank professors, and courses which provided this project developed.

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Section

V

RESPONSIVE & SENSORY ENVIRONMENTS

NARRATIVE ARCHITECTURAL FICTION IN MENTALLY BUILT ENVIRONMENTS

OMAR AMIREH, MANAL RYALAT AND TASBEEH ALAQTUM
University of Jordan, Amman, Jordan
amireh@ju.edu.jo | *manal-ryalat5@live.com* |
tasbeehaqtum@yahoo.com

Abstract. A thin line lies between reality and fiction; what is mentally imagined and what is visualized. It all depends on how ideas and images are perceived or what neurological activity is triggered in the user's brain. Architects and designers spare no effort or tools in presenting buildings, architecture or designs in all forms or ways that would augment users' experience whether on the perceptual or the cognitive level and in both the digital or the physical environments. In a progressive tendency they, the designers, tend to rely more and more on digitizing their vision and mission, which subsequently give them, impressive and expressive superiority, that would influence the users conscious on the one hand and manipulate their subconscious on the other. Within that process designers work hard to break any mental firewall that would prevent their ideas from pervading the space of any mental environment the user, build or visualize. In that context, to what extent such ways of mental entertainments used by architects, legitimize deception in design? What distinguishes employing the rhythmic simulation of the narrative fictional inceptions (virtual reality) from deploying the adaptive stimulation of the experience modeling conceptions. The difference between planting an idea and constructing an idea. It is not the intention of the paper to prove the failure of the computer aided design neither to stand against the digital architectural design media and applications development. It is rather to present a different way of understanding of how architectural design whether virtual, digital, or real can stimulates and induces codes and messages that is correlated to the brainwave cognitive attributes and can generate a narrative brain environment where the brain can construct and simulate its own fictional design. Doing so, the paper will review certain experimental architectural events and activities which integrate sound and sight elements and effects within some electronic, technical and digital environments.

Keywords: cognition, subconscious, fiction, fictional narrative, narrative, science fiction, inception, conception, architecture for brain.

1. Introduction

Rapid technological and digital developments have directly affected people's ideas, notions and cognitive psychology. Designers including film making directors benefited widely and extraordinarily from that development in fictionalizing reality or realizing fictions.[1]Their ideas formulation occurs concurrently within the brain's conscious or subconscious cognition, which in turn entices a novel architectural conception that stimulates mental spatial thoughts at the deepest parts of the brain. Also, it proposes how narrative fictions could provoke an idea seed that can be incepted conceptually in the human's minds. This virtual seed grows into a thought, vision, behaviour, or information and defines the human's cognitive psychology, subsequently his mental environment. This cognition happens in the two simultaneous parts of mind, the conscious and the subconscious.[2]

In the mental Environment, the conscious is the surface of the thinking mind. It acts as the objective mind and deals with the outward objects, and gains knowledge through the five physical senses. It is responsible for logic and reasoning and is affected by filters that any preponderant thoughts have created and stored in the second part. The subconscious is the inner space of the mind and acts as the deep self and the subjective mind. It deals with feelings, emotions, memories and inward intuitions. (Murphy & McMahan, 2000).

Therefore, this research investigates a novel architectural direction that stimulates and simulates thoughts on the outer and the deepest parts of the brain. (Al-Aqtum *et al*, 2016) It enhances a subtle human's cognition to the built environment which acts as fictional narrative, metaphors, characters and series of events.

The research addresses the link between the idea and the fiction and the difference between science fiction and fiction science. The fiction is generated by specific narrative starting with gaining information and ideas from people's subconscious which is the needed state for Inception. It is defined by Christopher Nolan in his movie "Inception", 2010, as planting an idea into someone's subconscious mind. This process couldn't happen unless the conscious defences are lowered according to him. (Irwin, 2011)

It is found, that the novel direction could be named as "Architecture for Brain" meant to enhance the main role of the human's subconscious in understanding the built environment. So, architecture should pay more

[1] Two of the most successful movies, The matrix (the series) and Avatar have stress in creating mentally built environment while the first fictionalizes reality, the second realizes the fiction.
[2] The matrix goes to the subconscious while Avatar refers to the conscious.

attention to the fictional narrative rather than the reality! Also, it should stimulate thoughts rather than human senses to promote brain cognition.

2. Architecture and the philosophy of mind

Architecture in the philosophy of mind is no longer concerned merely with designing appealing containers for people and things. It is a combination of perceptual intelligent brain modelling techniques and sensing technology. Architectural spaces are now endowed with the ability to sense, respond and adapt to the way people experience, interact with and use them. Mind in Architecture, Architecture, Neuroscience and the Human Mind and many other publications and researches have with no doubts prove the inter-relationship between architecture, neuroscience and the environment.

Anyhow it's being argued which of the three have the greater effect on the others or what is the inter-correlation or equation that relate them together.

Whether that relation discussed in Rasmussen classic book Experiencing Architecture, as he stresses the visual quality produced and processed in architecture, (Rasmussen, 1964) or in Sensing Architecture of Lehman as she stress the effect of the visual psychology of experiencing architecture.(Lehman, 2009). "As was determined, a lower ceiling within a room promotes greater attention to detail by occupants. Higher ceilings promoted greater abstract and creative thinking by occupants" (Anthes, 2009).The architecture which surrounds you influences your thought, and subsequently your behavior (Lehman, 2009). Whether sensing architecture or experiencing architecture both emphasis the brain conscious interpretations of the architecture or environment. Yet not all mind processes processed in conscious states. The law of mind explains that any reaction or response from the subconscious mind is according to the nature of thoughts or ideas that set in the conscious mind (Murphy and McMahan, 2000). Understanding the relationship between the environment and the mind is important as to understand where, how and when that particular relation turned into vision, process or structure. "All in all, architecture is a type of "food for thought" where your designed surroundings impact not only how you perceive that world, but also how you interact within it." (Lehman, 2009). In Scientific American Mind's most recent issue, an article by Emily Athens called "Building Around the Mind" highlights various architectural factors that influence the human mind.

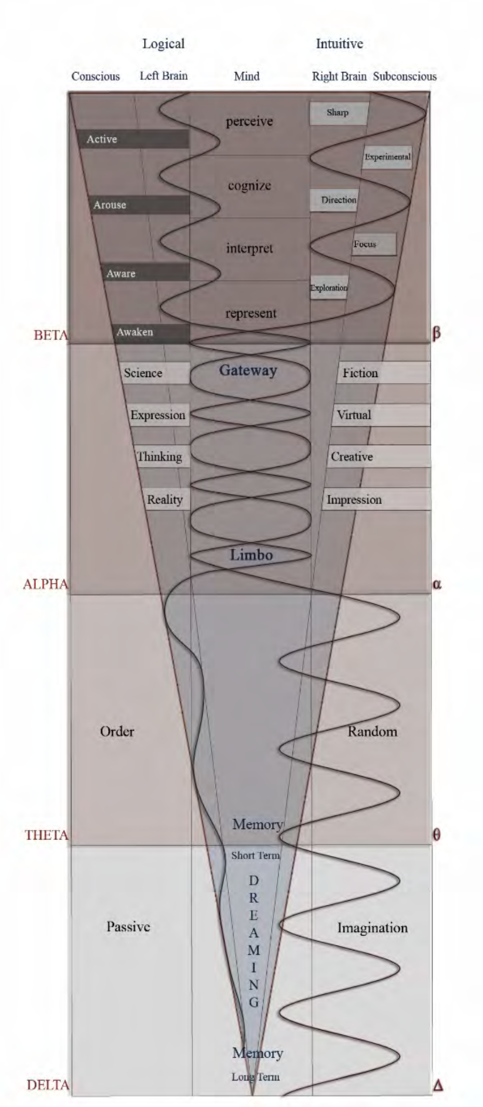

Figure 1 Brain Architecture Iceberg (Source: The Authors, 2016)

As described in the article — through the brain, architecture can impact our creativity, focus, health, attention, mood and social ability (Emily Anthes, 2009). "Of course, this is just the tip of the iceberg … Architecture plays a major role for our brains, not just as we perceive space; but also as we engage in interactions, behaviors and thoughts" (Lehman, 2009). Most of the studies discuss how architecture influences the human mind, while few tackle how the brain perceive, cognize, interpret and represent or process the in-taking ideas and concepts, and if did they refer to it either in the sensual psychology or the experimental behavior. Fortunately, enough new media, science fiction, virtual reality and movies move to the other side of the brain-architecture equation and while defying the law of physics and gravity they invaded the brain realities and created what we may call the generic mind, a mind that is not contained into a specific time or space, a mind that creates its own architecture and generates intuitive space out of the logical place, see Figure 1.

2. Intuitive and Logical Brain Environments

Changing a ceiling height from low to high, changes the users state of mind from the concentrated giving detailed attention mind, to an abstract greater thinking creative mind. So seeking architecture that stimulates change in the mental state of the space user, from the Beta (β) interactive wave to the Alpha (α) responsive wave, simply triggered only by moving the upper side of his/her perceptual cube (Anthes, 2009). In turn that change induced change in his/her spatial cognitive vision, which either match or stimulate, (a or the) mental environment that the user either visualized or constructed, See Figure 2.

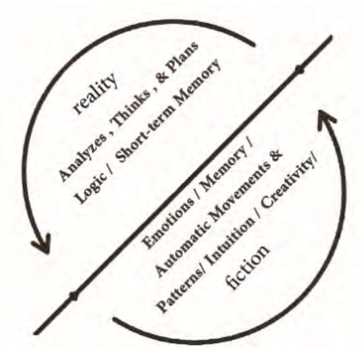

Figure2 the architecture experience (Source: the authors, 2016)

What are the possibilities, and of which environment, space, image, mental or the mind state that would induce, match or change the other environment? What is the case or the state needed for each environment in itself or the other, to interact, to respond or to influence? So what all designers need, is understand the philosophy of mind scientifically. Also to understand the mind cognition of the space morphology and the design procedures of the different Phenomenological perceptual experiences. Phenomenological concept strategies in architectural design intend to develop a unique experience of the phenomena of space, light and form. (Theory and context, 2016) simply to understand Architects need to design architecture that pass below the normal limit of perception, architecture that brings virtual to the real, and move the user mind from the science fiction to the abstract illusion. S Designing a mentally built environment and bringing what is mentally constructed into what is architecturally visualized needs this philosophy of mind to be supported by bringing neuroscience to the experience of the users and the designers.

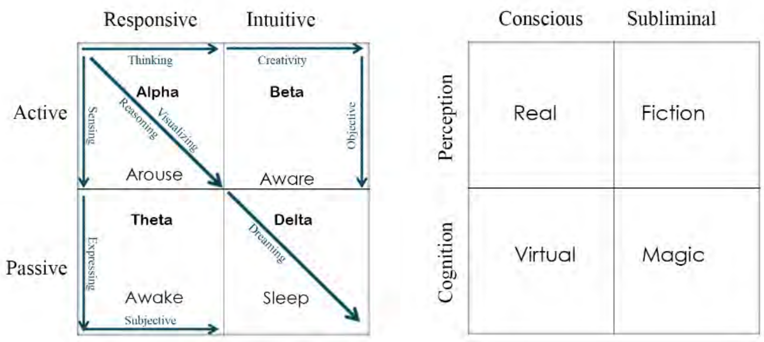

Figure 3 Brain and architecture in the JoHari chart (Source: The authors, 2016)

As if changing one side of the user perceptual cube, the upper side, changed his or her mental state-wave from the β to the Ω or vice versa, whether changing any other side or the whole sides would move the mind states to the Theta θ or the Delta Δ state. Or training the minds to change its mental state from one case to another by means of digital or electronic simulations would stimulate a mental environment which may substitute real architecture.

Another scenario of brain development goes to an ancient-contemporary training courses done under the ABCUS [3]and the ACMAS[4] programs. Both programs use the visual arithmetic system in employing the concept of brainpower shift between the Intuitive-Spatial right side and the Logical-Analytical left side or vice-versa. While ABCUS depend on user's perception of the real bar-rod-beads ancient tool to do any arithmetic calculations, ACMAS deploy user's visualized cognition of ABCUS in their brain virtual-spatial environments to do those operations. ACMAS brain inclusive operations owe its superiority over ABCUS for it claims all brain potentials, properties and activities at a timeless space-less mental environment. Beside its superiority in all brain activities ACMAS added the voiced value in transforming sound into visual narrative environment that is turning vocabularies into figures and images. The program, beside developing one's brain spatial environments is also distinguished with its ability to improve one's concentration, short and long term memory, intuitive and logical thinking, analytical and synthesizing pattern, real and virtual conception, subjective and objective reasoning. See Figure 3 (Naja, 2012).

[3] ABCUS an ancient calculating tool.
[4] ACMAS Mental Arithmetic System is an international concept of brain development program that originated in Japan

4. Architecture and Neuroscience

According to Gordon Chong, “neuroscience is beginning to provide architects with an understanding of how the brain ultimately affects how we think, move, perceive, learn and remember. (Eberhard, 2009).

Building around the mind, Brain landscape: The coexistance of neuroscience and architecture, and many other publications aimed to open a dialogue between architects and neuroscientists in order to understand how our brains and minds are interacting with the architectural setting and to invite the neuroscience community to devote a portion of their research agenda to architectural hypotheses (Eberhard, 2009).

“Neuroscience is the study of the brain; neuroscientists believe that the brain is the organ that controls behavior. The brain is a complex organ, composed of areas that control vision, somatic sensory experiences, and motor outputs, as well as areas that help us navigate through novel environments”. (Gage, 2003)

According to the neuroscience “the human brain is a network of approximately one hundred billion neurons, different experiences create different neural connections which bring about different emotions. And depending on which neurons get stimulated, certain connections become stronger. The connections between neurons can be increased or decreased based on the changes in experience and physical interaction with the environment” († wake up ‡, 2014).

“Each neuron has a voltage which can change when ions flow in or out of the cell, once a neuron’s voltage has reached a certain level, it will fire an electrical signal to other cells, which will repeat the process. When many neurons fire at the same time, we can measure these changes in the form of wave. Brainwaves underpin almost everything going in our minds, including memory, attention and even intelligence. As they oscillate different frequencies, they get classified in bands. Each are associated with different tasks” († Wake up ‡, 2014).

The role architecture plays is to stimulate human brainwave and projecting the architectural spatial design on these brainwave bands to create a mentally built environment that simulates the brainwave activities through the brainwave entrainment process.

The combination of the philosophy of mind with the neuroscience could establish a framework for the designers by transforming these brainwave bands into layers, each Layer has its own pattern according to its metaphor that is relating to the equation of WAVES, where the frequency of “brainwaves” changes from one layer to another. See Figure 1

Events and activities are classified according to these layers’ patterns and these bands of the brainwaves express the stages that user pass through the built environment which acts not only as setting but also as fictional narrative, metaphors, characters and series of fictional events. See Figure 2

5. The invisible augmented architecture

"Phenomenology demonstrated in architecture is the manipulation of space, material, and light and shadow to create a memorable encounter through an impact on the human senses. This theory promotes the integration of sensory perception as a function of a built form. This creates an experience that is beyond tangible, but rather abstract, observed and perceived (Theory and context, 2016). "In his engaging essays, The Five Senses, Gonzalez-Crussi (1989) reminded us that Aristotle first noted that sight and hearing were what distinguished humans from the animals because it was these two senses, he argued, that allowed the unique human ability of aesthetic appreciation—of art and music—a quality that animals and robots lack." (Baldwin, 2012)

Accordingly, the key to augment the user experience and tackle the human thought, it's to create an architectural narrative focusing on the rhythmic architectural elements (the sight and sound) that's used in the brainwave entrainment which is" a principle of physics", and defined as the synchronization of two or more rhythmic cycles, and stimulate the human brainwave activities (Corporation, 2016), and it should focus in the most important rhythmic architectural elements (the sight and sound).

Such narrative architectural fiction is used to augment the user's experience in the limbo state, through the invisible architectural elements, the light and sound, which are the characters of this architectural narrative. (Al-Aqtum *et al*, 2016)

In the limbo, the manipulation of light and sound are the distractor of people's attention, where people suspend their judgment in constructing the environment. See Figure 4. These experiences focusing on the spatial auditory cognition through the sound manipulation with people's emotions, See Figure 5. As application systems, the design proposes using laser beams and sound manipulation systems to affect people's subconscious minds by changing their state of consciousness and brainwaves.(Al-Aqtum et al, 2016)

The Limbo is an implementation of the "Suspension of Disbelief Theory". This theory defined the term Suspension of Disbelief as the willingness to suspend one's critical faculties and believe the unbelievable; sacrifice of realism and logic for the sake of enjoyment (Wikipedia, 2016). So, augmented architectural elements (light and sound) could provoke people's thoughts to believe of a wider space because of perspective illusions, See Figure 6.

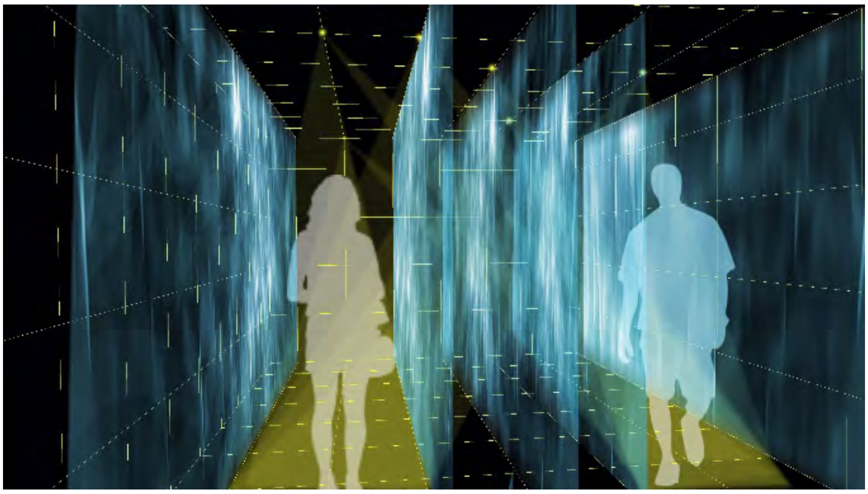

Figure 4 The Limbo Experience (source : Al-Aqtum et al, 2016)

Figure 5 The Spatial auditory experience in the Limbo (source : Al-Aqtum et al, 2016)

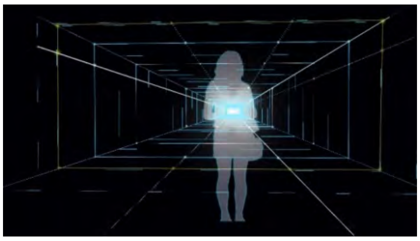

Figure 5 Invisible Augmented architecture (Source: Al-Aqtum et al, 2016)

6. Conclusion

Architecture plays an important role not only in providing a sensory built environment that stimulate human senses but also expanding and generating users spatial brain environment. Furth er it's rather providing spatial subliminal cues that stimulate the brain thoughts through a spatial cognitive design that simulates the mind's interpretation to the mentally built environment. Between the brain interpretation of the real environments or stimulated by it, architecture for brain is that which entice thoughts not senses; It is not that generate or change brainwaves but rather match and correspond with it; It should focus on the most important rhythmic architectural elements (sight and sound); It deploy user's experimental perception of the real environments in developing users virtual brain environments; It is an inclusive brain operation that owe its superiority for the phenomenology of architecture; It claims and utilize all brain potentials, properties and activities at a timeless and space-less mental environment; It is the philosophical investigation and description of conscious experience in all its varieties without reference to whether what is experienced is objectively real; Architecture that generates different circumstances in different types of mind wave-state and different situations of illusions, fictions and virtual; It moves effectively in-between the brain parts, states, waves, conscious and subconscious.

Architect should employ and deploy the narrative architectural fiction where important architectural elements such sight and sound are the characters, metaphors of the events and activities that enhances the subtle human's perception and cognition of the built environment.

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MULTIFLIGHT

Creating Interactive Stairs through Positive Technology

SULEIMAN ALHADIDI[1,2], JUSTIN MCLEAN[2], LUCHLAN SHARAH[2], ISABEL CHIA[2], ROGER SAM[2]
[1]BVN Australia
[2]University of New South Wales, Sydney, Australia
[1]suleimanalhadidi@gmail.com

Abstract. This paper details a pedagogical project which calls for an improved design performance of the existing built environment through the use of smart technology and data-driven design. The project is an investigation into ways in which to improve the performance of a ‘pre-selected university building’ through the use of a media facade that allows for interactive experiences. Existing problems of the selected building have been identified through observation and research using a rich picture and agile approach. An underutilised staircase was selected as the focus site for a series of computational design and interactive design studies. The brief of this mini-research project aims to encourage more people to use the stairs and create a memorable experience with a technological approach through the application of a site specific interactive media installation. The project is an interactive staircase which utilises LED strips and generative sound. The project features a series of light boxes which are connected to the existing staircase balustrade. Arduino, passive infra-red sensors, and other motion detection sensors were used to allow for light and generative sound interaction with users using visual scripting tools and a generative design platform. Sensing technology was used as a real-time data-gathering device during the site analysis phase as well as an input device for the designed prototype to allow the testing of the data-driven design. This paper details the study and resultant interactive prototypes. It also discusses the exploration of performance based design ideas into design workflows and the integration of sensing tools into the design process. It concludes by identifying possible implications on using the Internet of Things concepts to facilitate the design of interactive architecture.

Keywords: Performative Design; Interactive technology; Positive technology; Internet of Things

1. Antecedent: Architecture in the Internet of Things Era

The Internet of Things (IoT) is a current development that integrates the use of sensors and network connectivity into ordinary objects in order to send and receive data that can be fed back into systems and designs targeted at improved lifestyle and commercial activities. This process has caused a significant shift in our understanding of digital tools and the use of hardware in architecture and design in the last decade. IoT integration in product design can be seen with the Coke machine project at Carnegie Mellon University in the early 1990s (The "Only" Coke Machine on the Internet) which was, arguably, the first internet connected appliance able to auto-report its inventory and whether loaded drinks were cold. Although a simple application, it showed the potential of using sensors and the internet to enhance product performance and communication with users. Over the following decades, IoT has started to be gradually integrated into design due to the introduction of open-source hardware and software. The use of sensor technology in architecture, such as the Arduino platform, is causing the creation of sophisticated assemblies (RVTR, 2009), where buildings such as the North House Prototype, built in 2009, have an improved environmental performance through "computer-automated exterior shading louvers … based on real-time interior and exterior climate sensing" (Trubiano, 2013: p. 89).

2. Retrofitting University Buildings: a minimal approach based on data

A recent study by the Australian Learning and Teaching Council (2010) proposed guidelines for retrofitting university teaching spaces. The paper, '*Retrofitting University Learning Spaces*' (ALTC, 2010) explores 25 ways to help with the redevelopment of such spaces through the introduction of elements such as colour, allowing for interactivity, variation and individuality, and making 'spaces within spaces' (introducing hybrid spaces to enhance building performance) (ALTC, 2010).

Data in this research project is utilized as a driving force to allow for the creation of a hybrid space within a circulation space. The 'Grand Narrative' for this project called for improving the performance of the Red Centre, the Built Environment School at the University of New South Wales, through a series of design interventions that look at ways to improve the environmental and communication performance of existing buildings. Data was captured through a series of experiments. The integration of data-driven and interactive projects into educational spaces is relatively uncommon and the completion of this project will show insights into how it can be utilized to create a positive impact on a location and increase the visual and aural experience of the site.

There have been increasing numbers of architectural projects that integrate the use of sensors as a way of collecting data and/or utilising the resulting data and taking it into consideration in final design decisions. One example can be gathered from '*Generative Design Intervention – Creating a Computational Platform for Sensing Space*' (Alhadidi, 2013) where sensors were used as a method to track the motion of people. This helped determine the design decisions of optimal pathways that were created through a generative tool. Instead of using generative outputs to influence design decisions, MultiFLIGHT looked at generative outputs of light and sound as a major design gesture which is ever-changing to allow for interactive designs that are driven by end users. This paper explains how generative processes can create a memorable experience due to their unpredictable nature. Sound, which is often a neglected element when it comes to architecture was driven by data captured on-site that "embraces and transcends the spaces in which it occurs" (Avidar *et al.*, 2009).

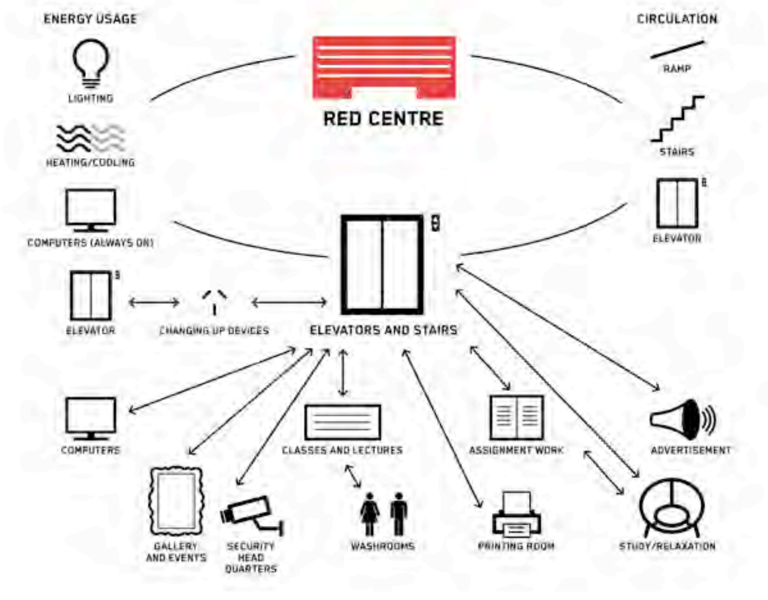

Figure 1. Rich Picture of the Red Centre.

3. Performance in Educational Spaces: Enhancing Communication Through ‘Positive’ Sensing Technology

Datasets through IoT are presenting an exciting opportunity to merge smart technology and physical architectural elements to achieve high degrees of communication to allow for better spatial quality. During the last decade, teaching spaces were influenced marginally by the implementation of smart devices using smart whiteboards and cloud computing as they “are an effective means [to make] learning more motivational and meaningful” (Giles & Shaw, 2011: p. 36). Smart white boards have not been as successful as anticipated in providing a positive impact to educational spaces.

The notion of designing with ‘smart’ technology to improve interactivity between students in teaching spaces is evident in newly retrofitted buildings, however the shift towards performative teaching spaces in older existing building stock, in reality, has not been developed due to the high cost and the need for further infrastructure to enable the installation of smart devices. Introducing sensing technology to circulation spaces within educational institutions may serve as another method to enhance the communication between students and enable neglected spaces to become actively utilised. For example, Passive Infrared Sensors (PIR sensors) can be used to gather real-time data from the existing space, which can then be used to inform and drive the design of the interactive prototype.

The creation of smart educational spaces enables the development of ‘positive technology’; that is, the use of technology to improve the quality of personal experience, through increased “emotional, psychological and social well-being” (Brooks *et al.*, 2014: p. 222). Previous projects such as the Piano Staircase in Brussels (Thefuntheory, 2009) is a notable example. The stairs were used as a positive technology intervention in order to raise awareness of health issues related to lack of exercise. This experiment was successful in attracting 66% more people to take the steps than the escalator (Hansen, 2012). Although this project has had positive results in the short term, the intervention may become predictable after several visits and raises the question as to how to make an experience more variable and dynamic for the user.

4. The Investigation

The Red Centre’s staircase was chosen as the location to implement the interactive intervention because it was assessed as an underutilised space. Through a series of studies, this project aimed at formulating a better understanding of how and why people move through the building. This project used the vertical circulation space as a ‘blank space’ that enabled a valuable opportunity to engage, stimulate and promote the use of, and engagement with the staircase by students. To this end, the staircase functioned as a canvas that allows users to adjust the built environment experience and encouraged a re-imaging of learning spaces.

4.1. DOCUMENTATION AND SITE RESEARCH: DATA CAPTURING

Documentation of the staircase was undertaken to determine any possible issues within the building. This process involved photographing the site and surrounding buildings and observing how people used the building so as to identify problems with the Red Centre and gather possible 'live' data with which to improve the immediate environment. The documentation approach used in this research was the first threshold for designing the interactive experience.

4.2. SURVEY VERSES TIME-LAPSE

In order to gain a clearer picture of the underutilisation of the staircase, a questionnaire consisting of eight questions was created and completed by students (N=50) to examine their perception and use of the space. From the survey it was found that there was an even split between people using the stairs and elevator in the Red Centre. The elevators were used mainly for going up three levels or higher in most cases. The survey indicated that the project could potentially motivate approximately 26% of occupants to take the stairs more often if the project provided a space for an interactive media zone consisting of lights, sound and sensors.

In addition to the survey, time-lapse photos of the Red Centre entrance were recorded from 09:00 to 17:00 over five regular teaching days. The camera was angled to view the number of people waiting for the elevator and to view how many people travelled via the staircase. This study served to verify the findings of the survey in relation to staircase utilisation.

Figure 2. Time-lapse of main circulation space from 10:30 to 13:00 on Monday.

4.3. MOVEMENT-DATA-DRIVEN-DESIGN

Smart technology refers to the incorporation of data and Internet Technology into an object or framework that enables autonomous communication within a network as nodes. One example of smart technology is the D-Tower, by Lars Spruybroek in the Netherlands. This tower reacts to information via submissions collected from a website which in turn determine its colour output and enables a dynamic and entertaining design. Within the proposed design intervention at the Red Centre, the movement of people provides a dynamic input and feedback via MUltifLIGHT, which in turn continuously adjusts the stair's performance. This data-driven feedback loop applies the use of data-mining from various mediums to create an interactive and engaging site intervention.

4.4. DESIGNING THE LIGHT AND SOUND

Architectural spaces have long been designed primarily through three-dimensional geometrical procedures that are presented and evaluated visually. However, the experience of the environment (natural or built) is one that is multisensory. Neurological evidence suggests that fidelity of aural stimuli is a significant parameter which alters an individual's perception of space and can "influence, both directly and indirectly, the mood and emotions of those who occupy or live within a space" (Blesser & Salter, 2009: p. 65).

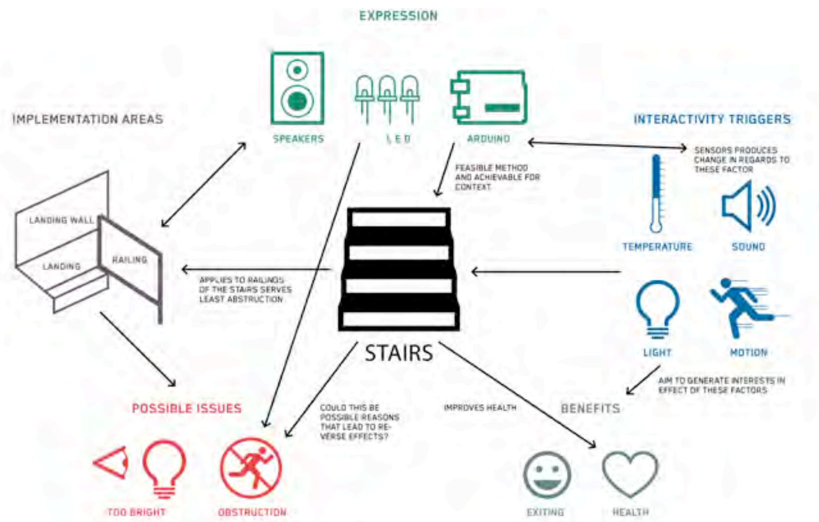

Figure 3. Rich picture of Stairs generated from the data mining exercise

Light and colour also have similar effects in relation to space as they can be used to “create focus, movement, balance, and to experience an emotional response” (Triedman, 2015: p. 200). Achieving a memorable experience relies heavily on “how novel and interesting the experience is, and the kinds of emotions that are evoked” (Koch, 2010). Using the Red Centre stairs will become a much more sensory experience which has the potential to improve the performance of the space by encouraging more people to use the stairs more often by emphasizing the visual and aural elements of architecture through the use of interactive light and sound to evoke an emotional response.

4.5. CONCEPT DEVELOPMENT

The experiments went through a number of iterations which gradually developed into a project featuring a series of acrylic boxes located on the external side of the staircase balustrade. Each box contained a number of vertical LED strips and speakers that were interactive and utilized both active and passive inputs. The interactions were divided into three categories which included passive lighting, active lighting and sound correlating with both the passive and active elements. While the light boxes were not being interacted with, coloured passive lighting generated from weather data was utilized. Active Lighting Interaction was incorporated in the design using Near Field Communication (NFC) stickers which can be activated by a series of inputs such as phones and student IDs.

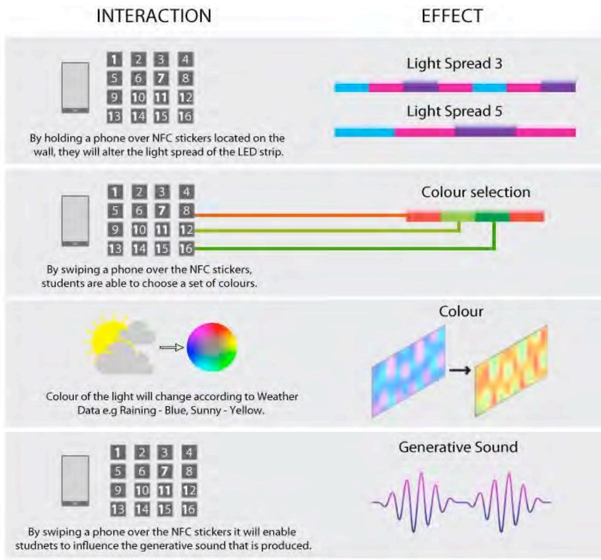

Figure 4. Diagram of interaction and effects

The NFC stickers were dispersed on different levels and generated different results from the sound and light elements. For example, level one generates slower lights and lower frequency sounds, while level five produces a different light spread and higher frequency sounds. Sound was generated from the value output from the varying arrangements of the NFC stickers, with the outputs then serving as the inputs for the musical notes in the MIDI data bank of instruments. PIR sensors located along with adjacent speakers then play sound when motion is detected at either the top or bottom of the stairs where sensors are located.

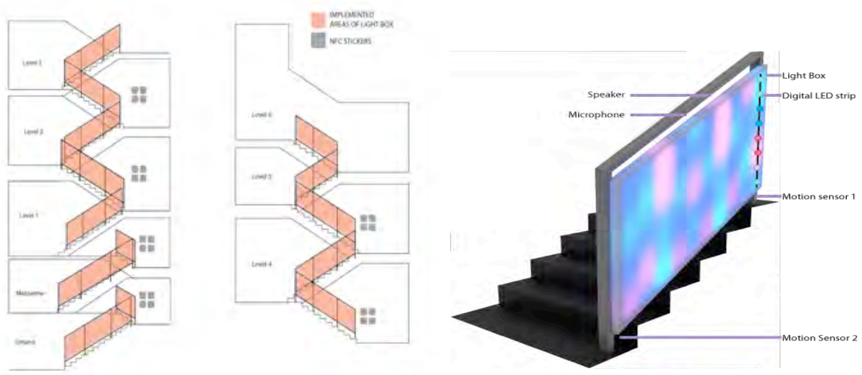

Figure 5. Section of Application Areas and Light Box Design

4.5. PROTOTYPING

IoT devices are increasing in speed and memory capacity. However, at present these small, low-powered devices still have a limited amount of memory, and some ingenuity is required to get them to perform complex operations beyond simple number crunching or simple computing. The ease and ubiquity of internet access (via Wi-Fi) and cloud computing can be used to get around these limitations, but often it is easier and provides a more robust solution to have a simple self-contained system that can run autonomously. Generative methods in programming can be utilized to create complex displays of lights and sounds. This complexity can be created out of very simple formulas, the results of which seem to the casual observer to be nondeterministic. These styles of formulae are similar to pseudo-random number generators. Given the same seed they will generate the same output each time, but that output is more ordered than a sequence of random numbers. This output of a generative formula can be used to set the individual colour of an RGB LED or play notes at certain frequencies. Consider a simple formula using bit operations like the following:

```
time * ((time >> shift1 | time >> shift2) & mask & time >> shift3)
```

This will produce a sequence of numbers in which each value depends on time and the resulting outputs grows and shrinks over time depending on the initial values for the shifts and marks. There are several overlapping cycles, and even when the output is examined for some time it is not obvious that it is repeating or how long the total cycle is. More dimensions of complexity can be added by altering the shifts or marks over time or as a response to user input, or even changing the formula and bit arithmetic operations within it. With a little exploration and fine-tuning the result can be complex. The code required to perform these calculation is small, fast and consumes very little memory, making it ideal for low power, low memory IoT devices. To explore the possibilities provided by a generative formula several simulators were created to explore the effect of changing the values of the shifts and marks and to see how the output could be manipulated. Simulators can be quickly coded and are a great way to explore the possibilities in a problem space. Several hardware prototypes were produced in this study, which were based on the use of LED strips with an embedded Arduino compatible chip, and an Arduino compatible board incorporating a 3G modem.

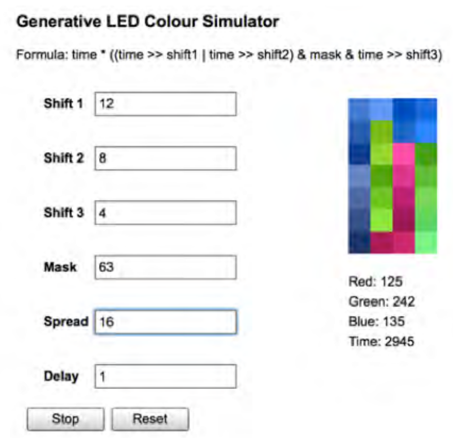

Figure 6. Diagram of Generative LED Colour Simulator

The 3G prototype was hooked up to a social network account (Twitter) to provide a simple way of controlling the generative formula. A function exposed in the cloud (as a URL) enabled the bit masks and shifts in the generative function to be changed by posting HTTP requests to this URL.

While investigating how NFC could be used to provide interaction, it was discovered that the student ID cards were NFC cards and thus provided a simple way for every student to have ‘unique’ interaction with MUltifLIGHT.

Figure 7. Fritzing(setup) of Arduino and Prototyping of Lightbox.

NFC stickers are cheap, easily placed and can be programmed to contain URLs and data. When an NFC-enabled phone is place near them they trigger a URL in the phone’s browser. A IFTTT IoT platform (If This Then That) was used to provide the ‘glue’ to connect different parts together and is another tool in creating prototypes and providing other diverse inputs to the system such as weather information.

4.7. MODEL DEVELOPMENT

When developing the model there was a need to ensure that users were able to experience the interactivity without disturbing or obstructing the existing space. So the final placement was on the exterior side of the railing where the LEDs were able to shine through the glass panel of the balustrade.

4.7.1. Generative design as an ongoing solution: What makes a space memorable?

In exploring mediums for this project, light became the most convenient and effective choice, having a dramatic impact on the way the space is perceived as seen in media facades. Not only is it visually stimulating, it could be a platform for interactivity being an open and novel communications medium (Davies *et al.*, 2012), Time Square is an example of this and attracts many people because of the scale of advertising and emotive nature of the media facades. It is these emotions that help create a memorable experience. Since this project deals with interior spaces and, in the presence of occupants, one of the aims was to gather and utilise data from sensors to create outputs that responded to occupant usage. For example, motion and other environmental factors were used as data inputs to design an installation that is an ever-changing system and creates a dynamic human experience. Through this body of knowledge, it can be understood that in order to make projects of intrigue and sensory experiences, there should be a level of interactivity and interest in addition to dynamic visual mediums.

4.7.2. Generative Design and Sound: How to Make It Memorable

In exploring strategies to create immersive experience, the use of sound was introduced, having an ability to change a space as it provides users sensory information which "defines, animates and enlarges the architecture" (Avidar *et al.*, 2009). Loop.pH's 2010 Spiratomic Space installation highlighted the potential of sound and light for the user, having a weave pattern that lit up a generative pattern that changed in response to environmental factors. The unpredictable outputs became memorable from not only its dynamic system but its open and novel opportunity to involve participants. This illustrated how a memorable experience can be established by making the project responsive to people and its surrounding environment, and therefore less predictable. A harmonious connection between the lighting and the form that it is displayed on must also be established.

To apply the sound aspect of MUltifLIGHT we needed to take into consideration different factors and conduct several on-site tests to ensure the most optimal outcome. It was important to look into finalising and deciding on the appropriate decibel level that would be sufficient to be heard but not loud enough to be disruptive to people. With the available equipment, the sound was tested using a Bluetooth speaker placed on the landings. It was concluded that the most appropriate sound level was around 50–55 decibels, one to one and a half meters away from the speaker.

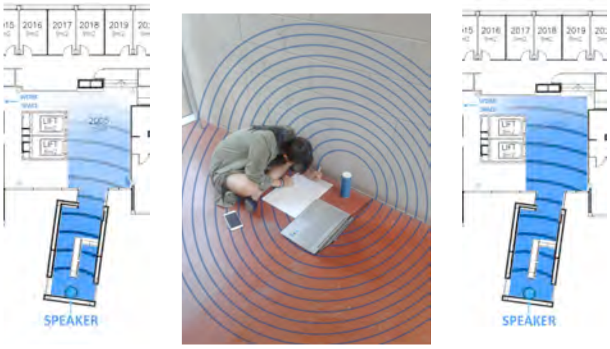

Figure 8. Diagram of Speaker Volume Level Ranging from 45–65 decibels (left to right)

5. Results and Analysis

There are many examples of the integration or use of technological application of interactive media within learning and teaching spaces; however, there are fewer cases that focus on applying media interactivity outside of these contexts. This project extends the application of interactive media to interstitial spaces, and explores how occupants can be engaged in what are often 'overlooked' spaces. This project reimagines conventional educational spaces through the utilization of 'ancillary' spaces such as circulation spaces as platforms through which to foster engagement through the purposeful application of interactive integrated technology.

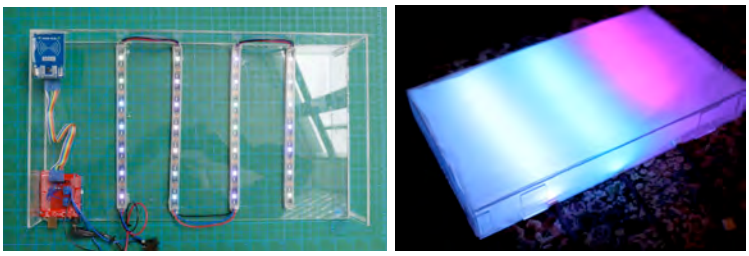

Figure 9. Lightbox Prototype for On-site Testing

6. Conclusion

MUltifLIGHT was a research project that examined the use of technological software and hardware tools as a method through which to explore the use of generative applications to create an engaging and interactive space. Through these mediums, a dynamic and interactive sensory experience was created for the occupants. There are promising potentials in the application of interactive media facades, and further research needs to be done to examine how this technology can be expanded to further enrich user experience.

The ever-increasing integration of the Internet of Things in different contexts brings with it the potential for new digital interactivity through the use of sensory tools. This research shows one of the many applications of the idea of generative responses that utilizes data gathered from occupants to produce a richer experience of the space. This project is an example of how media facades are a platform for enriching the experience of users. With the output medium of LEDs and sound being constant, the media facade is open to different inputs depending on the kind of sensors used. The type of sensor used and the interactivity involved will have to be considered against the occupant's behaviour whilst understanding limitations if the project is to be engaging. Although MUltiFLIGHT explores the use of sensors and interactivity as the means of entertainment, it touches slightly on informative purposes. With the right arrangements in hardware and software, its functionality could be extended to further applications such as data mining to understand how students utilise the building, and increased affective learning experiences.

Acknowledgements

We would like to acknowledge that this work was developed as part of the CODE 3100 'Digital Collaboration Studio' at the University of New South Wales in early 2016.

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ACTS OF SPATIALIZING HEALTHY

The Adolescent Body in Motion

ULYSSES S. VANCE III, NOEL. HERNANDEZ, O. TABOR, I. DONALDSON, M. ELLIOTT
Taubman College of Architecture & Urban Planning,
University of Michigan, USA
usvance@umich.edu | noelhdz@umich.edu | ojtabor@umich.edu | iancd@umich.edu | martjhe@umich.edu

Abstract. Physical Activity, which is essential for maintaining a healthy condition, is often a non-parallel particular in the curriculum of early adolescent education. Isolated to recess and gym class, or situated as separate extra-curricular activities, its metrics tend to be behavioral and external to cognitive activities. In order to address recent reductions in physical activity for adolescents, which the White House has interpreted as directly related to increased obesity rates in pre-adolescents over the last decade, a series of interventions within learning environments, class space, and facility syntax were developed to introduce activity breaks throughout the class day. This paper posits the findings from hybrid computer aided visualization and simulation tools used in defining adequate space for adolescent physical activity in the classroom. Primarily the research questions the volume of space attributable to each student based on the size of the classroom and number of students per academic year. The findings develop both the hybrid digital systems that map geographies of movement in adolescent bodies and work to facilitate an understanding of physical activity ecologies that can be prescribed to varying components in an educational institution. Additionally the findings contribute to multiple speculative apparatus intent on redefining class space, by situating certain physical activities with specific spatial modifications. In turn, establishing a formal agenda for situating activities in these conditions and determining the plausibility of devices in educational institutions that can encourage movement.

1. Introduction

Recently the United States shifted from the standardized Youth Fitness Test toward a more communal fitness concept, which is presented to students through specialized programs (White House, 2005). The new platforms allow for new mechanisms of demonstration, instruction and assessment, and require new metrics for evaluating the adequacy of facilities in preparation for such activities. Fluctuations annually in population create differing class sizes and make the ability to determine appropriate room configurations that account for all students difficult. In assessing the plausibility of incorporating activity breaks into the classroom this research project first sought mechanisms to prove the validity of predetermining space per child per classroom, and then by spatially mapping movements associated with a select cohort of children limited to between 8 and 11 years of age this research also sought an understanding of the range of displacement associated with the size of adolescent bodies. The representational means of studying movement was through a series of points and lines representing the skeletal frame, and quantified through the use of a contained volume to determine the specific spatial requirements for an individual student.

In this article, we explain how the research metrics posited to a single room provides a mechanism for visual cues and physical performance during physical activity in the classroom. This initial study establishes mappings of the body's movement through puppeteer mechanisms as a basis for studying: (1) the visualization of body displacement during select physical activities; (2) mechanisms of disciplinary specific software in assessing variations in height, dexterity, and range of motion for the study cohort. The use of digital simulation to anticipate the spectrum of performance of the proposed adolescent cohort is intended to provide designers the means to alter differences in: (1) categorizing exercises per classroom and/or class space assessing separately speculative classroom and/or class space elements; (2) the representation of complex human movement; (3) the varied participation typologies and the corresponding size and shape of the proposed classroom and/or class space (HMSO, 1967); and (4) the position of interface points in establishing a basis for interactive surface geometry in classroom and/or class space elements. The physical performances of puppeteers controlling the digital marionette bodies were also recorded separately as the simulations only account for metrics of agility and speed, but were not included in the final speculative proposition as they were only attributable to the puppeteer and not the intended cohort.

2. Literature Review

Compliance by definition can be understood as cooperative adherence whether to law or to a construct, and as such, accessible compliance is the interpretation of intended rules that most satisfies equal provisions for persons with limited ability or a disability, rather than a strict following of guidelines (AIA, 2014). The understanding of compliance is important in establishing the role of this research, as it inconsequentially defines equity of space rather than indemnifies responsibility. Historically, decisions that equalize our social and physical differences are based on the civic interpretation of rules governed by the code and considered equal to the protection of life, while the elevation of spatial experience through architectural reasoning tend to be less specific.

In understanding the means of fulfilling the most efficient means of a particular task it is important to understanding the varied situations of the human form during the working of relative instruments (HMSO, 1967). The utilization of engineering standards for quantifying space attributable to mass production and in particular the visualization techniques employed in the ergonomic studies of heavy industry and military equipment of the mid 1900s (Neufert, 2002) have significantly influenced the rationale used in formulating a scientific approach to architectural metrics used to represent the visual characteristics of space serving as the basis for promoting efficiency in appropriations for range of motion in this study. Comparatively, the singular nature by which compliance defines environments in relationship to the human form, more commonly defined by contemporary codes, reduces to exact measurements and ignores the human body's performance and natural complexity (Wang et al., 2010). This is similar to a reduction of intonation in order to simplify a language, where in doing so reduces the emotional connection to what is being articulated, leaving minimal flexibility for interpretation.

It is from these utilitarian ideals that the multi-axial metric used in quantifying displacement during physical activities is developed. A variety of associative standards for individuals were used in quantifying activity zones, buffers, and topological studies. Most prominent of these studies were when space limitations must resolve acute population increases, and the limitations confine the physical movement of persons within the classroom (HMSO, 1967). Previous studies of parameters for adolescent classroom furnishings served as the foundation for practices regarding modifications to the corresponding physical activity zones and their application. The basic application of which later defines the difference in spatial syntax for the classroom and the modification of class space element locations based on referenced biomechanical studies

(Wiktorin, 1986) for particular physiological body types (Table 1) (NCHS, 2001). The results demonstrate a means for varying the applicability of differing stages of activity in a single classroom or class space based on solitary, parallel, associative, and cooperative participation (Parten, 1932), giving teachers alternatives in arranging students during activities.

TABLE 1 Height Range Data

Lower, Middle, and Upper Height Limits 8-10 (in inches)

	Age 8		Age 9		Age 10	
	Boys	Girls	Boys	Girls	Boys	Girls
Upper	54.5	55.5	56.75	56.5	59	59
Average	50.5	50.5	52.75	52.5	54.75	54.5
Lower	46.75	46.5	49	48.5	50.5	50

Source: National Center for Chronic Disease Prevention and Health Promotion (2000)

Public education's current dilemmas with rising obesity rates (White House, 2016) reflect its continual struggle with the nuances of educational reform. By defining a systems approach to difficulties associated with limited spatial resources for physical activity, centers of early childhood education can focus on methodologies suitable to their specific classroom and class space conditions, and allowing students greater integration of the activities into their daily routine. Supporting the disposition that teachers should maintain conditional control of the classroom flexibility relative to behavioral issues and changing classroom populations, which at best lends itself readily to new organizational structures proposed but not solved within this research.

3. Problem and Methodology

Physical activity in educational environments during the pre-adolescent years is necessary for the development of physical and social behaviors that will influence personal development between students and external to the school. Properly articulating physical activities in class space settings that are confronted with environmental restrictions, serves as a laboratory for understanding how to facilitate the basic needs and interest of children in garnering enough physical activity to remain healthy in isolated settings. At the same time, studying the structured class space environment provides a setting for investigating the relationship between teacher and student in developing common techniques for guidance on the importance associated with physical movement, which is optimal for the heuristic ownership of personal wellbeing at an early age.

The challenge is in the appropriation of adequate space to formulate the planning of classroom activities and class space environments that encapsulates an understanding of the relatedness between the human body, its movements, and variability in size, shape when locating objects. This research demonstrates the digital testing of ranges in motion associated with levels of physical activity, and the processes of arranging these activities amongst sedentary furnishing arrangements in elementary classrooms. The quantifications garnered from these studies have multiple purposes, the most significant of which is the definition of space to be allocated during each exercise relative to the centroid of the range of motion based on the centre of gravity during each exercise. The measurement of displacement in three axes determines the volume rendered as a single activity zone, therein establishing a basis for determining a metric that when repeated informs the amount of space required in providing multiple physical activity zones per classroom based on the number of students in each classroom and/or class space.

4. The Investigation and Analysis

Derived from the observation of things that twist and turn as a means of avoidance, the formal investigations sought to create a continuance in a place of multiple interactions, from "barnacles" for interaction during play to more formal descriptors of a body moving to avoid another body, ranges of movement are applied to physical territories surrounding select movements. Often this was done unaware of the contextual or conditional needs between larger collaborative references or performance qualities quantifying how the speculative ideas correlated with intended outcomes. Therefore, it is not a factual pursuit of knowledge defined by external references, but rather a pursuit of techniques in forming new knowledge on movement in architecture, engaging physically the intentions of architecture by physically creating the diagrams of use. The caveat being that the research into physical activity, use, and movement happens through an architectural body that evokes movement instead of a preconceived perception of motion as a visual whole.

4.1 CATEGORIZATION OF EXERCISES AND ASSESSMENT OF CLASS SPACE

TABLE 2. Play Activity Matrix

	L	M	H	YES	NO	GROUP	INDIVIDUAL	MINUTES	NOTES	NOTES	#	~SQFT	LINK	LINK
Jungle gym				X		X	X	>6	fairly nuetral	heavy use of [illegible]			[illegible]	
Karate					X	X	X	>10	differentiated skills evident	disabled options available				[illegible]
Kick Boxing				X		X		>10	differentiated skills evident	requires full mobility				[illegible]
Pickball				X		X		>20	differentiated skills evident	requires full mobility				[illegible]
Knitting/crochet				X			X	~30-60	fairly nuetral	disabled options available	1+	3'x3'		
Laser Tag				X		X		>20	fairly nuetral	disabled options available				
Lava				X	X		X	any	fairly nuetral					[illegible]
Leap frog					X	X		5s-5m	fairly nuetral	Low skill, use of whole body	2+	10ft linear		[illegible]

Table 2 is a sample of the activities selected for comparative representation, querying available resources for specifics to each exercise and discussing the particulars of relevance to parallel research happening within the School of Public Health. The exercises were recorded using a Microsoft Xbox Kinect whose three-camera configuration captured individual and group skeletal registries (Figure 1). The representations investigated the formal characteristics of multiple exercises happening simultaneously within a confined space against spatial questions of solving for accessible pathways between students during the exercises. The subsequent results were then tested against desk arrangements and seating positions of students (Zacharkow, 1988).

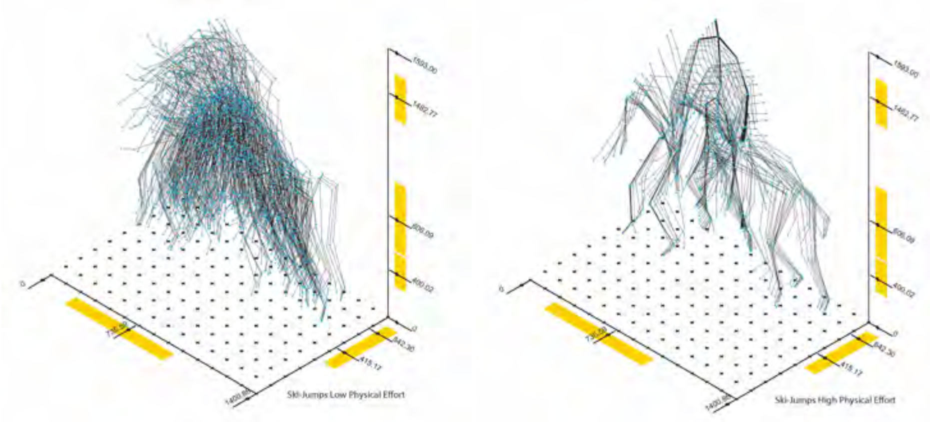

Figure 1. Ski-Jumps Low & High Physical Effort

The results from the initial studies demonstrated an applicability in measuring a variety of small and large movements associated with specific physical behaviors, previously described as low (seated or resting movements), medium (stretching to light walking), and high (climbing, jumping, running), and difficulties in developing objects that engage and encapsulate the body's physical movement when considering varied participatory activities: solitary, parallel, associative and cooperative. Consequently, the first representative simulations demonstrated that the use of puppeteer simulations increased the accuracy in tracking and evaluating the range of motion of non-similar physiological characteristics in differing cohorts as opposed to the control, which was the visual assessment of recorded data video through an analogue method of calculating spatial differences by visual measurement. Along with analysis documenting the existing elements that define a classroom and/or class space, these initial studies define the basis for how work zones and learning zones would be impacted by the introduction of activities zones.

4.2 REPRESENTATION OF COMPLEX HUMAN MOVEMENT

In creating an operative tool for adjusting physical variability in relationship to participant size and capability, modifications to input variables were created in Rhinoceros 3D using the Grasshopper plug-in. Data sets were derived internal to the grasshopper software using the Kangaroo plugin and received from video taken by a Microsoft XBox Kinect device. The Kangaroo plug-in along with script modifications separated the skeletal data into separate body segments; arms, legs, torso, and neck/head (Figure 2) as well as levels of physical activity.

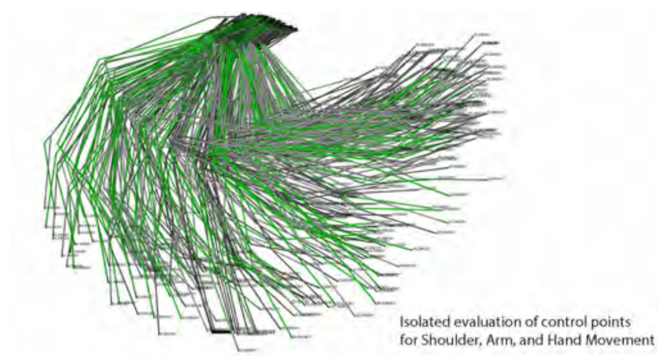

Figure 2. Isolated evaluation of control points for Shoulder, Arm and Hand Movement.

The density of line and point activity respective of the increment of time is based on the frame rate of assessment by the device and reflects the dexterity of the participant irrespective of the study cohort. However, it was observed that when assessing the projected length of study time per participant the model does capture the level of difficultly associated with maintaining an upright body position during such exercises, therein affecting the position of the participants centroid during high intensity exercises. This does have spatial implications for the clear zones around the cohort associated with the higher levels of intensity in the proposition of buffer zones adjacent to activity zones.

4.3 SPECULATIVE CLASSROOM AND/OR CLASS SPACE ELEMENTS

Three prototypes were developed; the composite wall system as a storage system, the system as furnishing, and the point of interface, to initiate studies defining the variety of transitions and territories suitable for modification. The selection of hallway and classroom space that would be utilized for scheduled in class activity breaks related to the isolation of the activities between or around existing furnishings, and is based on simulations conducted as part of this research evaluating the range of motion for particular exercises. The creation of a shelving system carrying interface and controller items served as control points for play, distancing the play surfaces from the chair and desk. What was found through introspective inquiry is that the wall's Cartesian grid worked well in establishing a regularized point of interface (Figure 3), allowing the differences in the controller locations and distortions in controller surfaces to be addressed individually in the structural frame. The geography of controllers offers a variety of hand and body interactions ranging from the notion of a "high five" hand smack, to the surface of the knee in a striking motion, and the tip of the foot in the pressing of a pedal. The higher controllers are all hand slaps, the middle controllers are a combination of hand slaps and knee taps, and the low controllers are foot pedals.

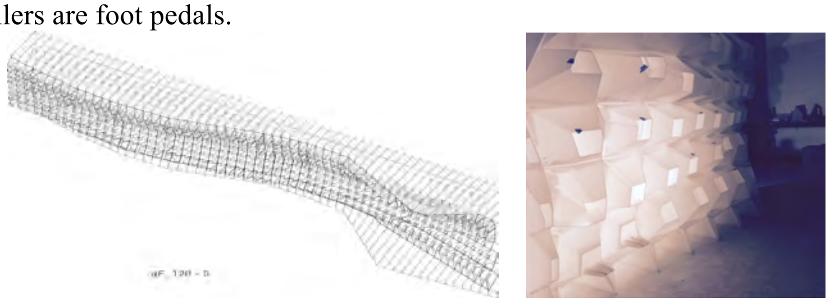

Figure 3. Class Space Wall Shelving Unit

5. Conclusion

Overall it is the testing of a variety of deformations within a specific architectural fragment composed of adjacent and non-adjacent elements, and the applicability of flexibility, resilience, strength and durability in withstanding repetitive activities related to compressive and tensile displacements based on a range of physical activities that defines the scope in relation to its making. The proposition that a practical application of metrics might lead to a more fluid architecture in these siteless settings challenges the pedagogical structure of the traditional design problem. Replacing it is a research-based model, from which proposition and implementation are as much studies on the role of artifacts to achieve variable degrees of performance as they are a discourse on the collaborative role of architects in quantifying their role in defining healthy spaces.

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Section

VI

CAAD EDUCATION & CURRICULUM

DESIGN FILMS

Implementing video creation techniques into undergraduate design education.

DAVID BROTHERS AND AUGUSTUS WENDELL
New Jersey Institute of Technology
wendell@njit.edu | david.a.brothers@njit.edu

Abstract. NJIT has been introducing video production projects into undergraduate design classes over the last two years. Linear motion projects open paths to understanding the built and virtual environments in ways that augment traditional design pedagogy.

1. Introduction

The ubiquity of smart phones equipped with video sensors has transformed the role of video in the lives of undergraduate students. Students frequently use their phones to create and share high-definition short format video content. The widespread social networks that students participate in propagate video content online. From Vimeo and Vine to YouTube, the phenomenon of "viral" videos have placed students in the potential role of linear narrative cultural influencers. Only a decade ago this role was shrouded in the realm of professional video content producers who could afford the cameras, equipment and skillsets to manage the production pipeline. The time has come to leverage these newly democratized technologies, techniques and perspectives in undergraduate design pedagogy.

2. Pedagogical Context

This paper chronicles the implementation of video production techniques in an undergraduate design school. The School of Art and Design at The New Jersey Institute of Technology was founded in 2008 within the College of Architecture and Design. Our school includes degree programs in Industrial

Design, Interior Design and Digital Design. It is clear that film can play an important role in the education of students across all three of these design disciplines.

The viewing and production of short films in the academic environment fosters a heightened engagement in students with the material presented (Kabadayi, 2012; Kruesmann, 2014). Additionally, the relatively recent focus on the "experiential" aspects of design is best studied, recorded, represented and discussed within the context of time-based mediums (Charitos, *et al.*, 2001)

In the past two years, NJIT's School of Art and Design has implemented video production into design courses throughout several years of our programs. The inclusion of video production creates an immediacy and connection with students which aids both the pedagogical approach and bolsters students' enthusiasm for fast paced project delivery.

3. Foundation Year Project

The Foundation year curriculum at the school has hewed closely to a traditional North American design school foundation. Students are engaged in the study of design principles that are broad-based and do not bias the application of these principles to any degree-specific projects. Courses in the foundation year cover topics that include colour theory, two-dimensional and three-dimensional composition, digital modelling, and art and design history. The project deliverables in these courses are typically written works or two- and three-dimensional static compositions in both analog and digital forms. Video and temporal-based media was largely absent in the first year curriculum with the exception of motion study that had been introduced in the context of film analysis for visual effect.

The faculty coordinator of the digital tooling course in the foundation year began including a video production project in the spring semester of the 2015/2016 academic year. The inclusion of this project was initially aimed at providing a skill set that could be leveraged in the subsequent design studio courses. After analysis of student work and discussion with other faculty in the relevant programs it was determined that the outcomes from the project confirmed its success as an introductory tool for design thinking, analysis and production, and provided a foundation for more directed student design inquiries using video format in later student work.

The foundation year video project assigns students the task of communicating a personal understanding of a basic principle of design drawn from a list that includes concepts such as line, shape, form, mass and color among others. Students are mandated to capture original footage in the built environment in a 1.5-minute-long video compilation. This exercise is paired with classroom studies of abstraction to provide a more comprehensive exposure to design principles that are both theoretical and applied. The screening of the final films in an open design critique environment creates a combination of (time-based) visual and verbal feedback akin to the benefits described in the "cinematic treatment" of architecture (Brooks, 1988). The combined usage of comprehensive spatial film recording paired with thorough design analysis produces a result surpassing more traditional fixed and/or differentiated image-based design communication methods.

Students were required to film in locations that were readily accessible in order to revisit during the assignment. In-progress critiques often focused on student understanding of the dual aspects of quantitative facts (syntax) and qualitative impressions (semantics) that time-based site recording can provide. (Cheng, 2001)

With a short timeframe (1.5 weeks) for creating and screening the final edits of these projects, students had no choice but to clarify and distil their message. Unlike a traditional presentation board or non-linear digital presentation, there is no "space" for excess content or unheeded detail. The timeline of the video medium is inescapable and persistent.

4. Upper Level Projects

There has been a concerted effort to utilize video as a supplementary medium for design investigation and communication in the upper level studios of the Interior Design program. In spite of the wholesale adoption of digital technologies for design of the built environment, its use has been primarily concentrated in leveraging the advanced capabilities of three-dimensional and parametric modeling for output that still relies heavily on two-dimensional representation. To be sure, students have been able to generate 3D walkthroughs of their designs for almost two decades, however, exercises have been recently introduced in the interior design studios to explore a variety of other ways that video can be used to capture the temporal aspects of spatial experiences.

In a final fourth year studio in the spring semester before graduation, students were asked to use video production in three different ways throughout the course of the semester as they developed their projects: as a vehicle for creative exploration and development; as a research presentation tool; and as a device for conceptual expression.

The semester-long project focused on the study of culinary arts as an analogue for thinking about interior design and culminated in the design of a culinary school and restaurant facility. Students were first asked to study a specific aspect of gastronomic culture and to create an interpretive video of a recipe that represented the essential characteristics and qualities of their category. They were asked to use a camera or a series of drawings that were digitally sequenced together to illustrate the process of creating the dish in a manner that was deliberately interpretive.

They were later required to present their building, site, and program research in a 2 to 3-minute clearly organized video compilation. Typically, this is done in a digitally sequenced series of slides that the student will orally present, so the challenge of relying on a temporal visual medium alone to create a coherent and self-explanatory narrative of their findings required alternative ways of thinking. By its very nature, video does not lend itself to text-dependent information. Therefore, the exercise was not an exclusively visual exercise; students needed to provide a narrative overview to clearly summarize the research findings that included interviews, site studies, existing building analysis, program, and adjacency diagrams.

Lastly, students were obliged to produce a conceptual representation of their final design using an animated GIF format. This required students to consider how our experiences of three-dimensional space are never static and embody movement and multiple perspectives. Video provided a terrific means of exploring this temporal aspect of interior design.

More than simply spatial documentation, the linear format and set presentation times for each exercise mandated that students edit their videos to distil the appropriate level of content for the given length. This became a very real constraint when students were obligated to play their pieces in front of an "audience" of both peers and design critics who needed to understand the students' position to their topic by the end of this set timeframe. Acknowledgement of these constraints focuses their research into a channelled and tightly nuanced set of key points, aiding in the distillation of complex and potentially ever expanding topics.

One technique that students used to achieve a distilled and effective means of communication, was by leveraging culturally rich signifiers to expedite understanding. Visual cues such as the use of graphic iconography and typeface appearance played to their points while audio tropes such as heavily weighted popular music soundtracks allowed the audience to share in an immediate common cultural platform for the films.

5. Codification

The video projects implemented at the school in recent years can be codified into the following matrix of three distinct classes.

5.1. INDEX

The creation of a collection of topics or subtopics describing a design phenomenon.

These project types require students to use video production techniques to explore specific design principles relevant to the course curriculum. These may be very basic in nature or may investigate complex design typologies.

Example projects have included: an exploration of the traditional colour wheel palette in suburban New Jersey market produce (Figure 1); the codification of lighting fixtures and lighting effects over the day to night cycle in New York City public space; the use of a GIF to animate a spatial design quality within a completed student project (Figure 2); and the classification of gastronomic techniques and philosophies in contemporary cuisine.

Figure 1. Produce Colour Palette.

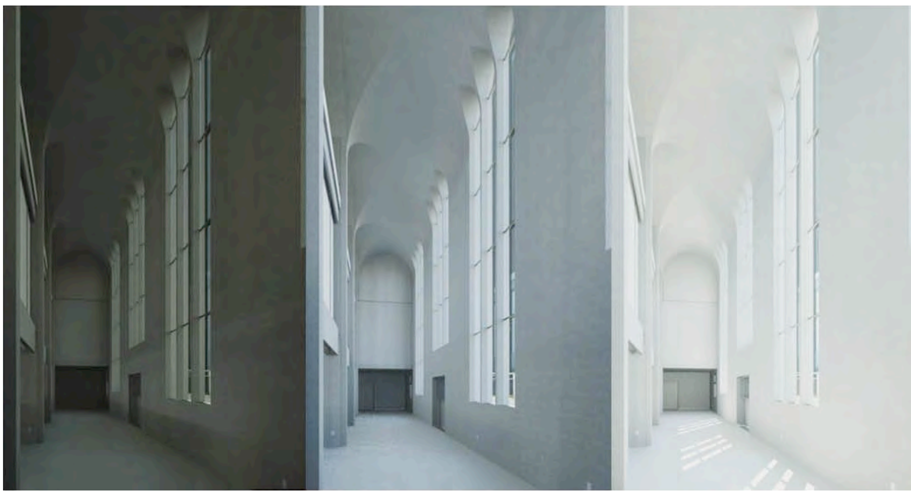

Figure 2. GIF Concept Image.

5.2. PROCESS

A sequence of steps often condensing a larger timeline into a short, edited deliverable.

The use of first person perspective in the cinematography creates an immediate connection between the viewer and the action(s) observed. When students are asked to document a process through the use of video, it reveals their design thinking more comprehensively than static images might and serves as a very effective teaching tool.

Example projects include: documentation of wood texture expressed through the transformation of a rough log that is gradually refined in a wood shop to become a finely polished cutting board; recording the sequence of following a prescribed recipe to make pancakes; cataloguing a series of steps in animated form to illustrate a model-making process (Figure 3); and, the investigation of a single walking sequence capturing built environment texture in each step at magnified scales (Figures 4 and 5).

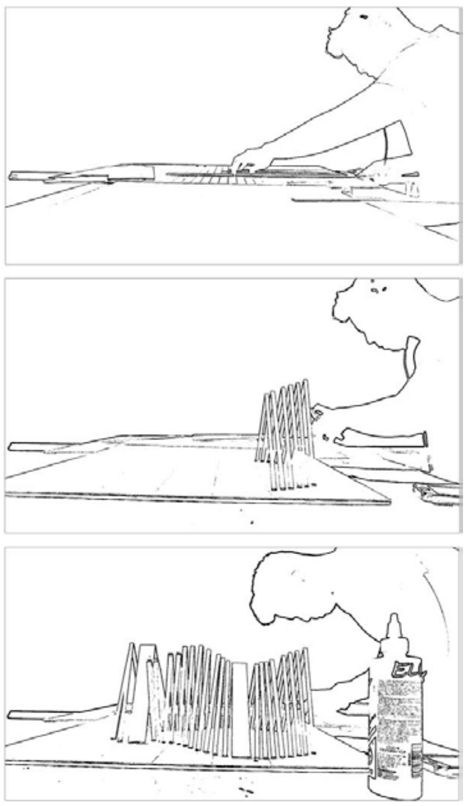

Figure 3. Model Making Process.

Figure 4. Built Texture (1 of 2).

Figure 5. Built Texture (2 of 2).

5.3. NARRATIVE

A linear story with characters playing recognizable roles.
Often these films leverage a clear beginning, middle and end (outcome) to create an understanding of a process, reaction or interaction. The characters may include unseen actors or stakeholders in this narrative account.

Example projects include: a day in the life routine of students capturing the encounters their bodies make with the built environment throughout a 24-hour cycle; the story of how ice cream is created viewed as a metaphor of a three-way love story between cream, sugar and chocolate set within a polar cabin (Figure 6).

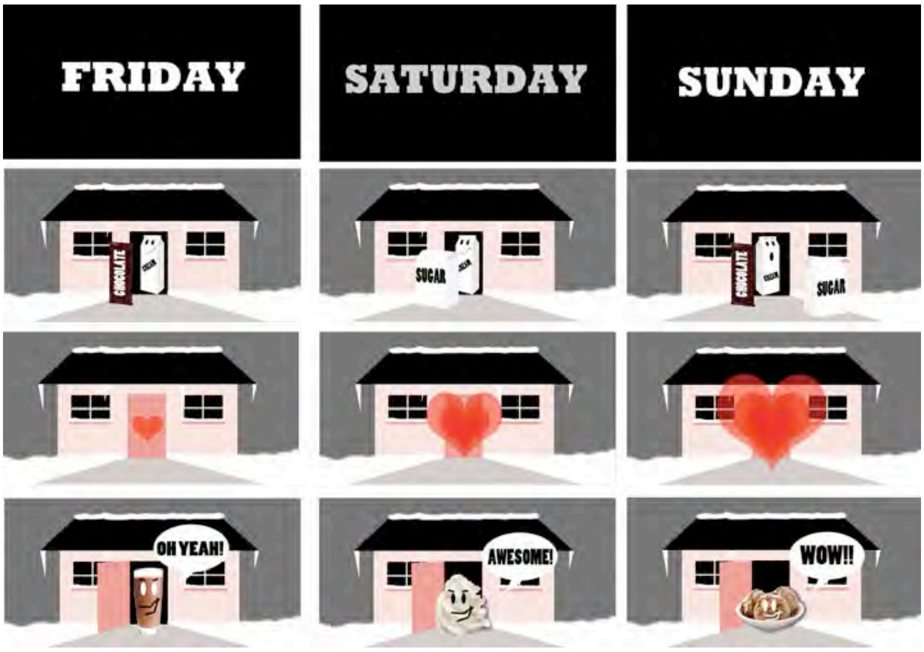

Figure 6. Ice Cream Creation Story.

6. Conclusion

Moving into a new academic year, the faculty at NJIT's School of Art and Design is actively engaged in a dialogue about how to create a learning environment that embraces an even broader, more expansive use of video as a legitimate medium of exploration and expression in disciplines currently unfamiliar with its potential. Learning outcomes have already demonstrated that students feel empowered as designers when the richness and immediacy of their work as video producers resembles the mediums they are familiar with and experience outside the academic environment. As video technologies and time-based media tools such as motion-capture and virtual reality become ever more accessible and affordable, it is inevitable that these will disrupt the current paradigm of studio courses in many design disciplines in a positive fashion. Continued experimentation and analysis of the use of video production in the classroom will leverage these ubiquitous technologies with increased sophistication and self-awareness.

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ASSESSING THE IMPACT OF CAD TOOLS ON ARCHITECTURAL DESIGN QUALITY

A Case Study of Graduation Projects in Jordan

RANA AL-MATARNEH AND IHSAN FETHI
Al- Ahliyya Amman University, Amman, Jordan
ggcc_1995@hotmail.com | ihsanfethi@hotmail.com

Abstract. The current concept of architectural design education in most schools of architecture in Jordan is a blend between manual pen drafting and digital approaches. However, the disconnection between these two methods has resulted in the students' failure to transfer skills learnt through traditional methods to the digital method of CAD. The objective of this study is twofold: to first compare students' attitudes toward using both methods and to then assess the impact of CAD use on the quality of architectural design. An open-ended questionnaire was designed to measure variables related to students' preferences toward CAD and traditional methods. The quality of sixty graduation projects at three Jordanian universities was investigated. The results appear to support the assumption that CAD tools are used largely as visual means and thereby cause a marked decline in design quality. These findings call for a reconsideration of the status quo and a rethinking of perhaps the entire architectural educational model.

Keywords: Design; architectural design; design methodology; CAD; IT impact on design; architectural education; architectural education in Jordan

1. Introduction

In the last few decades, revolutionary developments in the field of Information and Communication Technology (ICT) have significantly impacted everyday life. The internet, advanced illustration tools and Computer Aided Design (CAD) software are obvious examples of this digital revolution that has affected the very process of teaching architectural design and, in fact, has even transformed the architectural profession itself. Thus, the development of such digital tools over a relatively short time and their continuous advancement and refinement had, and continues to have, an inevitable major impact on many key pedagogical aspects of architectural education and curricula design.

A fundamental pillar of the contemporary theory of architectural design education is the approach of combining the traditional method of drafting with a drawing board and T-square with the new method of using digital tools in the design process. Most architectural schools developed and introduced computational courses into their curricula, which resulted in a dramatic shift in their educational context, i.e., from "traditional methods" to computational "new methods”, and other various shifts in architectural design media, design thinking and design theory. Although digital media has become an essential part of the design studio culture, this transition has not been clearly addressed because schools of architecture have had difficulty in appreciating the dramatic impact of this new technology on their existing and long-established educational infrastructure.

This paper presents a framework to assess the impact of CAD on the architectural design process and the quality of its product. The framework focuses on four major aspects of the architectural design process, namely, the generation of design solutions, communication, the evaluation of design solutions and decision-making. Furthermore, the following group of indicators was also investigated: architectural program; site analysis; conceptual design development; buildability; and design presentation. This assessment may reveal certain indicators that can help educators and practitioners to understand the impact of this rapid and radical transition on the architectural design process and thus help to redirect the future of architectural education into a more adaptive and qualitative system.

1.1. DEFINTION OF THE PROBLEM

The current concept of architectural design education is a blend of the traditional method of drafting on paper and the modern method of using CAD in the design process. This paper argues that the transition to the new digital media has been vague and largely ill-defined, which causes several serious pedagogical problems. The introduction of these new tools into design teaching has been combined with a dysfunctional relationship between the tools and the intended end tasks. Consequently, this dysfunction has resulted in a separation between architectural design and the context of the project, specifically its sense of scale and proportion, and has led to a marked decline in the spatial quality experience and a disproportionate dependence on illustrative techniques. The inappropriate use of the digital tools and the heavy reliance on them, the lack of integration among different digital tools and, more importantly, the absence of effective coordination between theoretical courses and design projects has resulted in a relatively poorer overall design quality.

1.2. AIM OF THE STUDY

The aim of this study is twofold. First, this study quantitatively compares students' preferences and attitudes toward the use of CAD tools and traditional methods and analyzes these attitudes. Second, this study assesses the potential impact of these digital tools on the quality and creativity of architectural design by examining graduation projects. The main objectives of this paper can be summarized as follows.

- What motivates the student to use CAD software in the design process?
- What is the importance of the role of CAD in an architectural curriculum?
- What impacts do CAD tools have on the overall quality of architectural design in all of its stages (conceptual, design development, presentation)?

1.3. METHODOLOGY OF THE STUDY

This study was designed to gather empirical data to assess the impact of CAD software programs on architectural design. The data collection methods that are used in this study included a paper-based questionnaire survey, interviews, and graduation projects.

This study was completed in two distinct stages. This study used a case-study approach to assemble the main data through the following.

(a) Qualitative in-depth interviews: The data and information used for evaluation were based on qualitative in-depth interviews that were conducted with a sample that comprised the following:

- 90 fifth-year architecture students, who have acquired and developed various design skills and practices and whose studio work incorporates traditional and new architectural design methods; and
- 60 educators from three universities in Jordan (Al-Ahliyya Amman University, Petra University, and Philadelphia University).

(b) Extensive survey questionnaire: The data that were used for assessment were based on an extensive survey questionnaire that was completed by the 90 fifth-year students and 60 educators in 3 different universities in Jordan.

The conducted interviews and questionnaire involved open ended-questions based on the collected qualitative data from the students, such as students' preferences and attitudes toward the use of CAD, the types of CAD software used by students, CAD learning methodology, proficiency level in CAD, the frequency of using CAD in different design phases, and the advantages of using CAD software.

(c) CAD impact matrix: Sixty graduation projects in the study area were examined through five suggested indicators to assess the architectural product quality (Table 1). The gathered data of graduation projects was important in providing evidence of the benefits that the respondents mentioned in the questionnaire survey and interview.

TABLE 1. *Matrix of main criteria assessed for the impact of CAD on the quality of architectural design of graduation projects. (scores 1 poor to 5 high).*

A. Architectural Program [15 points]	[1]	[2]	[3]	[4]	[5]
1. Analysis of the needs, values and main goals of the client, tentative cost analysis of the proposed project and its feasibility					
2. Provision of detailed inventories, required facilities, functional relationships of main components of the project.					
3. Compliance with local and/or international space standards and binding codes and regulations					
Total A					
B. Site Analysis [15 points]	[1]	[2]	[3]	[4]	[5]
1. Response to urban context, surroundings and accessibility					
2. Site layout, topography and overall landscape design					
3. Appropriateness of plot's shape, area and location					
4. Use of CAD to develop the overall site design					
Total B					
C. Architectural Concept [30 points]	[1]	[2]	[3]	[4]	[5]
1. Philosophical and intellectual basis adopted to explain the architectural concept to client					
2. Quality of conceptual development and evolution of main design theme					
3. Aesthetic and artistic considerations					
4. Regional/cultural/environmental considerations					
5. Appropriateness of adopted design approach to overall function and context					
6. Appropriate use of digital software in generating design?					
Total C					
D. Architectural Presentation [25 points]	[1]	[2]	[3]	[4]	[5]

1. Overall poster design theme and clarity					
2. Compliance to 2D minimum submission requirements (plans, elevations, sections, site plan, etc.)					
3. Compliance to 3D requirements (perspectives, 3D shots, interior, details, virtual models etc.)					
4. Physical modeling: Compliance to submit several study models showing design development at different stages					
5. Appropriate use of digital software?					
Total D					
E. Buildability [15 points]	[1]	[2]	[3]	[4]	[5]
1. Use of appropriate structural system(s)					
2. Submission of technical services & details					
3. Appropriate use of digital software?					
Total E	[1]	[2]	[3]	[4]	[5]
Total Score					

1.4. STUDY AREA

Table 2 shows the study area in the departments of architecture at three universities in Jordan, namely, Al-Ahliyya Amman, Petra, and Philadelphia, which were founded in 2009, 2010, and 2012, respectively.

Table 2. The CAD in architectural education stratified sample survey analyzed by universities numbers

University name	Year founded	Degrees offered	No. of students in	CAD type	Age of CAD employed at
Al-Ahliyya Amman	2009	B.Sc.	440	AutoCAD	4
				3-D MAX	4
				REVIT	2
				BIM	2
Petra	1991	B.Sc.	400	AutoCAD	7
				3-D MAX	7
				REVIT	2
				BIM	0
Philadelphia	2005	B.Sc.	350	AutoCAD	5
				3-D MAX	5
				REVIT	00
				BIM	0

2. Theoretical Framework

2.1. ARCHITECTURAL DESIGN

Architectural design is a complex process of creating a coherent structure or system that comprises many unified elements. During the past several years, many theoreticians and practitioners have attempted to define the word "design". Some of these attempts are the following:

"A goal-directed problem-solving activity", L.B. Archer;

"Decision-making, in the face of uncertainty, with high penalties for error", M. Asimov;

"A creative activity - it involves bringing into being something new and useful that has not existed previously", J.B. Reswick; and

"Design is a process of inventing physical things which display new physical order, organization, form, in response to function".

During the last two decades, architecture has been influenced by the increasing use of digital technology—both in the process and in the final outcome of design—to meet certain functional, cultural, aesthetic, environmental, and socio-economic needs. Thus, digital technology became the mediating factor between design theory and architectural theory. Accordingly, architectural design has become engaged in the exploration of complicated forms that depend heavily on the use of sophisticated "generative" computational programs. This transformation has begun to show a significant influence on architectural design theory, concepts and approaches. Much of the earlier basis for design methodology, such as the study of typological precedents and contextual setting, has now been replaced by emerging digital tools, such as generative modeling, animation and performance-based indicators.

2.2. ARCHITECTURAL EDUCATION

The advance of the ICT revolution with the accompanied digital technologies has changed the traditional context of architecture as a profession and in education.1 Students have increasing tendencies toward ICT and are becoming more skilled and involved in using various design media in their design processes, which, in turn, has affected the traditional design studio culture. Thus, this transformation should be considered, which requires us to rethink architectural design education.

A study prepared by Andia suggested that ICTs have been used for different purposes at different times. ICTs have been used in the profession over the past 25 years to enhance existing practices by facilitating the production of vast quantities of drawings with high accuracy and over less time. ICT has been used by schools of architecture to transform architectural imagination and architectural practical possibilities. Furthermore, Andia indicated that ICT has affected both practitioners and students in terms of their skills and the setting of educational and professional culture. 2 Simultaneously, combining traditional design approaches with digital technology is effectively improving architectural practice. Al-Qawasmi emphasized that digital media, as used in the e-studio, can bring important changes to the architectural design process but might have unintended restricting effects.

However, architectural schools are becoming a laboratory setting for various digital design media, and the architectural studio itself has become a space to examine the role of computers in architectural design (i.e., Schenk). In contrast, CAD software tools have had a negative impact in many ways. First, these tools have weakened, or sometimes totally replaced, physical design tools, such as manual sketching by pen on paper, which often provides the necessary direct physical link between the hand and the brain. Second, CAD software has provided an alluring, easy, and inexpensive alternative to physical architectural models and has replaced them with a set of seducing graphics that are usually designed to impress the audience.

According to Guney, the disadvantage of using CAD tools is to make the student addicted and design his/her projects without creativity.3 Salman et al. anticipated that the use of CAD tools by students came as early as the conceptual stage in the investigation of specific formal themes.4 However, many educators and practitioners have called for a combination of both physical and digital design methods rather than the use of either method separately. Breen indicated that the combination of both techniques gives the designer added insights and more “real” approaches to develop, reconsider and refine any design. Breen also emphasized that the combination of both techniques should be actively incorporated in the educational curriculum to prepare the students as they move toward practice.

2.3. THE STATE OF CAD EDUCATION IN ARCHITECTURE SCHOOLS IN JORDAN

CAD systems have been used in Jordan since the mid-1990s. Several engineering firms and contracting companies were interested in the potential of digital technologies as drafting and modeling tools. As an educational tool, CAD software was installed as an introductory course for undergraduate architectural programs in 1994,5 but there were only a few faculty members who could teach it then. Several years later, CAD courses became obligatory (i.e., CAD I, CAD II) over two semesters, typically for second-year students. Moreover, most Jordanian schools of architecture attempted to update their curricula through software and digital technologies to bridge the gaps between design theory and practice. Since 2014, however, some schools have begun to re-think the use of digital software as an analytical, generative and constructive tool. Consequently, software such as "Revit" and "Introduction to BIM" were installed in their curricula.

Generally, schools of architecture in Jordan combine the physical method with the digital method to ensure that students enjoy the benefits of both methods. Thus, most, if not all, schools of architecture prohibit the use of CAD tools in design for students in their first two years. Design teaching for first- and second-year studios emphasize the importance of developing manual graphic communication skills, sketching, and the experience of making physical models. However, the current curriculum of architectural design education in most schools suffers from a lack of synchronization and integration between computer courses and design projects. The prevalent tendency at present is to treat each course as a separate entity with its own distinct particularity, which prevents the necessary coordination between theoretical and design courses and applied computer courses. Moreover, although the structure of the curricula remains relatively flexible to manage new digital technologies, integrating these technologies with design courses is highly advisable and will ensure a more holistic and creative environment and not to use this software only as drafting tools.

3. Findings from the Analysis

An open-ended interview and an extensive survey questionnaire were conducted with 150 participants to record their responses to certain parameters. The questions were therefore structured in four phases that included the following:

- Part one: questions that determine the preference and attitude toward the use of CAD, such as the type of CAD software used by students, CAD learning methodology, proficiency level in CAD, and preference toward the use of CAD compared with traditional methods;
- Part two: questions on the advantages of using CAD software compared with traditional methods; and

- Part three: questions regarding the impact of CAD on the quality and creativity of the design compared with traditional methods.

The interview survey was designed to measure separate variables concerning the students' preferences toward the use of CAD in design. The survey was prepared and conducted from January to June 2016. The questionnaire comprised a number of questions with 3 different scores for each answer.

The students evaluated each of the standardized answers on a three-step scale from absolute acceptance to absolute negation (each of them had an assigned numeric value to calculate the sum for each answer). To compare the answers, each sum was divided by the number of times that a specific answer was chosen.

3.1. DATA PRESENTATIONS

Part one, Question 1: Sixty respondents were asked to describe their attitudes toward the importance of CAD compared with traditional methods. Figure 1 shows that the majority (85%) of the respondents had positive attitudes. However, 5% of the respondents were indifferent, and 10% had negative attitudes regarding the use of CAD.

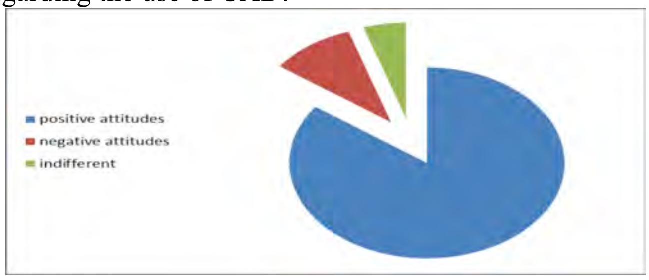

Figure 1. Respondents' preferences and attitudes toward the use of CAD.

Question 2: On the superiority of using CAD over the traditional method of sketching, 80% of the students preferred to use CAD media over traditional methods, whereas traditional-method users accounted for only 5% of the total (Figure 2). A great interest in CAD was noted among all respondents. There seems to be a strong trend for architectural students to convert from traditional methods to CAD. The dramatic increase of CAD users suggests that there should be a serious reconsideration of the current curriculum to adapt to the new CAD trends.

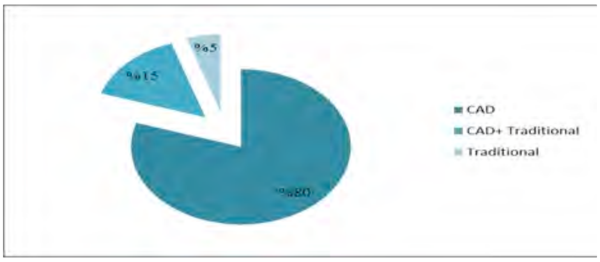

Figure 2. Responses to questions pertaining to preference toward the use of CAD versus traditional method tools.

Question 3: Type of CAD software used by students: The respondents were asked to identify the type of CAD software used in their graduation design project. Among the 60 respondents, 52 used AutoCAD, 3D-MAX and Photoshop, which are the most widely used software in education. However, the results revealed that the highest response rate was reported in Revit (7%), followed by Google Sketch-up (4.5%), Archi-CAD (4.5%), Grasshopper (2.1%), Maya (1.1%), and Vasari (1%) (Figure 3). None of the respondents used Heliotrope. Nevertheless, students employ various CAD software to produce the best graphical representations with minimum cost, maximum functionality, and the highest quality.

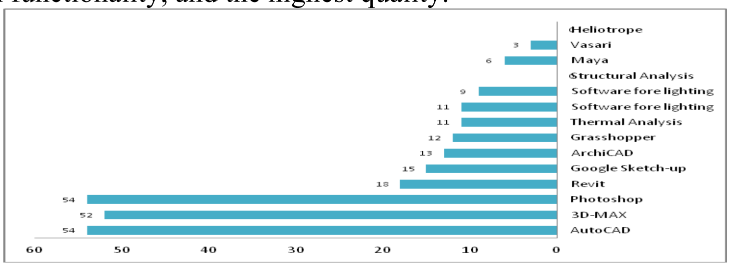

Figure 3. Type of CAD software used by students.

Question 4: The students were asked to evaluate their proficiency level with CAD applications. Figure 4 indicates that 90% of the respondents had high proficiency in AutoCAD, 85% had high proficiency in Photoshop, and 70% had moderate proficiency in 3-D MAX. In total, 40% and 35% of the respondents reported proficiency in Revit and Sketch-up, respectively. Moreover, 10% of the respondents used ArchiCAD, and 10% used Grasshopper. In contrast, regarding the use and performance of CAD environmental software, the results revealed that a very low response rate was reported for Heliotrope (0%), Vasari (1%) and software for lighting (3%) (Figure 4). This result can be explained by the lack of competent tutors in different CAD areas.

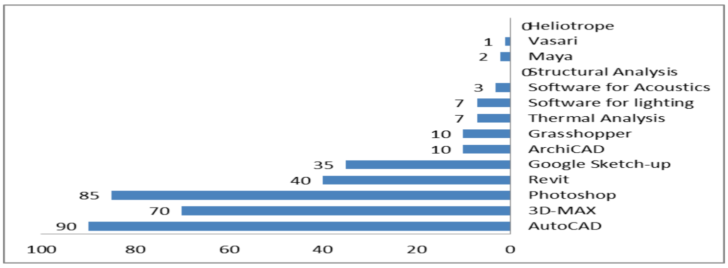

Figure 4. Proficiency level in CAD software application.

Question 5: CAD learning methodology by students: The respondents were asked to describe how they gained CAD proficiency based on the parameters of departmental courses, self-learning, and private classes. As shown in Figure 5, 30% of the respondents stated that they gained proficiency in CAD by self-learning first, and 25% gained their CAD proficiency through departmental courses. This result confirms the finding when students were asked about their preferences toward CAD. As shown in Figure 5, the majority (85%) of the respondents had positive attitudes concerning the use of CAD, which explains the percentage of the respondents who were interested (55%) in learning CAD either by themselves or in the department. The least number of respondents (15%) learned CAD through private classes.

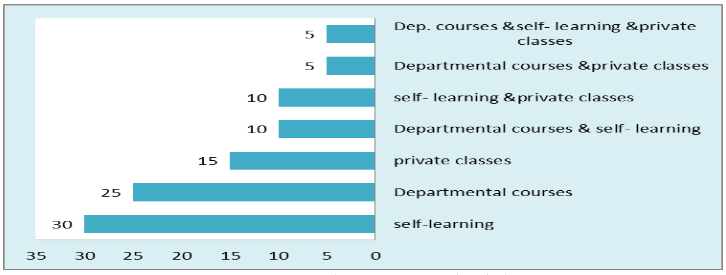

Figure 5. CAD learning methodology.

Question 6: The students were asked to specify the design method that was used in each stage/stages of the design process. Interestingly, both design methods were employed in all design stages. However, Figure 6 shows that traditional methods were used the most (80%) at the initial or conceptual stage and were utilized much less in the schematic design stage (30%). CAD was used as a design method mostly in design development, construction drawing, and the detailing and specification phases at 55%, 80% and 90%, respectively. Few respondents may use CAD in the conceptual stage because CAD has not replaced the traditional method of manually sketching designs. Instead, CAD acts as an extension of manual methods with a vast potential to advance various design ideals that previously were impossible to develop with traditional methods.

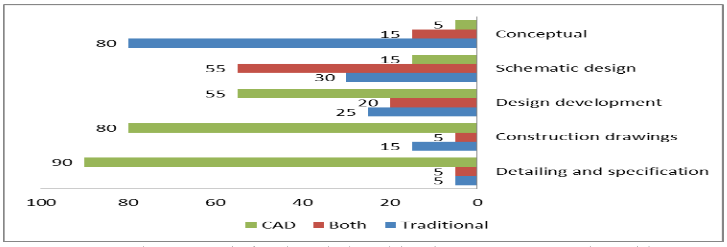

Figure 6. Responses to how much freehand sketching/CAD were employed in executing their designs' different stages.

3.1.1. Part Two: Questions about the Advantages of Using CAD Software

As shown in Figure 7, 90% of the respondents preferred to use CAD for its various advantages, such as accuracy, neatness, speed and lower cost. Interestingly, 70-90% of the students stated that using the combination of CAD with traditional methods typically helps them to visualize the end product better than using the CAD method alone.

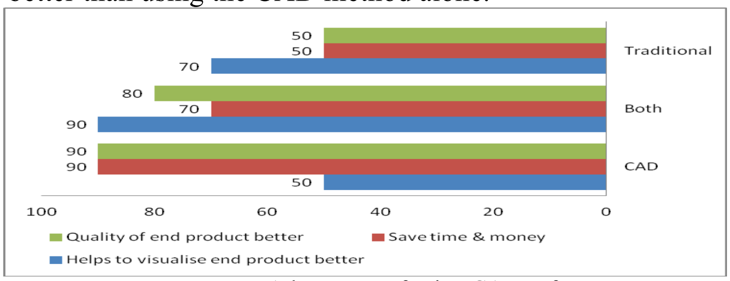

Figure 7. Advantages of using CAD software.

3.1.2. Part Three: Questions about the Quality of the End Product by Using CAD Compared with Traditional Methods

Figure 8 clarifies that the majority (90%) of the respondents considered the quality of the projects that used CAD to be higher than the quality of the projects that used traditional methods. However, 5% of the respondents are indifferent, and another 5% considered the design that is generated by CAD to be of lesser quality than the design that is generated by traditional drafting.

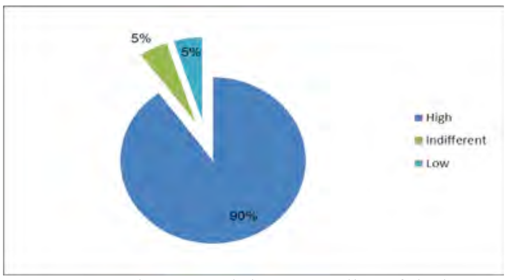

Figure 8. Responses to questions pertaining to quality of designs created with CAD.

3.1.3. The Role of CAD Courses Across the Curriculum of Architecture Schools

The respondents were asked to identify the importance of CAD in the architectural curriculum across the different knowledge areas. As shown in Figure 9, the results indicated that CAD has an important role in three central areas in the architectural curriculum, namely, design, urban design, and building technology, according to 90%, 85%, and 80% of the respondents, respectively. However, CAD has a weak role in other areas, such as theoretical courses (45%), engineering systems (35%), and project management (25%).

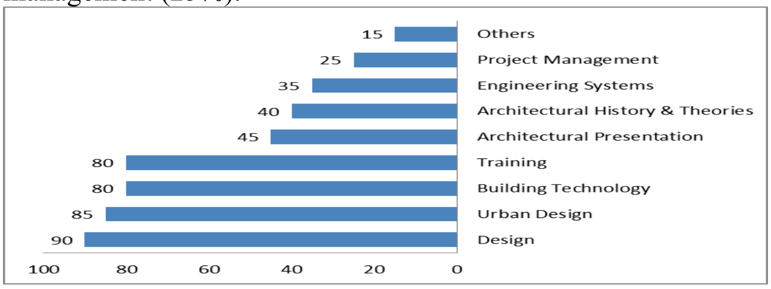

Figure 9. The role of CAD course across the curriculum of architecture schools.

3.2. GRADUATION PROJECT ANALYSES

3.2.1. Assessment Criteria

Five essential criteria were chosen to assess the quality of the graduation projects with differing score weights that totaled 100. These criteria were architectural program (15 points), site analysis (15 points), architectural concept (30 points), presentation and illustration (25 points), and buildability (15 points). The criteria are basically self-explanatory, but the architectural concept criterion needs some elaboration. Here, architectural concept was subdivided into 6 main considerations. First (1), a philosophical and intellectual basis is adopted to explain the concept and conceptual development and shows how the student arrived at his/her final solution and whether any design reference or precedent was adopted. Second (2), aesthetic and creative considerations refer to the overall formal, spatial and sculptural aspects of the project, including proposed materials, colors, patterns and textures. Third (3), regional and cultural factors refer to how the student responded to the sense of place and whether cultural influences such as local and/or regional architectural heritage had any role in the overall design or architectural trend that was adopted. Fourth (4), environmental considerations include the student's response to the question of sustainability, energy consumption, climatic factors, such as orientation and solar shading devices, etc. Fifth (5), the appropriateness of the adopted trend refers to what degree the design approach has succeeded in being relevant and workable with the overall function of the project. The final (6) consideration is the degree of use of the CAD tools, including generative design software, to develop the final solution.

A. Architectural Program is the thorough and systemic evaluation of the interrelated values, goals, facts, and needs of users and the surrounding community. A well-conceived program leads to a high quality design. As shown in Table 3, the projects were assessed for their adherence to standards and codes, and the functional relationships of the main components.

Table 3. Architectural program assessment criteria

Criteria [15 points]	Low [1]	Below Average [2]	Average [3]	Above Average [4]	High [5]
Analysis of the needs, values and main goals of the project, and tentative cost estimate of the project					
Provision of detailed inventories, required facilities, functional relationships of main components of the project.					
Compliance with local and/or international space standards, codes and regulations.					

As shown in Figure 10, the majority (55%) of the graduation projects demonstrated that their designers were unaware of the projects' needs, values, main goals and tentative cost estimate. However, the designers of 30% of the examined projects were somewhat aware of these issues, and only 10% of the projects had a very clear architectural program with defined needs and values. Overall, 25-55% of the projects had problems with the functional relationships of the main components of the project. Finally, 60% of the projects' designs did not adhere to local or international standards, and the designers of only 15% of the projects actually considered the standards.

Site Analysis

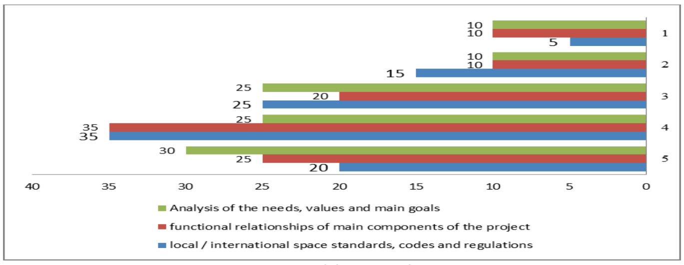

Figure 10. Architectural program.

Table 4. Site analysis assessment criteria

criteria [15 points]	Low [1]	Below Average	Average [3]	Above Average	High [5]
Response to urban context, surroundings and					
Site layout, topography and overall landscape					
Use of CAD to develop the overall site design					

A very interesting finding here was the absence of the use of CAD or any other digital software in analyzing the site. Figure 11 indicates that only 5% of the graduation projects had used digital applications in analyzing or planning the site. This result accords with the findings in part 2, question 2, regarding the types of CAD software. Because most respondents had a good command of traditional AutoCAD, the absence of specialized software to analyze or plan the site obviously caused the wrong design decisions. In all, 40-80% of the examined projects had no or low responses to the urban context, surroundings and accessibility. Furthermore, 80% of the projects in the study area did not have a proper plot in terms of shape, area and topography.

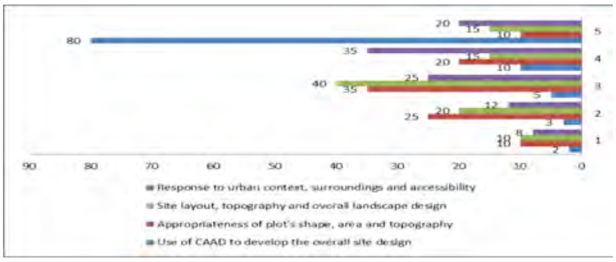

Figure 11. Site analysis.

C. Architectural Concept

Architectural concept is a representation of the designer thoughts of functional ideas that would become the adopted solution for the architectural design problem.i Architectural concept can be expressed through drawings, texts and verbal expressions. Table 5 shows the five essential criteria that were chosen to assess the impact of using CAD on architectural concept.

Table 5. Architectural concept assessment criteria

Criteria [30 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
1. Philosophical and intellectual basis					
2. Aesthetic considerations					
3.Regional/cultural/environmental considerations					
4. Appropriateness of adopted approach to overall function and context					
5. Appropriate use of digital software					
6. Appropriate use of digital software in generating design?					

As shown in Figure 12, the majority of the students showed a tendency to use CAD even at the conceptual stage for drafting or site planning. Meanwhile, only 5% of the projects showed a tendency to use "generative" software to investigate a specific conceptual theme and its formal potential, such as Grasshopper, Maya, and Vasari. The interviews also revealed that because generative design software is not taught at the 3 schools, few students used this software by learning it on their own. Consequently, the projects were largely developed by using CAD for drafting and illustrative goals and lacked the necessary basis to comply with the required criteria to generate rational and creative designs, with little or no attention paid to regional, cultural and environmental or artistic considerations.

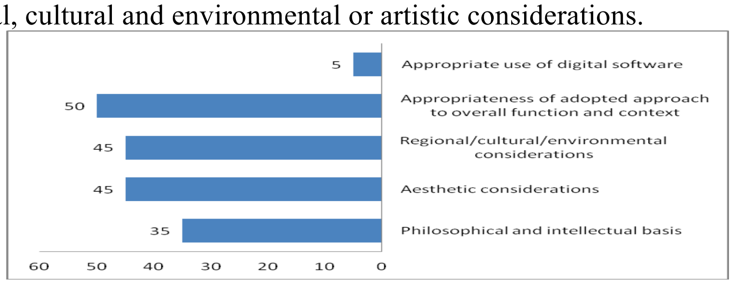

Figure 12. Architectural concept.

Architectural Presentation

Table 6. Architectural presentation assessment criteria.

Criteria [25 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
Overall poster design theme					
Adherence to 2D requirements (plans, elevations, sections, site plan, etc.)					
Adherence to 3D requirements (perspectives, 3D shots, interior, details, virtual models)					
Physical modeling: Adherence to present several sketch models showing design development					
Appropriate use of digital software?					

As shown in Figure 13, the majority (90%) of the analyzed graduation projects were mainly concentrated on the poster design theme. Regarding "3D presentation", a higher use was reported; 85% reported that they used it in their graduation projects, whereas only 35% responded that they employed the traditional methods of physical modelling in their projects. Furthermore, the 3D presentations were delivered as seductive conceptual images that were incompatible with the 2D drawings and in some cases, with the physical models. This result means that the students are concentrating on images rather than on content, which leads to irrational and unrealistic projects. This result confirms our findings from the questionnaire survey, part 3, where most respondents indicated that CAD would guarantee a higher quality project. Certainly, there is no integration between CAD and other courses in the curricula.

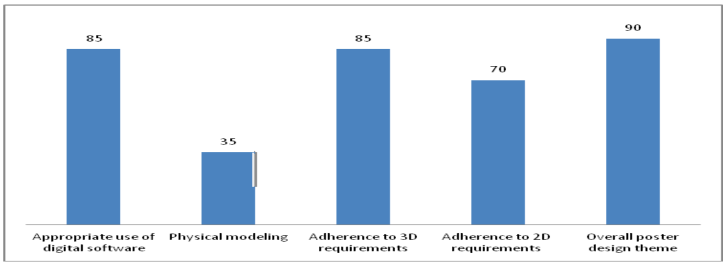

Figure 13. A sample of architectural graduation projects from three different Jordanian universities, 2012-2016.

Buildability

Buildability refers to the feasibility of realizing the proposed design and includes how the designer intends to integrate all the architectural and engineering elements into a wholesome building that has a proper structure, internal technical services and external skin (see Table 7).

Table 7. Buildability assessment criteria.

Buildability [15 points]	Low [1]	Below Avg [2]	Avg [3]	Above Avg [4]	High [5]
Use of appropriate structural system					
Submission of technical services & details (structural, electrical, mechanical, etc.)					
Appropriate use of digital software					

The survey revealed that no digital software was used to achieve a certain level of buildability (see Figure 14). The overwhelming majority of graduation projects lacked the necessary information regarding the structural and constructional aspects of the proposed design and mostly had a graphic nature with no meaningful impact on the architectural concept.

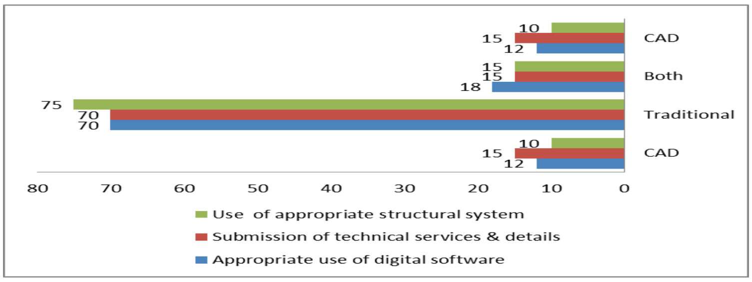

Figure 14. Buildability assessment criteria.

3.2.2. Main Criteria Used in the Assessment of the Impact of CAD on the Quality of the Architectural Design of Graduation Projects at Three Universities

As shown in Figure 15, the evaluation of 60 graduation projects from three architectural schools in Jordan according to criteria of program, site analysis, concept, presentation and realization revealed relatively similar results for the three schools. As expected, the architectural presentation criteria consistently scored the highest, ranging from 75 to 61.3, and the site analysis and concept criteria presented the next highest scores, ranging from 67.7 to 59.1 and from 59 to 55.1 respectively. However, the architectural program and buildability criteria had the lowest scores, in the ranges of 59.7 to 48 and 32 to 30.5 respectively. These disappointing results reinforce the notion that the overall quality of design has declined significantly due to the misuse of digital visual tools.

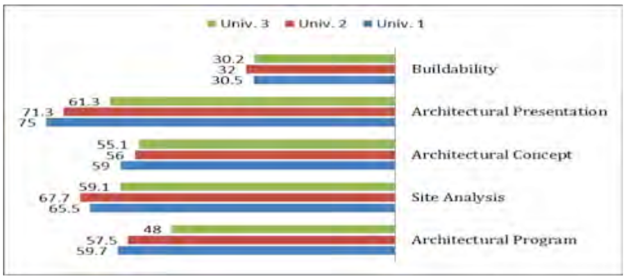

Figure 15. Criteria used in the assessment of the impact of CAD on the architectural design quality of graduation projects at three universities.

4. Discussion and Conclusions

This paper assessed the impact of CAD tools on the design process and on the quality of the architectural end product at three schools of architecture in Jordan. The findings revealed that all three schools have the same design educational approach that mixes traditional design methods with digital methods.

Although the students were found to have a strong tendency to employ new technologies, such as CAD software, in their design process, CAD is still being utilized for drafting and virtual modelling rather than as a problem-solving strategy. Moreover, the transformation of students' design trends from traditional methods to CAD is still not clearly defined; thus, students are unable to transfer the skills that are learned through traditional methods to the more complicated CAD method. Therefore, this shift in students' preferences toward CAD systems has resulted in a dramatic change in the study context together with other various shifts in design media, design thinking and design theory. The relationships among architectural design thinking, representation and media should be continual such that media provides the means for engaging in design thinking and progressing through various representational media. Moreover, digital media should be utilized as an essential part of the new design studio culture that integrates with other design methods and other courses in the architectural education curriculum. Thus, we must rethink and reconsider the potential of computers and communication technology to orient the entire institutional infrastructure and pattern of behavior for better architectural education and practice. There is also a crucial need to review the national accreditation criteria for architectural education to make them more adaptable to these emerging and ever-changing digital technologies.

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GO WITH THE FLOW

Tutorials to support architectural education

ROSA M. MENDOZA ROBLES, FERNANDO SALDAÑA CORDOBA
Universidad de Sonora
Rosa.mendoza@unison.mx | fsaldana@arq.uson.mx

AND

MARIO Y. RENDON SALLARD
Yadir42@hotmail.com

Abstract. The project described here aims to exploit use of information and communications technology, presenting to the undergrad student of Architecture a library of self-study through video tutorials that support the academic content they are coursing, with the aim to improve their learning and obtain their grades. The first phase of this research in progress develops and measures use of the library, and records the quality of work in search of impact on efficiency and development of the students.

1. Introduction

The widespread growing and acceptance of Information and Communication Technologies (ICT) among students of all levels is undeniable; today, the variety of broadcasting technology from smartphones, tablets, personal computers, TV, to all kind of electronic media, compete restless for the attention of young people. Conversely, the reading of books and printed material does not show nearly the same acceptance, on literate behavior Mexico ranked thirty-eight on a study of 61 countries (Miller and McKenna, 2016) which in higher education translates to a problem of students highly limiting their learning resources.

This paper addresses alternative ways of learning, complementing traditional forms as classrooms and books. The project works with ICT, and appeals to its popularity (West and Chew, 2014). The student is presented with a viable and realistic alternative for self-study through a website and a video channel of tutorials to support their academic agenda at the architecture program of the Universidad de Sonora (Mexico). This is a project in progress, the first set published covers monochromatic graphic expression, and we pretend eventually house every knowledge area of the program.

Different studies carried to assess the utility of video tutorials in architectural education have shown that the use of video has a positive impact on learning by providing flexibility and encouraging students to become more active learners (Comiskey and McCartan, 2011, Leijen et al., 2009, Paliokas, 2009). Additionally the use of video tutorials has been studied extensively in teaching methodologies such as the Flipped Classroom. These studies have documented the learning benefits of video tutorials and the fact that students prefer them to other types of support materials, but also they have identified some of the pitfalls, including the difficulty of finding good quality videos and the need to have videos tailored specifically to the class in question (Herreid and Schiller, 2013). Despite the fact that technology is ubiquitous at current students' environment, one could assume that the benefits of using technology-based resources such as video-tutorials is a given, however, Lohnes and Kinzer observe that all students are different, and point out the need for mixed-method studies to assess the influence of technology on student education (Lohnes and Kinzer, 2007). Comeskey and McCartan comment, as a downside, the high amount of time consumed on preparing recording, editing and producing all the materials, downside that we faced as well, on doing all the processes and learning to get them in a more efficient manner.

On official policies of education and the use technology, some countries establish clear policies on the use of technology, for example the Higher Education Funding Council for England justifies its use under expected benefits of technology enhanced learning (HEFCE, 2009):

- Efficiency (existing processes carried out in a more cost-effective, time-effective, sustainable or scalable manner)
- Enhancement (improving existing processes and the outcomes)
- Transformation (radical, positive change in existing processes or introducing new processes).

In other countries, like Mexico, the struggle to provide Internet to public schools of every level remains in the present (SEP, 2014). Video tutorials are used to some extent on remote learning for elementary and middle level education at distant areas of the country; with some sporadic programs to provide electronic tablets to all students coursing 5th and 6th grade of elementary education (Notimex, 2014). The work in progress presented in here is developed to support the Architecture degree students at Universidad de Sonora, however we expect a wider impact since the access to the online video tutorials will not have firewalls. Goals of the project include: a) Encourage self-study by presenting attractive alternatives of e-learning, b) Promote a better understanding of in-classroom classes, c) Rise the grades of students by a better support, and d) Reduce the dropping of studies. Our research focus on working out the better ways to produce such video tutorials while measuring their effectiveness on its application, and the ways to measure all the previous on assets in terms of quantity and quality.

Methodological Procedures

Language is an important issue that also drives this project, being based at a Spanish speaking country, public universities accept students with a low English level. At the Universidad of Sonora, English proficiency is evaluated through the admission process, and average students rank the basic score of Toefl test –this score varies some degree from year to year, and from school to school but maintains on lower levels– consequently we had to develop new options in our mother tongue.

The initial research examined about 200 links of video tutorials on both languages, English and Spanish, finding that most good quality material is produced in English, for architecture education very few resources in Spanish were identified: MOOC, and *Profesor de Dibujo* and Luis Tutorials (Avada, 2015, PDD, 2014, Tejeda, 2010). Note that the project does not attempt to promote learning of other languages, nor promotes the reading of printed material: it is designed for students with low level of English, and little love for books, it does attempt to counteract the shortage of tutorials in Spanish, while supports the Program of Architecture regular classes' content.

We faced two main questions, how tutorials will enhance learning? And, how we can measure it? The first question was solved by the didactics, which we established through three main directives: a) Description of means, b) Explanation of technic, and c) exercises applying the technique in architectural items. For the measure of success on learning, we have several means, a) the spread of visualization can be observed through the analytics that the video´s host provides, b) in every video is available a survey to be replied for the students doing the tutorials, c) five years from now we will have people finishing their degrees with this tool available, and we will be able to survey the quality levels of their degree dissertations and compare them to pervious years, d) and also with focus groups we will measure the influence of the tutorials on their work, in order to separate from multiple variables that can influence the student life.

The production of the tutorials was time consuming in all stages of recording audio and video, editing, post-producing and publishing the videos, nearly 3 years of work, aided by students on social service, and mainly with scarcely economic support.

Evaluation

The first three finished tutorials were tested by two focus groups, which responded a survey after doing the tutorials. The survey included questions about the frequency of using tutorials, quality of the instruction, quality of video and duration of the tutorial. Focal Group A (FG-A) consisted of 8 participants: 6 students of middle and advanced level, and 2 newly graduates. Their results were of good quality, but not having a reference on their previous work, showed us that we had to request a previous drawing before watching the tutorials, as we did with Focal Group B (FG-B). FG-B was composed of 13 participants: eleven students of architecture first semester, one of fifth semester and a student basic level of Graphic Design. Some examples are on Table 1, were the improvement of the sketching can be seen.

Before watching tutorial	Tutorial	After tutorial

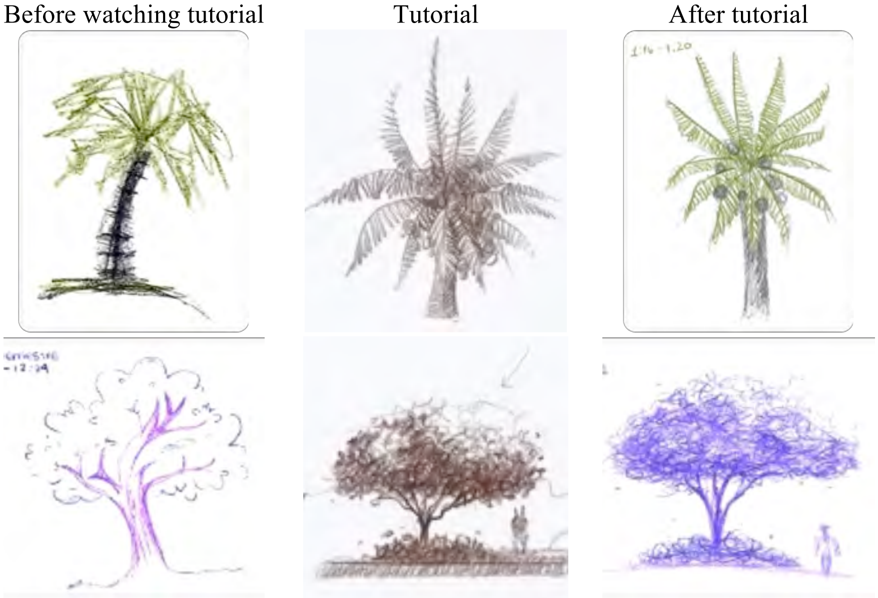

TABLE 1. Results of FG-B.

After complete the tutorial they responded a survey online: The level of detail of the tutorials was considered very to extremely detailed, by 61.9% of respondents; length of the video was considered acceptable by 85.7% of respondents, only 14.3% considered that the duration was short. Regarding the clarity of the instructor 81% felt that he was clear to extremely clear. Within the quality of images and video, also the majority of respondents (76.2%) thought that the video was clear enough.

There was an observation on some spaces without sound in the video, which caused concern to the student because he could not identify whether it was failing the sound of the tutorial or not. To avoid this soft background music has been included.

Conclusion

Today, the site − http://www.dad.uson.mx/tutoriales − includes thirty-four videos about manual graphic expression. The average duration of the videos is five minutes. The next batch to publish will include digital technics. In middle and long term, we plan to extend the video tutorials to other areas of knowledge like design, theory, building and sustainability enable the student "to learn how they want, when they want, and at a pace that suits their needs."(Wells et al., 2012)

Wider impact of this tutorials will be able to be measured from 3 years from now, when students accessing the site will finish their studies with the analysis of their grade dissertations and surveys at the end of studies.

From our title "Go With the Flow: Tutorials to Support Architectural Education" we assimilate architectural education to a river flow, following a path that has been built by years of water erosion on the land, a flow that most times is predictable and has a clear route to the sea of built environment. The water that feed the river is full of students, which in accordance to their time navigate gladly among social networks and Internet. This river, as many on Earth, has different passages and some times it diverts and splits in two o more flows, for later on joining again in a single flow in order to disembogue at the sea, the sea of their grade of Architects. The video tutorial website is a canal on that river, built with a purpose, provide alternatives of study. Lets construct canals where the students can navigate and supply their ships of knowledge and practice, to return to the main flow again with reinforced creativity and a sincere interest to look beyond the established cannons.

Acknowledgements

This project would not be possible without the support of Universidad de Sonora, and to El Atelier, Taller de Arquitectura y Diseño. We also recognize and thank all the students who helped to produce the library: Alan Galindo, Misael Landon, Misael Rivera, Thania Moncayo and Gabriela Grijalva; also we thank all the students who accepted take part on the trials and focus groups.

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TEACHING PARAMETRIC DESIGN IN ARCHITECTURE

A Case Study

SAMER R. WANNAN
Birzeit University, Ramallah, Palestine.
samer.wannan@gmail.com | *swannan@birzeit.edu*

Abstract. The increasing technological advancements nowadays make the integration of digital tools and techniques in architecture pedagogy a must. A course in the department of architecture at Birzeit University in Palestine was proposed as a summer course in order to introduce students to the possibilities of using digital parametric tools and techniques in architecture design and manufacturing. In reflection of the experiment of the course, in which students were asked to design and construct a temporary pavilion, the paper will examine the potentials and challenges of using parametric digital tools in architecture design, and the way students imagine and conceive the performance of their design ideas virtually and practically. Furthermore, the project proposes that form is not constrained to the form-making process, but form must be a response to a material system and its properties, and thus material should be engaged in the design process. Initial design ideas are explored by building a parametric 3D digital model using a visual scripting platform. This virtual model allows for the evaluation of the performance of the design and the assembly method before realization and, moreover, experiments with design alternatives and forms. The final full-detailed digital model will be used in the fabrication phase to construct a one-to-one scale physical model in the real world, which gives students the chance to get sense and interact with the implemented environment and to experience their designs in real world.

Keywords: Parametric Design, Material systems, Architecture Education.

1. Introduction

How do technological advancements and tools affect the practice of architecture? We have been witnessing a paradigm shift in the role of architect recently; the technological developments that have offered the digital methods and techniques of fabrication in architecture brought the architect much closer to the making processes.

In other words, architects cannot leave their drawings to someone else to think about the details of fabrication (making the joints for example) of the forms they propose (especially complex ones), but they are also asked to think about how such forms and shapes will be fabricated. This means that architects have to be part of all design stages; not only do they take part in the conceptual design stage, but they also have to be part of building the project up by proposing ways of fabricating it. (Hassan, 2016)

The increasing need to understand the implications of designs, which include thinking of their construction and fabrication, is key in contemporary practice. Hence, it is crucial to include and embrace this way of thinking in architecture pedagogy and to be part of architecture design studios.

As an attempt to think of digital tools and techniques as part of the architectural education, a course was proposed in the department of architecture at Birzeit University in Palestine for the first time as an initiative to introduce students to the innovative processes using such tools and techniques in architecture design and fabrication processes. Parametric modeling and digital fabrication methodologies have been adopted in this course. Through the course, students have been working on designing a temporary pavilion and investigating the material systems that affect the method of construction and fabrication.

In the first stage of the course, students are challenged to produce a fully detailed virtual 3D model using software such as Rhinoceros and Grasshopper as a starting point, to finally build it up in a one-to-one scale physical model. Such working approach enables students to test and explore their design ideas before implementation. Using such innovative tools will bring a new level of thinking when students master them, which could help students create designs which would have been unimaginable before and thus enhancing creativity.

2. Literature Review

Two main topics were explored in the course: parametric design techniques and digital fabrication methods.

2.1. PARAMETRIC DESIGN TECHNIQUES

'A particular "style" is embedded in the digital code and graphical interface used.' The term 'Parametricism' was coined by Patrick Schumacher, a partner in Zaha Hadid Architects, as the name of a putative new movement in architecture in which architects can create complex forms using computer tools through the description of a design problem using variables.(Weston, 2011)

But what does it mean to think in a parametric way? And how does thinking within a 3D environment help architects in their design process? The basic principle of parametric modeling is to "develop a *generic description* of an object or class of objects, in which the shape is controlled by the values of a set of design variables or parameters" (Ugail, 1999). So, to create a parametric model includes creating a schema, which shows the relationship between the geometry of the design and its mathematical logic.

An increasing number of architects are now using parametric tools and techniques that allow them to define the relationships between various parameters in their designs, and change them in an iterative manner. This has produced an architecture of previously unimagined forms (Weston, 2011).

Many architects such as Zaha Hadid and Norman Foster, among others, use parametric design software to convert their forms into a dynamic parametric models to control the detailed building geometry. Consequently, architects and architectural firms find themselves in need to employ persons with a range of skills to master the new techniques as part of their design teams.

Grasshopper -a plugin for Rhinoceros software- was used in the course as a parametric modelling tool to create virtual simulations of students' concepts. The plugin is mainly an algorithmic modelling tool for Rhinoceros which provides a visual scripting interface, allowing users to build their 3D models without a prior knowledge of complex programming languages or scripting experience. It is worth mentioning that Grasshopper should be treated as a tool in the design process; it can be an extension of the process, which enables architects to create innovative new possibilities and to test a variety of new ideas in a quick and easy way.

2.2. DIGITAL FABRICATION

With the increasing cost of crafting and the decreasing number of skilled people who have the ability to craft, Digital technologies and fabrication methods allow for re-invention of crafting through a new 'digital lens' (Sheil and sixteen makers, 2011). Digital fabrication allows for the creation of complex crafted objects that were no longer possible.

Furthermore, digital technologies allow architects to explore new architectural possibilities with current materials through engaging with material systems. There are many ongoing initiatives that promote and facilitate the use of digital fabrication techniques for design communities and the public as well. This in turn makes the interest in these methods quickly becoming widespread and networked.

For this course, students used laser-cutting machine as one of the digital fabrication tools to cut the pieces and components in order to be assembled later. Students can use the laser cutter not just for cutting, but also to etch onto a material, which would be useful for labelling.

3. Problem and Methodology

The adoption of digital design methods in the realm of architecture is often interrogated superficially; merely used as tools for form finding with the lack of any depth or inherent meaning.

The main goal of the proposed course is to challenge the current paradigms of digital methodologies by looking at architectural design through a new 'digital lens'. This digital lens can engender a new design process by bridging the gap between the virtual and the physical environments. A process that looks critically at material engagement within the digital processes. The Nordpark Cable Railway project, by Zaha Hadid Architects, is considered as an example that represents a disconnection between form finding and material construction, which is clear in the adopted approach of cladding.

In this course, the project was conceived to test how parametric modelling tools could be employed, not for form generation, but also as a way to think of engineering and constructional detailing. Material engagement can be facilitated by following this methodology:

1. Encoding a computational geometrical and functional representation of the design virtually, Grasshopper can be used to create an associative parametric definition to build a virtual prototype.
2. Thinking of the fabrication method as part of the design. For physical prototyping, students were asked to explore and test a range of digital fabrication techniques for model making. This can help them to understand the correlation between the virtual and physical environments.

4. The Investigation

Students have been challenged by the course's assignment to design a temporary pavilion and then fabricating it. This pavilion is seen as a test bed of form generation that works hand in hand with material practices which allows for experimentation of concepts, methods, forms, materials... etc.

Site selection and thinking of the pavilion design in relation to its surrounding context was part of the assignment. Students were asked to select a site within the boundaries of the university campus in order to involve students in the current master planning process in which the department of architecture is part of. So, they need to think of the notion of public and design gathering spaces that can function as seating areas or platform for lectures.

To do so, four groups have been assigned to work on their pavilion prototypes. Students were asked to keep the following framework in mind in their designing process and to keep it integrated together; this is to make sure that the development of their projects goes through a rigorous approach to material properties and digital fabrication methods:

-The understanding of the selected material systems and the interrelation with the parametric design process to create new possibilities.

- An understanding of the methods of digital fabrication associated with the selected material and how these methods affect the assembly of the chosen design.

The following phases characterize the experiment undertaken:

4.1. **PHASE A.** PARAMETRIC DESIGN

In the first phase, students were assigned into four groups, four students in each group, in order to produce 4 concept models at the end of this part through using the digital parametric design techniques.

First, they were asked to choose a material system to work with and explore. The reason behind choosing a material is to explore how the material properties can determine design. Then, students have to explore the selected material system in more detail through engaging with its properties. This was in help for students to apply an appropriate geometry and fabrication method in a parametric form, which corresponds to the selected material.

Structurally speaking, and since the pavilion is temporary, students need to think carefully about the methods of construction that they choose which best suited the selected materials. The way the pavilion touches the ground also needs to be considered.

Figures (1-2) show two concept models that proposed at the end of this phase (of scale 1:10). The proposed systems create an integrated form of geometry and structure. Each group worked on a method of fabrication, which is appropriate for the chosen material. The digital fabrication methods that students worked on include: sectioning, contouring, triangulation and waffle structuring.

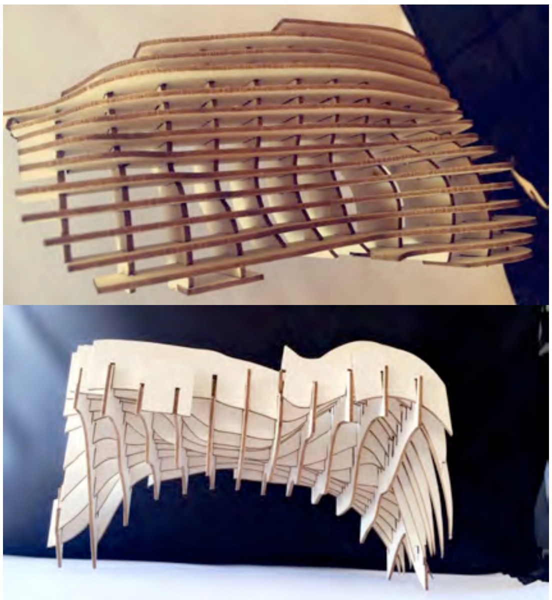

Figure 1. 1st group prototype using the system of waffle structuring

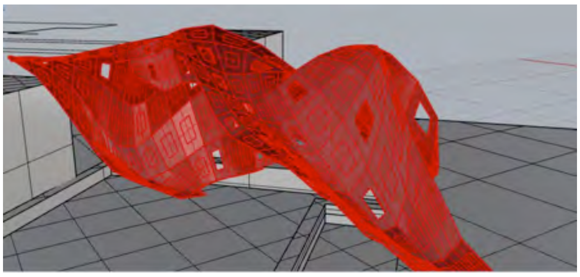

Figure 2. 2nd group prototype using panelizing system for fabrication

An evaluation session was held in order to select one concept pavilion to be developed and implemented by all the students in the next phase. The methodology mentioned above was the main criteria for the selection in addition to the practicality and stability of the proposed pavilion. Figure.1 shows the selected prototype that intended to be fabricated by the end of the summer course through applying the waffle structure system.

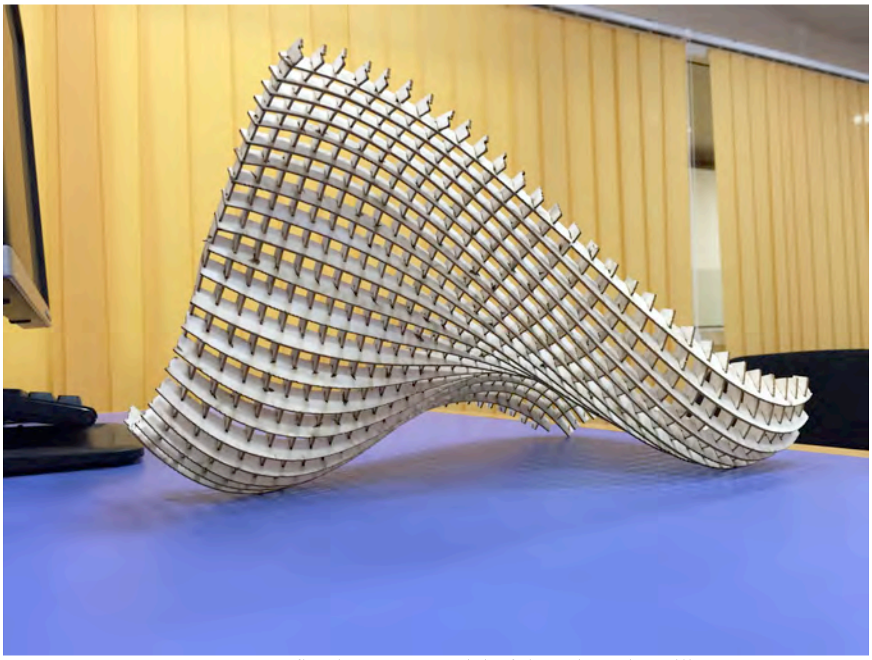

Figure 3. A refined concept model of the selected pavilion.

4.2. **PHASE B.** PAVILION FABRICATION

The second phase of the course is concerned with the further development of the selected pavilion that is designed in the first one. This was achieved through the engagement with architectural detailing of the pavilion and the method of digital fabrication.

In addition, students investigated the designed pavilion in terms of its joints and connection details, material dimensions and thickness and how its structural stability can be achieved through the careful development of the cross-sectional ribs in order to afford easy assembly and rigidity.

For the adopted pavilion, students worked initially in the development of the pavilion design digitally in relation to the maximum size of plywood sheets able to fit on the laser cutting bed with dimensions of 70*100 cm. Material thickness and its relation to joint and slots details (including the ribs intersection) were further investigated.

At the end of this course, students were able to make a physical interaction with the implemented pavilion. They enjoyed seeing the things they proposed in the first prototype are constructed in a one-to-one scale physical model; the combination of working with the digital model and the possibility of cutting it and assembling its parts together.

Figure 5. Assembly phase.

Figure 6. Final constructed pavilion

5. Discussion

Thinking parametrically has been very helpful in this course as expressed by students; they found this way of thinking is so compatible with the nature of architecture design process; a process which is very iterative or cyclic with constant modification in design.

It was a unique experience to work with students throughout the course using the approach of parametric design, this approach helped to develop the level of their analytical thinking which informs the use of parametric design tools; the engagement with the material systems and properties.

While students were working in their designs digitally, many constrains have emerged including material dimensions and their characteristics. Many of the materials used in the production of architecture are from a sheet format; this means that students had to think of their proposed forms and shapes out of planar elements. Identifying such constrains can inform the construction techniques.

6. Conclusion

Technology can change the design approach entirely. Creating a fully detailed virtual model allow the designers to experiment with various options from a single model. Through the working in this course, it was clear that parametric design tools can drastically reduce the required time to explore the variability in design that they create and the associations between different facets of the design. This variability is not only offered in the form-finding stage, but it also can be achieved in how the project is constructed.

Technological tools and techniques can open up new possibilities for architects and designers. Thus, it has to be taken seriously in the architectural pedagogy. I firmly believe that such courses and initiatives can reduce the gap between architecture education and its practice.

This project also taught students about the constraints, potentials and difficulties of processes, materials and techniques. One advantage of the approach introduced here is that it doesn't rely on specific knowledge and skills to be able to produce the design; using computer-aided design and manufacturing techniques bring flexibility and ensure feasible production.

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UTILIZING CAAD IN THE DESIGN STUDIO TO CONSOLIDATE WITH PROFESSIONAL PRACTICES

Pedagogical approach

EMAD H. RABBOH AND ALI A. ELMANSORY
Canadian International College (CIC), Egypt.
Email: emadeldin_hamdy@cic-cairo.com
Al Azhar University in Cairo, Egypt.
Email: mansory74@yahoo.com

Abstract. Utilization of computer-aided architectural design CAAD in architectural design studio has its problems. Recently, CAAD has been over used within education, , and applied, presumably, more efficiently in professional contexts.. Noticeably, time available for the application of CAAD in architectural firms outweights that of academy. Consequently, it has to be utilized effectively and efficiently in the design studio. The current study proposes and discusses techniques to expand and consolidate CAAD utilization in the design studio by analysing stages of work of design professionals, as well as the utilization of CAAD in architectural firms, in the first phase. The second phase looks at the stages of work in the design studio academically. Later, we conduct a survey and categorization of the Egyptian schools of architecture, to identify the mechanisms of their CAAD applications. We aim to improve the synergies between academia and professional practice and, in this respect, we hold a comparison between the professional context and the academic context with emphasis on the pedagogical aspects of architecture in design studio. The third part makes proposals to bridge the gap between the professional practices in the applications of CAAD and academic practices via enhancement of architectural technology-based learning milieu. The proposed techniques are applied and examined in the design studio. They aim to establish the parallelism between academic objectives and professional and technological objectives.

Keywords: CAAD - professional practices- design studio.

1. Introduction

The Design Studio is the primary forming aspect of architecture students' mindset, where they pass successive stages relying on the nature of the project.. Out of necessity, educational subject and techniques, and in particular, the design studio changes and adapts ever advancing technologies. There is no doubt that the design studio nowadays is facing vast challenges questioning the success of its role. On one hand, there are internal challenges. For instance, the design studio is influenced by tutors' varying skills and backgrounds, which must be coordinated between them in order to avoid varying feedbacks to students. Likewise, the challenging issues of architectural design education, particularly in the first year, are the diverse backgrounds, expectations, skills, and the level of the motivations of the students (Aktan A., 2008). On the other hand there are external challenges,. One of which is emergence of contemporary architectural trends, which requires continuous development and education on the part of studio teaching team to keep up with these trends. Accordingly, they should also propose development strategies for design studio's technical performance, as well as the techniques of critique. By contrast, there is a general resistance to development among seasoned academics who are comfortable in their ways. They prefer to apply their old methods and ways. The current architectural development dictates maximum utilization of CAAD and effective employment of it in the studio, to assist students' in acquiring skills and in applying the acquired skills. Hence the need for developing a contemporary pedagogical and technological development mechanism.

2. Background

Design studio evolution commenced in Italy, during the latter part of the 15th Century. A number of schools flourished based on the humanistic discourse. The *Academie Royale d'Architecture* was established in 1671. By the early part of the 18th Century, the *Academie* had become entrenched and unfashionable and, as a result, Blondels's *Ecole des Arts* was established in 1743 (Green *et al*., 2003). The *Beaux Ecole des Beaux Arts* in France started the idea of the arch-design studio in the 18th century. It had a particular teaching practice; theory in the classroom and design in the ateliers (studios) (Eigbeonan A., 2013).

As Lackney (1999) stated, the University of Oregon, architecture program, founded in 1914, was the first in the United States. The Bauhaus, formed in 1919, moved to its famous Dessau, Germany, location in 1925, but was closed down by the Nazis in 1933. In 1936, Walter Gropius came to the United States.

Recently, contemporary pedagogical methods emerged in design studio already depend on; 'learning by doing' (Uzunoglu & Quriesh, 2012), using CAAD in the design studio. Historically, the early eighties are to be regarded as the period of first encounters with computers by larger proportions of people involved in architecture (Martens, 1999).

In the beginning, adding CAAD to the architectural studio curriculum faced strong rejection by studio Professors, thinking that CAAD skills would affect the student's willingness to acquire traditional drafting and design skills (Salman *et al*., 2008).

The next contemporary step introduced was ‘using virtual design studio’ (VDS) (Donath & Regenbrecht, 1995). Since 1993 schools of architecture all over the world, used various forms of Virtual Design Studio (Schnabel *et al*., 2001). ‘Virtual Reality’ (VR) started as an experimental tool to assess the impact of VR technology on design (Achten *et al*., 1999). Virtual Design Studio (VDS) paradigm focuses on the dynamic control of social aspects in the design process by the exploitation of technological possibilities (Donath *et al*., 1999), whereas, Bermudez discusses the Virtual Architectural Experiences (1994).

Clearly, other contemporary pedagogical methods emerged in the design studio, such as utilizing ‘electronic studio’ (E-Studio) (Al-Qawasmi, 2005). Similarly, ‘paperless design studio’ emerged initially in the early nineties (Reffat, 2007). The tools of Computer-aided design tools are nothing new; however, the emphasis shifted from *automation of* design tasks to *collaboration on* design tasks (Bojduj *et al*., 2008). Moreover, a great importance is placed on the use of information and communication technology in architectural education (Wang, 2009), resulting in the emergence of CAAD. Hence, the repetitive comparison between the use of manual design vs. design with computers (Şenyapili & Basa, 2005).

There are three main types of sketching modes—i.e. fully manual, mixed and fully digital (Ibrahim & Rahimian, 2010.). Without a doubt, the role and vision of design instructor in the design studio are highly critical in guiding students toward choosing the sketching type and to choose their own style (Cil & Pakdil, 2007). A vast proportion of students are turning to the use of CAAD. Hence, there is another debate about CAAD’s impact on the architectural design process (Hanna & Barber, 2001). Moreover, various studies discuss the pros & cons of using CAAD in architectural design (Guney, 2015; Schmitt, 2004; Lawson, 2002).

3. Research Problem and Methodology

The architectural design process is passing through successive stages that require a variety of skills. The research problem is summarized in the lack of architectural skills of alumni to work in various stages of design. This is highlighted by the lack of work-based professional training and transferable skills such as the use of architectural software. Furthrmore, the process does not prepare them adequately for the marketplace demands, which has been observed in the Architecture, Engineering, and Construction (AEC), Egyptian firms sine 2000 to 2016. Obviously, this lack of training leads to a decline in the level professional practice of architecture in Egypt. The research adopted the method of comparative analysis, to determine the reasons for the gap between the method of academic architectural pedagogy v.s. professional practice in Egypt, followed by proposing techniques to bridge the gap between them. This is followed by the application of these techniques in the design studio in the architecture department in Canadian International College (CIC) for 'architectural design 2' in the fall 2015 semester, 'architectural design 3' in the spring 2016 semester, 'working drawings 1' in fall 2015, and 'working drawings 2' in spring 2016. Ultimately, the proposed techniques were validated by a student survey made up of a questionnaire to measure the levels of satisfaction and the impact of overall outcome on the future employability.

4. Professional Architecture Design Phases

4.1. ARCHITECTURAL PROGRAMMING (BRIEFING) PHASE

Briefing phase has long been recognized as the critical activity that begins the building process, which the architect as a building designer must elicit the brief from the client before any design activity can begin (Cornick, 1991).

4.2. SCHEMATIC DESIGN PHASE

American Institute of Architects (AIA) identifies the first phase of services as schematic design. Schematic design establishes the general scope, conceptual design, and scale and relationships among the components of the project (Haviland, 1996.).

4.3. DESIGN DEVELOPMENT PHASE

Design development is the period in which the design itself achieves the refinement and coordination necessary for a really polished work of architecture. The decisions made in schematic design are worked out at a scale that minimizes the possibility of major modification during the construction document phase (Haviland, 1996.).

4.4. CONSTRUCTION DOCUMENTS PHASE

As work becomes more complex, more diverse skills are needed to accomplish it (Gray & Hughes, 2001). The construction documents show in graphic and quantitative form the extent, design, location, relationships, and dimensions of the work to be done. They generally contain site and building plans, elevations, sections, details, schedules, and diagrams.

5. Architecture Design Phases/CAAD in Egyptian Academia

A considerable sample of Egyptian universities demonstrates that architectural design programmes consist of specialised courses on the topic that range from 5 to 6 courses, in addition to the graduation project. We note that the curriculum barely addresses the schematic design phase and does not address the architectural briefing phase. by comparison, building construction and working drawings courses address the construction documents phase. The above suggests the presence of a failure in the architectural programming phase as well as the design development phase. The current research recommends that students should prepare the briefing phase and architectural schematic design phase as early as the second course of design ‘design 02’. The design tutors set the project type and, subsequently, the students set architectural space programme and find the appropriate area for each space under the guidance of tutors. The current research offers a solution to students trained to the third phase. It suggests that they prepare the construction documents phase for students' projects they have designed earlier, and then demonstrate their ability to achieve the design development deliverables and apply them to the design before commencing the fourth phase.

A survey of CAAD use in Egyptian schools of architecture shows that schools allow the use of CAAD from ‘design 5’. Some other, allow from ‘design 2’. After surveying and evaluating the professional practices, it is recommended student training on the use of CAAD must be highly emphasised. While it is possible to develop manual skills in architectural design through independent freehand drawing curriculum, in order to graduate as an architect and inline with workplace demands requirements of the labor marketplace, the survey found that CAAD skills are form a pointo f dependency for the 50 architectural firms that formed our survey.

6. Techniques to Consolidate CAAD & Practices in Design Studio

The research suggests improving the use of CAAD within the professional practice by applying the following points:

- Divide students into groups according to their level in terms of the use of architectural drawing software, so that each group learn particular architecture software under the supervision of a tutor.
- Simplify the parameters that the student must learn to master the professional practice of the architectural software.
- The author holding a lecture to view different architectural software and the deliverables of each software and the pros and cons.
- Support the technologically-challenged students in the use of modern software, and demonstrate how to overcome self-resistance to work with new methods. Clarify the possibility of error as well as the difficulty of the work at the beginning of the learning curve.
- Demonstrate the best practices of CAAD in the various phases of the design process through lectures using computer displays to resolve design problems using modern architectural software.

- Set bonus marks to increase the use of CAAD in the studio, to solve design problems through modern architectural software.
- Demonstrate contemporary architectural trends (parametric design-bionic architecture-Bio mimicry architecture ..... etc.) and its projects samples, and the connection between software and the production of the samples.

7. Discussion

The current search sheds some light on the mechanics of the professional practice of architecture; likewise, examines the academic context and attempts to foster the synergies between academia and professional practice, in an attempt to bridge the gap between both, so as to help graduates in commencing their professional carrer immediately. Further examination of the proposed techniques through a student questionnaire (Desing2-3, Working drawings 1-2) shows that the percentage of students using CAAD software increased from 13% before the proposed techniques to 87%. The results also highlighted the effectiveness of the role of the tutor in helping students acquire the skills. It also demonstrated how influential this role can be in developing the student's design personality and attitudes. It also guides students in their professional carrer path which could have a huge impact on the whole market by producing not only academically exceptional students, but also professional architects.

8. Results & Recommendations

Professional practice of architecture requires considerable training in the use of CAAD techniques. This study aims to explore ways of improving the use of CAAD among undergraduate students. The study examined the design studio as a key activity in architectural education, and noted its reliance on IT. The study indicates the further need for more research into how to increase students' interaction with CAAD. The study analyses design into and its different phases then surveys academic practice in these phases, then uses a questionnaire presented to students to report their opinion.
The study recommends the following:

- The increase of CAAD software utilization in design in order to break the psychological barriers of resistance from the beginning.
- Highlight the importance of student interaction with modern technology.
- Emphasize the role of design studio tutors in highlighting the importance of CAAD .
- Demonstrate modern trends, and software used to produce such trends.
- Present students with the new additions of CAAD software, and demonstrate its use and best practices.
- Deploying architectural professional practices in the design studio.

- Applying open-minded strategies with the students, and help them take advantage of their energy and creative potential.
- Show interest in and observing students behavioral trends and how they accesses creativity.
- Aplying contemporary educational methods in design studio to develop the creative capabilities of students of architecture.

Eventually, a variety of projects emerged based on the technique as shown in figure (1).

Figure (1) students' project samples after implementing the proposed techniques.

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UNDERSTANDING DIGITAL DESIGN TECHNIQUES IN SAUDI ARCHITECTURAL EDUCATION

WAJDY QATTAN AND STEPHEN HARFIELD
University of Technology Sydney, Sydney, Australia
wajdy.s.qattan@student.uts.edu.au | *Stephen.harfield@uts.edu.au*

Abstract. To understand the current architectural digital design techniques, architects and architecture educators and students need to know that these techniques are the new tool set. These techniques offer architects a new way of thinking and designing and enhance complexity. They will link architecture design with mathematics and computation, and they will generate and improve ideas. Giving that Saudi architectural education is still using traditional manual techniques and using technology only for drawing and montaging, this evokes the fact that there is a need to know and understand these techniques and their importance.

1. Introduction

With recent technological developments, digital design techniques are becoming more complex, which radically affects architectural design and architectural education. In architecture, computers have become more available and affordable than ever before, which enables the production of curvilinear and complex surfaces. This has triggered the need to understand these techniques, especially at the architectural education level in Saudi.

Architecture has witnessed a transformation movement from the manual tool-based design to a global computer-based design. But, due to a lack of architectural computational education or increased confusion on digital design ,this transformation has not reached its full potential (Terzidis, 2006: p. 40). The use of this technology is still at an unstable phase, especially in Arab countries. Some architects develop their designs in the traditional manual way, whereas others in the West are using computers to explore new possibilities and expand beyond the limitations of the human mind.

Now, computers have become an intelligent system that help designers to maximise the decision-making options. Computers have become an intrinsic aspect of architectural teaching to the extent that architects may not be able to design or build without them. For instance, Carpo (2013: p. 8) states that a building in the digital age is not one that is being designed and built using digital technology; in fact it is one that could not be designed or built without it.

This paper will discuss five main aspects as an introductory platform to inform architecture educators and students in Saudi Arabia. The first part will describe how these techniques became a new way of thinking and designing. The second section will talk about the role of digital technologies in increasing complexity in architecture design. Then the relationship between architecture and mathematics will be discussed. Coupled with that is the relationship between architecture and computation. The last part will study the debates on considering computers as a drawing tool or as a generative system.

The recent Saudi architectural education appears to be removed from these techniques. According to some Saudi educators and students interviewed by the first author, Saudi architectural education still uses the old school way of delivering architecture design knowledge and skills. They also agree that computers are used at Saudi architectural schools, but only for drafting and montaging. For example, Alkharoubi (interviewed 2014) described the current process in their school: using manual techniques such as 2D, 3D, shade, shadow and others. Then they move to draw in 2D using AutoCAD, then to 3D modelling. While other interviewees such as Al Jabali, Gadi and Alsamhan (interviewed 2014) agreed that, in terms of technologies used at Saudi universities, computers are used in traditional “2D and 3D” ways, the new digital design techniques, their software and programming languages are not used yet.

2. A new way of thinking and designing

Digital design techniques have been introduced as a new way of thinking and designing. These new technologies have the ability to go beyond the limitations of the human mind, which cannot perform such sophisticated processes and cannot run for a very long time in the way that technology can. According to Jakob (2011: p. 142), the digital and technological revolution has expanded the limitations of imagination and possibility.

Using computers in architectural design should be an extension of the human mind, enhancing the ability to produce, generate and evaluate. Terzidis (2006: p. 22) claims that architects have been using computers as a device to generate, discuss, and critique new forms in an attempt to introduce a new way of thinking and designing.

The generation of digital computational forms is contrasted with the traditional way of designing. It uses logical steps and/or calculations, whereas the latter depends on intuition and decisions of the human designer. Today, architects are using a collection of digital techniques, such as algorithms, scripting and simulation, to generate complex forms (Tang, 2014: p. 19). Architects can now conceive and construct geometries that were very difficult to achieve using traditional methods; as such, the popularity of these technologies has increased (Dunn, 2012: p. 6). This is evidence that technology is a driving trigger that has opened up endless opportunities (Barkow & Leibinger, 2012, p. 94).

From an architectural perspective the exploitation of digital technologies is the ideal way to explore the new and/or future architecture. By introducing digital technologies to architectural design, the designer can achieve a coherent integration of concept, investigate form-finding and generative approaches, and add intelligence and performative aspects to the outcome (Tang, 2014: p. 8).

Computers can extend the capacity of our imagination and allow us to communicate as never before (Cook, 2004: p. 41). It is a relationship where both designer and computer take advantage of each other. Computers provide enormous calculation power but with no intelligence, meanwhile humans have limited calculation power but with enormous intelligence (Williams, 2004: p. 79).

3. Complexity like never before

Recently, complexity issues have been raised which relate to the architects' concerns and interests. With the available technological techniques, architects can maximise the exploration of the unknown world of complexity.

Before the intervention of computation in architectural design, forms which are difficult to draw and measure used to be difficult or impossible to build or, in other words, there was no complexity. Carpo (2011: p. 32) states that you cannot build what is in your mind if you cannot draw it in order to have others make it for you. But when you cannot make what you cannot draw, what then? In this case, the role of computers is emphasised, as architects need technology to help them draw and make what is in their minds, even if it is extremely complex.

One of the key ideas behind complexity is manifested in the replication, combination and changing of small, simple parts that follow simple rules to generate a series of unpredictable iterations and new information (Burry & Burry, 2010: p. 53). Often these ideas are discerned from some process in nature such as self-organisation. Frazer (1995: pp. 19–20, 102) claims that in nature the developmental processes led inevitably to complexity. This complexity could be the result of mimicking the natural behaviour of flocks, swarms, crowds and schools.

Kolarevic (2004: p. 7) is certain that using digital technology opens up new possibilities to generate and construct complex forms in novel ways. This strengthens the connection between complexity and computation in architecture. With the aid of computers, designers have the ability to handle greater complexity that could not be handled in the conventional way "by hand" (Schroder 2008: p. 154).

4. Architecture and mathematics

Architects have been able to link algorithms, computation and design in one logic to derive "algorithmic design". The term "algorithmic design" brings together computational complexity and the creative way of using computers to allow architects to move towards programming architecture (Terzidis, 2006: p. xii). Therefore, digital algorithms are mathematical models that tie together all contemporary architectural intentions.

An algorithm is actually a set of information and instructions given by users and performed by either humans or computers, and is based on the way that the problem is addressed and understood. Where the instruction is performed by humans, it will be direct, precise, definite and logical, but where it is performed by computers, it is a linguistic expression – code or script – written by humans to be run by computers to produce the same quality as the human outcome but in a shorter time and with huge iterations.

When architects code an algorithm to help solve a design problem, they can explore more options by modifying the program or sketching it by algorithms. It is crucial to know that using algorithms is conditioned upon fully understanding the rules from the very beginning to the end. Williams (2004: p. 79) argues that an algorithm is only complete when every rule it contains is fully described.

Algorithms could be assigned to handle more than one particular design problem that they were never designed to address. For example, if an algorithm is being designed to help find the ultimate curvature of a building cladding, the same algorithm can be developed to address completely different problems. Terzidis (2006: p. 23) indicates that the same algorithms can be used with different parameters to produce completely unexpected behaviour. However, the designers can keep changing and tweaking the algorithmic variables until they are satisfied.

Recently, the relationship between algorithms and computers has become very intimate, but the human aspect still plays a vital role in the process. Some scholars such as Terzidis, Carpo and Burry and Burry, agree that the relationship between algorithms and computers is not necessarily associated with computer science. Most of the algorithmic preparatory steps are predetermined by the designer according to the design problem. Then the designer interprets these steps to allow the computer to understand them and calculate them in an algorithmic format. But overall, the designer has the responsibility of creating and understanding these algorithms.

5. Architecture and computation

Terzidis (2006: pp. vii–viii) points out that usually the computer's involvement in architectural design takes two trends. First, some designers consider computers as an advanced drawing tool. Second, other designers decided to enter the world of scripting and programming to take advantage of what computers can do. Indeed, computers are a complementary tool to humans that helps them to think outside the box.

Architecture has moved from hand drawings to computerisation and, more recently, to computation. Computation means calculating, or using a mathematical or logical method to determine something. It is less popular as it requires extra knowledge in programming and scripting fields, and is "the hard way".

Compared to the conventional tool set, architectural computation has a notion of the exceptional and unprecedented. Traditionally, designers use the available manual tools. As a result, the outcome will be something predictable, doable and usual. The digital way, however, depends on the available techniques or sometimes requires developing new techniques, and the resultant outcome is most likely something unexpected. Terzidis (2006: p. 55) stresses that concepts such as randomness, complexity, emergence or recession are incomprehensible by the human mind because they depend on intellectual means that are external and foreign to the human mind.

Architects categorise computer use into tool makers and tool users. Tool makers refer to computation aspects that provide design exploration tools by using computers and they are usually software developers, computer scientists and mathematicians. In contrast, tool users seek to connect their design ideas with the digital phenomena (Terzidis, 2006: p. 56).

Architectural programmers could be architects who want to describe the design process using algorithms that use the computer's capacity to produce a desirable outcome. Understanding algorithms is not enough; architects need to grasp computation as an operator who can run algorithms faster and with more accuracy. According to Dunn (2012: p. 60), algorithms and their use in architecture may generate and develop design ideas, but architects need to understand that this requires a shift in the way they use computers.

Computer-aided design applications offer a collection of algorithmic commands which deal with a specific graphical design issue. The user of these applications may not understand the algorithmic logic running behind them, nor do they have enough knowledge of how they work, and therefore the user is not able to grasp the application's ultimate power.

6. Drawing tool or generative system

Throughout history, architects' work has been linked to drawing as representational and designing tools, but today's computerisation and computation still do the same job but in a more advanced manner. Peters (2013: p. 15) argues that as pen and pencil are used to draw conceptual sketches and building details, computation tools can be used to provide better communication, increased efficiency and conceptual sketching of algorithmic concepts. Architecture is now experiencing a shift from drawing to generative algorithms.

In architecture, the term 'tool' refers to the cooperation between designers and computers, but digital technology may be viewed as a drawing tool or as a generative system. Some scholars look at it as just a drawing tool, some as a generative system, some as a collaborative partner, and others see it as both drawing and generative at the same time.

Ramona Albert, in a conversation with Terzidis (2006: p. 149), argues that computers are just tools that fulfil the designers' needs because they do not have a mind of their own. Albert says that we even use algorithms because we need to be in control, "imagine if computers have their own mind and control, we will be living in a nightmare".

On the other hand, Christopher Shusta (Terzidis, 2006: p. 150) emphasises the role of computers in decision-making. He argues that "computers are not the equivalent of pencil", as a pencil never acts to generate forms, it only represents the designers' ideas while computers can help in the decision-making.

Marble (2012: p. 9) and Frazer (1995: p. 10) claim that the use of computers in architectural design is varied, for they could be used as representational tools, and they could also be used as generative systems that receive coded algorithms to produce architectural outputs, hence can be used to increase the designer's imaginative capability.

The design process has changed from drawing surfaces to setting up rules through programming. The new generative and parametric design systems use a collection of constrained rules and relationships between objects (Vanucci, 2008: p. 118). It is an exploratory shift towards programming in architecture in order to get the most benefit from computation. Programming is a method where we can experiment using rules and principles, for it questions the way people think and the way the mental process develops through the use of computers, which is the only way to benefit from the full capacity of computers, and is also the vehicle for obtaining knowledge and seeing hidden things. For example, instead of changing a whole set of drawings using the computer mouse by clicking and dragging, it is easier to use algorithms by changing some of their variables.

7. Conclusion

Computers are not fully automated machines which have the ability to run, process and produce without human intervention. Some architects think that they are great users or fans of digital design, but what they are doing is manual transaction "mouse manipulation" which allows them to move, drag, bend and stretch what they see on their screens. Digital design is a process, not a tool or a product; it is about using algorithms to make patterns to be run by computers, to explore the imaginary and unpredictable concepts which are impossible to be explored by the human mind.

With digital design techniques, Saudi educators and students need to (re)think and design differently. They need to know that technology has been used to generate, discuss and critique new architecture in an attempt to introduce a new way of thinking and designing. Architects are now able to understand and produce geometries that were previously very difficult to achieve using traditional methods. This will also allow architects to explore far more complex shapes, in addition to breaking the barriers of physical constraints. They need to understand that using technologies in architectural design will promote complexity, novelty and better opportunities, more than ever, to the extent that complexity itself is not complex to achieve.

They also need to grasp that they are now able to link mathematics, computation and design as 'one logic' aimed at algorithmic design and programming architecture. Finally, they need to comprehend that using computer-aided design packages to manipulate architectural geometries is not ideal for this exploration. This exploration needs a new generation who are willing to channel their efforts through computation, algorithms and architectural logics towards new digital architectural designs.

Acknowledgements

The authors would like to acknowledge The University of Technology Sydney, Umm Al Qura University, King Suad University and King Fahda University of Petroleum and Minerals for hosting and funding. Further the authors would like to acknowledge all teaching staff and students who participated in this research.

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Section

VII

DIGITAL HERITAGE

A GRAPHIC RECONSTRUCTION METHODOLOGY FOR THE CONSERVATION OF CULTURAL HERITAGE

TAREK TEBA
School of Architecture, University of Portsmouth, UK
Tarek.teba@port.ac.uk
DIMITRIS THEODOSSOPOULOS
Edinburgh School of Architecture and Landscape Architecture, University of Edinburgh, UK
D.Theodossopoulos@ed.ac.uk

Abstract. Virtual modelling enables the testing of conceptual, constructional and environmental aspects, prior to embarking on the in situ construction process. This is being gradually implemented in architectural heritage, particularly with monuments that are at risk. Various international heritage conventions have emphasised the great role that virtual reconstruction plays in building a comprehensive repository of the selected case studies. This repository would be used for educational and professional purposes as well as raising community awareness of heritage values and conservation. On the other hand, only few genuine attempts have been made to develop a virtual reconstruction approach in a conservation project to integrate concept, materiality or spatial quality of the conservation proposal into the perception of the heritage cultural values.

This paper presents a conservation framework with a virtual reconstruction approach that allows the conservation strategy and proposed architectural interventions to be tested via remodelling them together with the original fabric in the virtual environment. The study is intended to apply the conservation framework on the Public Plaza, Residential Quarter of Ugarit and its associated structures in order to examine how this proposal affects the spatial and architectural settings of the fabric and enhances the perception of its cultural significance. A 3D model of the original fabric and proposed conservation strategy is built using CAD modelling techniques and, consequently, high-quality realistic photos and virtual tours are produced. These outputs will be analysed in order to highlight the contribution of the conservation framework to the original fabric and its cultural values.

1. Introduction

By the end of 20th century, increasing attempts have sought to extend the application of virtual reality (VR) technologies into multidisciplinary areas (e.g. archaeology, architecture and cultural heritage). The main aim has been to involve these technologies in more educational activities and create a vehicle that approaches public perceptions and response. The use of VR in the heritage sector constitutes an evolutionary endeavor that places more focus on the documentation and representation of the people's past and cultural aspects. The outcome of these technologies facilitates a broad-based public acceptance of using computer-based approaches in heritage studies, despite the challenges (e.g. costs and inaccessibility) involved (Addison, 2000). The concept of virtual archaeology that came to light by the beginning of 21st century (Roussou, 2002) aims to establish a virtual interface between historic structures and the public. It offers an interactive environment where people can experience spatial and architectural settings and also learn about their past and the skills of their ancestors. These technologies are sometimes very expensive, which limits their application outside the academic domain.

Therefore, this paper sheds a useful light on the use of CAD modeling in order to enhance the decision-making process in the preservation and presentation of cultural heritage and create temporary educational activities that promote engagement with and understanding of heritage cultural significance. The paper explores how the conservation strategy and proposed architectural interventions of the Public Plaza in Ugarit can be tested via a graphic reconstruction approach, VR, before proceeding to the in situ implementation of the proposal.

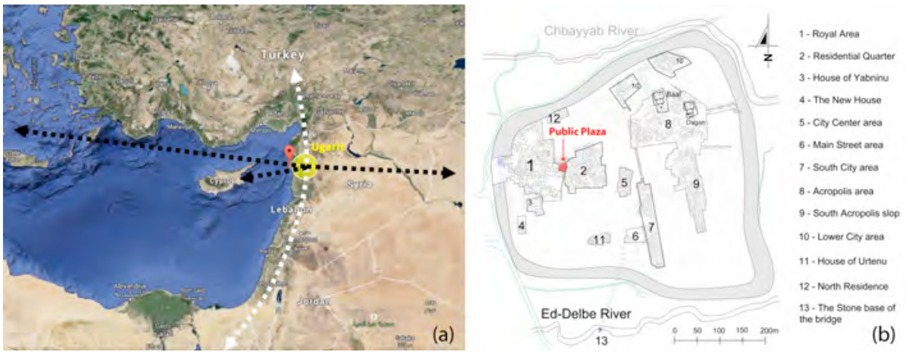

Figure 1. (a) Google map of Ugarit's location,
(b) Schematic plan of the City of Ugarit

The City of Ugarit is a Bronze Age site, located in northwest Syria, Figure 1a. Its strategic location that dominated the city trade routes (Malbran-Labat, 1999; 2000; Yon, 2000; 2006) promoted the city's importance and enabled Ugaritic people to establish a unique homogeneity with surrounding cultures and develop advanced architectural principles and techniques. The Public Plaza, Figure 1b, connected the Royal Area to the rest of the city. It was formed by a set of structures that were devoted to public functions.

1.1. METHODOLOGY

This paper establishes a conservation framework for the Public Plaza, which uses critical conservation approaches and a graphic reconstruction methodology to materialise the theoretical discussion and map the proposed architectural and conservation approaches onto the original fabric. The conservation discussion is based on a detailed reading of archaeology and in situ architectural analyses of the plaza and its structures. Proposed interventions will be constructed onto the original fabric in virtual reality. 3D models, which show the new settings of the area after applying the conservation strategy, will be created using ArchiCAD, an architectural computer program from Graphisoft. Analysing the outputs of the virtual models aims to evaluate the contribution of the conservation strategy to the perception of the plaza's intimacy, cultural values and original architectural and spatial settings and its impact on the original fabric.

Henceforward, the present paper will be divided into three main sections which respectively draw on the literature relevant to this topic and discuss the conservation proposal and the outcomes. The following section presents a brief account of using computer based approaches in heritage studies.

2. Literature Review: the Use of VR in Heritage Studies

Moving the application of VR to public context has brought high recognition of and hope to cultural heritage studies. VR has been considered to be a unique potential for achieving public engagement and appreciation as well as a realistic and non-destructive representation of the past. These applications have initially started with applying a photorealistic approach to virtually reconstruct ancient sites (e.g. Pompeii, Luxor and Stonehenge) (Barceló *et al.*, 2000). The low-quality output did not meet the hopes of conservators, historians and the public and was a good criticising material for anti-technology groups (Addison, 2000). Therefore, a second wave of applications has started in order to confirm the efficiency of VR for documenting and preserving historic buildings and enhancing public engagement and entertainment. The new wave included 3D documentation projects which were based on digitising existing data of architectural (the Colosseum) or natural (Yosemite Valley) heritage. Also, 3D representation attempts, that range from historic reconstruction to visualisation (e.g. the virtual model of Loire Valley and the fully navigable model of Notre Dame Cathedral, Figure 2a), have been carried out. The key introduced aspects were the visual presentation and dissemination and the in situ augmented reality using Computer-Aided Virtual Environment to reconstruct and project buildings' past and/or diverse interpretation onto the actual ruins (e.g. the live video that represents the archaeological site and its history on available ruins at Ename Center in Belgium, Figure 2b) (Addison, 2000).

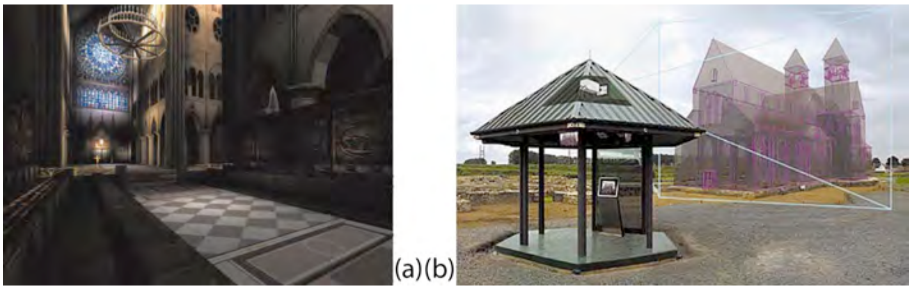

Figure 2. (a) Notre Dame Cathedral, (b) Virtual representation at Ename Center in Belgium.

Later developments have sought to establish a rich repository of digitised heritage environment and enhance public participation and experience (Thomas and Mintz, 1998). Thus, Visitors are not only viewers; they become learners and participants through identifying their values, actions and engagement mode (Roussou, 2002). VR started to be an educative, entertaining and sparkling method, allowing visitors to travel in space and time (Roussou and Efraimoglou, 1999). As a result, people are able to access sites that are at risk and experience diverse interpretations and representations. Thus, VR established an informal educational environment in which interaction, response and collaboration are key elements that engage the public, particularly the young generation (Roussou, 2002).

The "Magic Screen" project is a key attempt through which the Foundation of Hellenic World actively promoted understanding of Hellenic cultural values and encouraged scholars to use advanced technologies for representing their ideas and work on this cultural heritage. The foundation is recognised for its contribution to the virtual reconstruction of the city of Miletus and "Kivotos" exhibition (Roussou, 2002). Thus, for educational and entertainment purposes, building 3D reconstructions and journeys on heritage sites has dominated the use of virtual reality in heritage studies. For example, a journey through Ancient Miletus takes visitors 2000 years back through history and enables them to experience iconic buildings, the architectural and landscape settings and their evolution over time. Other successful examples of this approach are the virtual reconstruction of the

Temple of Zeus at Olympia, the Byzantine costumes and the traditional olive oil press in the Mediterranean culture (Roussou, 2002).

The former 25th Ephorate of Byzantine Antiquities in Greece has also used graphic reconstruction method to enhance the digital representation of sites of castles (e.g. Argolid Arcadia and Corinthia castles) and create a digital repository that facilitates easy communication with researchers and the public (Athanasoulis *et al.*, 2015). The development of VR approach has not stopped; virtual reconstruction started to use automated distance measurements, together with photographs, in order to produce 3D textured realistic models. This method was used in modelling the Salon Delacroix at the French National Assembly, Paris, and the Sala dello Scrutinio at the Doges' Palace, Venice (Gonqalves and Sequeira, 2001).

International charters have also regarded VR as a method for the communication and preservation of cultural heritage. The London Charter for the computer-based visualisation of cultural heritage encourages the use of computer-based technologies believed to develop interpretation, preservation, and communication strategies for heritage assets (Denard, 2009). Also, the Seville Charter introduced the definition of virtual archaeology and virtual restoration, anastylosis, reconstruction and recreation to frame the anticipated outcomes of using VR methods in heritage conservation. The charter focuses more on setting up criteria and guidelines that ensure the effectiveness of virtual methods, and encourages the use of new technologies for better conservation, management and dissemination of cultural values. Enhancing public appreciation and engagement is a main focus as well (Lopez-Menchero and Grande, 2011).

In the UK, the use of VR technologies to enhance public engagement was explored through collaboration between the University of York and Heritage Technology Limited. The project aimed to test public engagement and appreciation of historic churches through VR. Exterior and interior virtual reconstructions of Trinity parish church in York and Guild Chapel in Stratford-upon-Avon were created (Figure 3). The project could encourage visitors, academics and professionals to look beyond the church experience and explore the cultural significance of this heritage (Giles *et al.*, 2010).

Figure 3. (a) Trinity parish church in York, (b) Guild Chapel in Stratford-upon-Avon

3. The Public Plaza of Ugarit: Analysis and Proposal

The Public Plaza constitutes a significant urban element that connects the Royal Palace to the Residential Quarter and, subsequently, the rest of the city to the east (Figure 4). Excavated structures around this plaza are of a public nature, which further promoted its importance.

The Oven House (3) to the north is characterised by its findings (e.g. ovens, jars, drainage, pit and stone vat) and attached to the owner's private house (2) to the east. A lightweight structure (5) attached to the Royal Palace and looking over the plaza occupies the western side. Moreover, a direct street, Palace Street, connects the plaza to the New Royal Zone to the west through a simple check point. The eastern side accommodates a well-preserved structure, the Tavern (4), around which an agglomeration of shops (1), bazaar, flanks the eastern and southern sides of the Public Plaza.

The principal building material is sandstone which varies in size and condition. The buildings were constructed using big keystones both at the access and in the corners and large flagged stones in between. The Royal Palace to the west and the Tavern to the east are exceptional structures which were built with large cut stones. In addition to the tangible evidence it provides, the plaza offers valuable insights into Ugaritic people's urban experience and public social life during the Bronze Age.

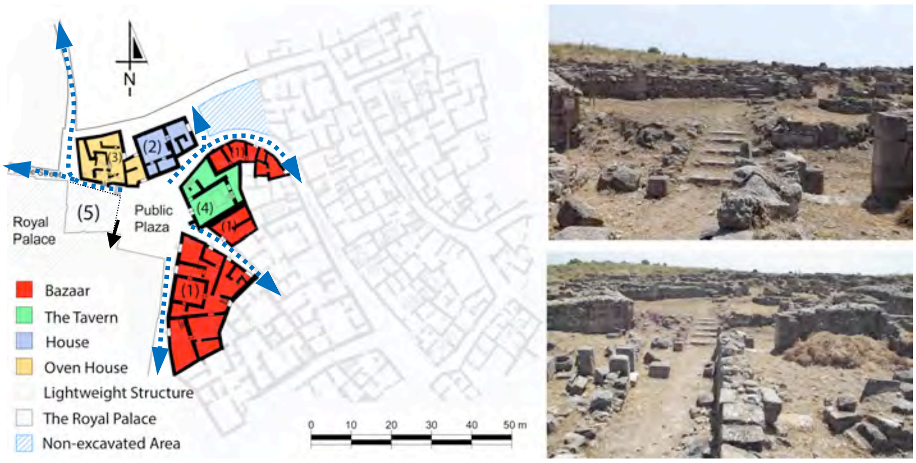

Figure 4. The Public Plaza of Ugarit: plan and in situ observation May 2013.

3.1 THE ANALYSIS

Considering its location, the Public Plaza is a very important urban element where public and private lives meet in the city. The street network that connects the plaza to the surrounding areas confirms the significance it holds to the overall urban circulation. Also, public, social and entertainment buildings constructed around this plaza emphasise its importance not only to the city's planning but also to the people's social life. The lightweight structure (5), attached to the palace, Figure 4, was most probably used by the royal family, keen to engage with their people. The northeastern secondary access to the palace is located beside this structure, which most likely facilitated the connection between the palace and the plaza.

On an architectural scale, Ugaritic people had dedicated a public function to all buildings surrounding this urban element; this clearly shows their intention to highlight the meaning of this plaza to their life. The people of Ugarit developed similar concepts in the city: the Public Plaza in the South City and The Royal Plaza (Yon, 2006); however, in both cases, one type of structure, domestic or royal, formed the plaza. This plaza is unique especially in terms of its diverse surrounding activities (public, private, commercial and entertainment). A detailed analysis of surrounding structures will promote the understanding of the Public Plaza and its cultural values.

The entrance to the Oven House, for instance, shows monumental characteristics; very large cut stones formed this entrance (Figure 5). Having a monumental entrance to a simple building confirms Ugaritic people's intention to monumentalise the periphery of this plaza.

Figure 5. The ruins of the Oven House, Ugarit, May 2013.

Another important building overlooking the plaza is the Tavern, also known as the Building with the Stone Vase, which was built in high architectural and structural quality (Yon and Arnaud, 2001: pp. 65–82); it was built with cut stones almost the same size of the Royal Palace's (Figure 6). The monumental entrance to this building, which rises three steps above the plaza's level, highlights its importance to the community. The existence of the big hall and the big vase strongly advocates the assumption of its function as a tavern. This building was likely the place where the community met and enjoyed good social relationships. The architectural analysis of the building and discovered foundations has pointed out that the main hall had a high interior space, while the rest of the building was built in two storeys.

Figure 6. The ruins of the Building with the Stone Vase, the Tavern, Ugarit, May 2013.

Consequently, the Plaza's cultural values are as follows: (a) the plaza is an important urban element in the city; (b) it reflects the unique social life of Ugarit: strong relationships both among Ugaritic people themselves and between the people and their royal family; (c) the Plaza and surrounding structures are evidence of the advanced architectural and urban experience that Ugaritic people had had during the Bronze Age.

3.2 CONSERVATION PROPOSAL AND VIRTUAL MODELS

The cultural values assigned to the Public Plaza need to be treated as fundamental aspects in the conservation plan. Therefore, architectural interventions and their materials should be critically chosen in order to avoid compromising the plaza's originality and authenticity. Thus, the critical conservation approach which advocates reversibility and compatibility is essential. This dynamic approach upholds contemporary design principles and materials with full appreciation of the original fabric; it recognises architecture's ability to express the aspirations and values of a society in their spatial resolution and cultural context. The authentic fabric, the faithful representative of the past, has the ability to control the design and reconstruction processes, and the architect has a responsibility to prioritise the cultural values and critically operate their preservation with full engagement with and understanding of all associations and meanings.

It is essential, first of all, to highlight the relationship between the plaza and surrounding structures. Therefore, the first procedure will be to restore a sense of space and orientation by bringing the demolished walls back up to some height and clarifying the original layout. An anastylosis approach will be applied to the fragmented fabric using only the original stones. Rectified stone walls should be repointed using the original lime mortar (soil, water and lime). Also, the original level of the plaza will be restored using a stones and compact soil pavement as a reference to a public and open space.

The Public Plaza promotes evidence of an evolution in Ugaritic people's appreciation of their public spaces and gives a clue of a high urban advancement in Ugaritic architecture. It is a strong representation of the people's attempts to involve new urban concepts that reflect the requirements of their social life in the city. Also, the concept of Public Plaza in Ugarit constitutes a historical anchor linking modern Syrian communities with their ancestors in terms of the use of public plaza with public facilities around it, which is a common urban aspect in 19th and early 20th century AD cities in Syria. Therefore, reconstructing all facades around the Public Plaza will, above all, give the real volumetric impression of this urban element and highlight the public nature of the buildings around it. Differentiating the added fabric is very important. The new facades should be reconstructed with light and flexible materials. Steel framework and timber cladding are sufficient materials for the reconstruction work (Figures 7 and 8); they are easily manufactured offsite and, simultaneously, distinguished from the original fabric. The reconstructed part, although light, should have its own separate foundations and apply no further loads on the original structures. However, when it is necessary, some loads can be transferred to the wall intersection points or corners as these key points of the buildings were built in ashlars and are in a very good condition (Callot, 1994: pp. 115–147).

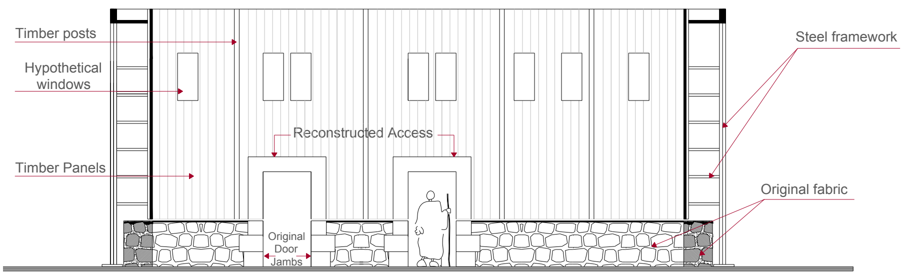

Figure 7. Proposed reconstruction of the surrounding facades.

The main access to the buildings around the plaza will be reconstructed in a U-shape timber profile in order to highlight the entrance and point out the different structure and material quality of these accesses. Also, a timber platform will be installed on the ground of the lightweight structure attached to the palace aiming to emphasise the unique relationship between Ugaritic people and their king. The pavement of the public structures around the plaza will be restored in different textures or colours and differentiated from the surrounding residential spaces; this approach has been successfully applied to enhance the reading of many archaeological sites (e.g. Saint-Romain-en-Gal Museum in France and Roman ruins of Empuries in Spain).

Figure 8. Restoring the volumetric sense of the plaza: Virtual model.

Special intervention will be dedicated to the Tavern structure in the hope of highlighting its importance and reconstruct its interior public and entertainment environment. An enveloping box, made of timber, will be added on top of the building ruins, Figure 9, 10. Since some original artefacts are still there, especially the original stone vase, most probably used as a wine container, the original interior environment of the building will be reconstructed using natural light. Therefore, some perforations will be added to the new timber box in order to control the natural light coming into the building interior; this principle has been successfully applied in Badalona Roman Museum in Spain and Kolumba Museum in Germany. The added timber structure should be an abstract and conceptual choice, without restoring any anticipated architectural details from the Bronze Age. The location of structural supports of the new addition will be identified based on a detailed archaeological and architectural analysis. This intervention will allow visitors to explore the original environment of the interior spaces of an entertainment public building from the Bronze Age. It will also enhance visitors' appreciation of the Public Plaza as a focal point that hosted everyday public, social and entertainment activities.

Figure 9. The Reconstruction of the Tavern structure: Virtual model.

Figure 10. The Reconstruction of the Tavern structure: Virtual model.

The presence of some shop agglomerations differentiates this area from other domestic areas in Ugarit. The professional workshops which are usually found in the Ugaritic house are replaced here with these shop agglomerations, similar to what is known as bazaar in Middle Eastern cities. Restoring these agglomerations as much as possible and differentiating them from the rest of the structures is very significant in that it serves to highlight the relationship between these compounds and the surrounding fabric. It would also give an idea about how these shops had worked together in each agglomeration and been linked to the assigned streets and residential blocks.

4. Discussion

The graphic reconstruction method has contributed to the understanding of the physical output of the conservation proposal. The virtual models have enabled the perception of a real implementation of the proposed interventions. These models show the new spatial, urban and material settings of the plaza after applying the conservation strategy. The new reconstructed facades and the original fabric are simulated together highlighting the reversible nature and minimal cons of this reconstruction on the plaza's authenticity. The rendered pictures and virtual tour (https://goo.gl/RGLXkI) mimic the real in situ experience that will be offered to the visitors as part of the conservation strategy. The virtual experience has confirmed the effectiveness of the proposed interventions in reconstructing the urban form of the Public Plaza and its relationship to the surrounding structures, and also showed the good communication between the original fabric and added materials (the timber facades).

The virtual model of the Tavern proposal actively recreates the original dim and cozy interior environment of the building. The output of the virtual model is presented in the virtual tour (https://goo.gl/2PNIHp) and rendered pictures inside the new complex, which demonstrates how proposed interventions have successfully reconstructed the interior environment and established a simple and engaging public life museum on the site. The virtual output presents the sought-after experience that visitors would have in the new structure.

In addition, virtual tours create an opportunity for in situ screen display to be installed in the plaza and the Tavern for visitors before implementing the actual proposal on the site; they also constitute reliable evidence and basis for the second stage of the conservation proposal, the design stage.

5. Conclusion

Virtual reconstruction has become a predominant method in heritage and conservation studies. Using a graphic reconstruction approach in the conservation of the Public Plaza in Ugarit has introduced many practical, educational and entertaining dimensions for the visitors. By using CAD programs, commonly-used and cheap ones, the conservation proposal of the plaza has been tested and the reconstructed self-experience has been presented in a virtual tour format.

This output provides good materials for public engagement with the ruins and their conservation. The output of this paper (the conservation strategy and the virtual models) prepares a rich platform for the second stage of the conservation process where feedback on the conservation proposal from the public, academics and professionals will be sought in order to proceed to the design stage and finalise designs and details of the interventions.

The main limitation has been that there is no 3D documentation of the original fabric in Ugarit. Therefore, we had to build a virtual model of the Plaza's original fabric using ArchiCAD program, which does not provide a realistic perception of the ruins' materiality as much as other technologies (e.g. photography-based) would do. Thus, building a 3D virtual model of the excavated fabric in Ugarit would be a key future project that would enhance the site's engagement and communication as well as contribute to both its conservation and presentation.

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VISUALISING HERITAGE-MEMORY

The paradigm of Chambers Street

NIKOLIA KARTALOU
Edinburgh School of Architecture and Landscape Architecture
N.Kartalou@ed.ac.uk

Abstract. Aristotle in his treatise, *On the Soul*, defined memory as knowledge of the past, obtained through seeing, sensing, observing, listening and learning. Memory can be envisaged as the mental imprint of an image that can be recalled through the experience of existing objects and places. How is cultural heritage related to the experience and knowledge called memory? Why do memories appear to have a strong influence in unconscious spatial perception? How can visualisation techniques activate heritage-memory? Buildings, as tangible elements of the historic city, disclose the memories of the past into the present, and direct us to an experience of time through matter. Buildings serve as a link bridging the past with the present, and eventually, the future sites of memory. Their fabric is constantly altered with engraved layers of historical change, a sequence of past events which emerge from the remnants of their structure. The past, imprinted on the city's artefacts, manifests its tangible form, and through a new reading of heritage, as 'heritage-memory', immaterial qualities of previous eras can perhaps be revealed. This paper, part of an ongoing research situated in between theory and practice, argues that the immaterial elements of cultural heritage emerging from historic urban spaces, can be critically explored in a new way through the use of digital technology, as a tool to revisualise the memory of a locus. Taking Chambers Street in the Old Town of Edinburgh as a site of focus, this presentation demonstrates several steps towards visualising the heritage-memory of the site. The paper poses the question of how the site might serve as a memorial itself, revealing to the observer the knowledge of past events engraved on its locus. Chambers Street serves as a paradigm of constructing a virtual narrative of heritage-memory, examining the site in parts and whole.

> "Memory takes root in the concrete, in spaces, gestures, images, and objects; history binds itself strictly to temporal continuities, to progressions and to relations between things. Memory is absolute, while history can only conceive the relative." (Nora, 1989: p. 9)

1. Ways of *parāstasis* [1]

While this research aims to explore the embodiment of memory in space, both the relations between the observing subject and ways of *parāstasis* have to be examined. Assuming that imagination requires the insertion of "mental pictures" (Yates, 1992: p. 33) from sense perceptions into the continuum of memory, the conceptual apparatus of heritage-memory that will be presented in the following section of this paper, can serve both as an analytical tool, and as a matrix towards shaping practical criteria for digital representation of 'non-tangible' heritage. The aim is to activate the notion of heritage-memory through analogue and digital objects that could allow one to appreciate a more complete image of cultural heritage. On that account, the following sections of this paper will illustrate approaches towards analysing a site of focus (Edinburgh's Chambers Street), by employing the visual competence that digital means provide with the support of the "mimetic capacities of analogue media" (Crary, 1992: p. 1).

Since this paper proposes ways that digital technology can be utilised in order to expose 'non-tangible' heritage, it is important to outline the distinction from other digital heritage approaches. While digital heritage is usually applied to visually reconstruct an artefact in order to document, detect or diagnose its hidden vulnerabilities (such as the examples of Scottish Ten, UK Thermography Authority, and Visualising Venice' works), here the interest lies on the intermediate interplay between the real and the virtual in an existing urban environment where the past is not always detectable on the present fabric. The examination also concerns settlements with layers annihilated or even buried under or within the present artefacts. This enquiry demands the use of appropriate means of representation, with the aid of technological tools with unrestricted utilities (Allen, 2009: p. 81), in order to expose the invisible notion of heritage-memory that emerges from a *locus*.

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[1] Ways of presentation. The term *presentation,* (Aristotle, transl. by J. I. Beare), was originally used from Aristotle as *parāstasis* (Greek: *παράστασις* < *παρίστημι* < *παρά* + *ίστημι* – 'bring a form into existence') which means 'to manifest something in front of someone'. It was used by the ancient philosopher in order to state that human cognition is impossible without (mental)images.

2. Heritage-memory

2.1. ARCHITECTURE AS THE TÉCHNĒ OF CULTURAL HERITAGE

Architecture (Greek: *αρχιτεκτονική* < *αρχή* – 'principle' + *τέχνη* – 'art' or *τεκτονική* – 'construction / creation') can be understood both as the *téchnē* (Greek: *τέχνη*), or else, the craft knowledge of construction, and also, as the *epistémē* (Greek: *επιστήμη* – science) of creating physical structures that serve human needs (see Heidegger, 1969). On that account, monuments and historic buildings, as material elements originating from the *téchnē* of architecture and falling into the category "of outstanding universal value from the point of view of history, art or science" (UNESCO, 1972), signify an essential aspect of what is called 'tangible cultural heritage'. The latter, and in consequence of the valued artefacts it encompasses, discloses an ethical view on the field of architectural conservation. In this sense, 'tangible cultural heritage' is narrated through history, which according to Pierre Nora is the indicator of knowledge acquired by investigating the past (1989), and thus it is highly associated with 'intangible cultural heritage'; the complex notion that includes knowledge related to human development, social principles and oral traditions (UNESCO, 2003). That said, heritage, referring to 'valued objects and qualities that have been passed down from previous generations' (Oxford English Dictionary), carries the notion of time, and manifests bonds with the past by material and immaterial means.

Yet, architecture, as the *téchnē* addressing human needs, presupposes a direct interaction of humans and space through its function, with the latter being articulated while users experience a space. The correlations between experience and architecture can be expressed through the tangible objects that shape the space – the buildings – whose value can be assessed in time. Their enduring architectural/urban fabric [2], implies a commitment to history while, from an anthropological and ethnographical perspective, human generations intertwine with the artefacts. This interrelation of humans with material artefacts perhaps echoes Aristotle's description of *the present* and *the past*, with the former understood as a *sense-perception*, and with the latter relating to *memory*, i.e. "neither perception nor conception, but a state or affection of one of these, conditioned by lapse of time" (Aristotle, transl. by J. I. Beare).

[2] The term *fabric* refers to "[…] all the physical material of the place including components, fixtures, contents and objects." (Burra Charter; 1999, P. 2)

2.2. 'NON-TANGIBLE' HERITAGE; AN APPROACH

In Plato's passage *Theaetetus*, Socrates describes *memory* as a block of wax in humans' souls symbolising the gift of knowledge they received from Mnemosyne, the daughter of Uranus and Earth and mother of the Muses (Yates, 1992: p. 36). Mnemosyne, also known as *Mnēmē* (Memory), was one of the three precedent inspirational goddesses of arts in ancient Greek mythology, and a figure encompassing both nature and ether, giving birth to both material and immaterial forms of expression. A similar mouldable surface relating to *memory* is also described in Aristotle's treatise *On Memory and Reminiscence*. The point of interest, and following Frances Yates' analysis, is that Aristotle relates the imprint of *memory* with that of *imagination* by suggesting that both "belong to the same part of the soul", since both are associated with experience and knowledge (Yates, 1992: pp. 32–34).

Drawing from Aristotle's writings on memory and in conjunction with a wider context of a theoretical framework stated in short below, this paper aims to introduce a new reading of heritage of the historic city [3] as heritage-memory. The conceptual apparatus shaped for the purpose of a wider research on 'non-tangible' heritage, borrows the concepts of *heterotopia* (Foucault & Miskowiec, 1986), *emergence* (Serres, 1995) and *meshwork* (Ingold, 2007). Epigrammatically, the framework suggests the examination of the historic city as a heterotopic constitution where the tangible elements of heritage juxtapose in space as representations of estrangement. The half-real/half-fictional space that heterotopia (Foucault & Miskowiec, 1986: p. 24) indicates, is loaded with immaterial qualities that every artefact brings in the city, and provides the *soundscape* of a city's timeless repetition. This 'murmur', in Michel Serres' words (1995, p. 13), assumes a virtual condition, where all possibilities are present and ready to emerge from the fabric, as the 'multiple' reveals itself, through the amplification of events and moments. These occurrences presuppose humans' entanglement with the city while experiencing it. The interconnections of people with artefacts, indicate a *kind-of* experience, where all individuals observing and experiencing the urban fabric constitute lines of a 'breathing' meshwork (Ingold, 2007: p. 72–84), equally shaping the emergent immaterial qualities of a historic city; or else, the 'non-tangible' elements of heritage.

Ostensibly, this association with memory requires objects, and by extension, images, in order to identify and reveal what is yet-to-be

[3] The term *historic city* refers to a city that has maintained its heritage values, through a significant number of protected architectural artefacts of previous eras, within a socio-political and economical framework, while being important from a historical, scientific, aesthetical and technological point of view.

uncovered; especially when only the tangible has the privilege of being seen, sensed, observed and listened to. Buildings have the potential to reveal memories of the past, since the space they form is part of the reality we experience in present time. By exploring heritage city through the theoretical framework and its connection with the concept of memory, the following section of this paper will discuss ways to revisualise a locus through digital and analogue means, in order to explore, identify and reveal, 'non-tangible' heritage.

3. The Paradigm of Chambers Street

3.1. LOCUS

"*Locus* is the relationship between a certain specific location and the buildings that are in it. It is at once singular and universal" (Rossi, 1982: p. 103). The significance of the locus not only lies on its identity, as a place [4] that reflects the social, morphological and historical values that has established its uniqueness, but also on its capacity of being the *starting point* of the process of recollecting the contents of memory (Yates, 1992: p. 34–35). Echoing Aristotle, memory requires knowledge, while knowledge premises presentation (*parāstasis*). As memory needs a stimulus to be recalled, in a similar manner, heritage-memory involves objects to expose and unveil past events. In the interest of examining the complex interconnection of memory and locus, Chambers Street was selected as a site to explore, while responding to criteria associated with its location and also character. The area illustrates an old side of a larger period of time with established layers of history in the urban fabric during the city's transformation and expansion. It contains architectural characteristics of different eras engraved on the locus, while the majority of buildings that occupy the street represent significant values, usage and ethos (i.e. Old College–University of Edinburgh, National Museum of Scotland, Crown Office–Sheriff Court, Minto House–Edinburgh School of Architecture and Landscape Architecture, etc.).

3.2. PARTS AND WHOLE

The history of Chambers Street was examined from the period of 12th century onwards, comprising a range of tangible and intangible

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[4] The term *place* is used here following Burra Charter's (1999) definition: "Place means site, area, land, landscape, building or other work, group of buildings or other works, and may include components, contents, spaces and views."

interdependent parts. It is separated in relation to the condition of interdependence of the (two scales) buildings as tangible parts of the urban whole, and the site in its totality. Architectural parts and urban whole are inextricably intertwined, since the amount of information gathered for buildings as entities cannot be interpreted separately from their location, and the location itself cannot be investigated without the artefacts composing it. Therefore, the buildings' tangible connection with the locus manipulates to a certain extent the investigation, the experimentation and also the analysis of findings.

The collected data, concerning mostly the history of the site and its previous condition(s), illustrate information gathered from various sources, such as archives and online databases; while they vary in nature (analogue and digital) and also in type: texts, diagrams, oral, audio-visual records, maps and drawings. As far as the current condition of Chambers Street is concerned, the site was examined independently through the lens of architectural and urban scale, and conjointly, through in situ visits, corresponding to static or moving point of observation. The fieldwork involves mostly visual and photographic surveys, in conjunction with archival sources regarding the listing of the buildings, planning applications received and usages. Preliminary analogue means, such as sketches, have been used at the first stages of analysis, for the comprehension of the urban tissue and its morphological transformation in time. Even though the analogue techniques used concern mostly the first steps of analysis, digital means were preferred for the following stages, since "elements and details are continuously added, stored and filed, all in perfect transparency" (Allen, 2008: p. 76) with the aid of computer technology. The examples shown briefly below concern exclusively the tangible components of Chambers Street, due to the primary interest on the instrumentality of the site's architecture.

The urban-tangible scale outlines the evaluation of findings and serves as the starting point of the site's analysis. Historic maps have been collected, from 1765 until today, thirty-five in total; yet, only twelve have been selected and interpreted, as verified to illustrate accurately, to the greatest degree possible, the geometry of the site, and by extension, of the surrounding area. The selected maps were displayed in a chronological order, following a timeline with distances between them in proportion to the eras illustrated. This allowed a further examination of the historical changes which had occurred on site over time, allowing a rigorous experimentation of the urban tissue through established but also empirical design techniques. The results of the transformation of the urban morphology of Chambers Street during the years examined is shown analytically in Figure 1, where an overall perspective of key dates illustrates the total change and expansion of the original settlement, revealing values such as integrity and authenticity.

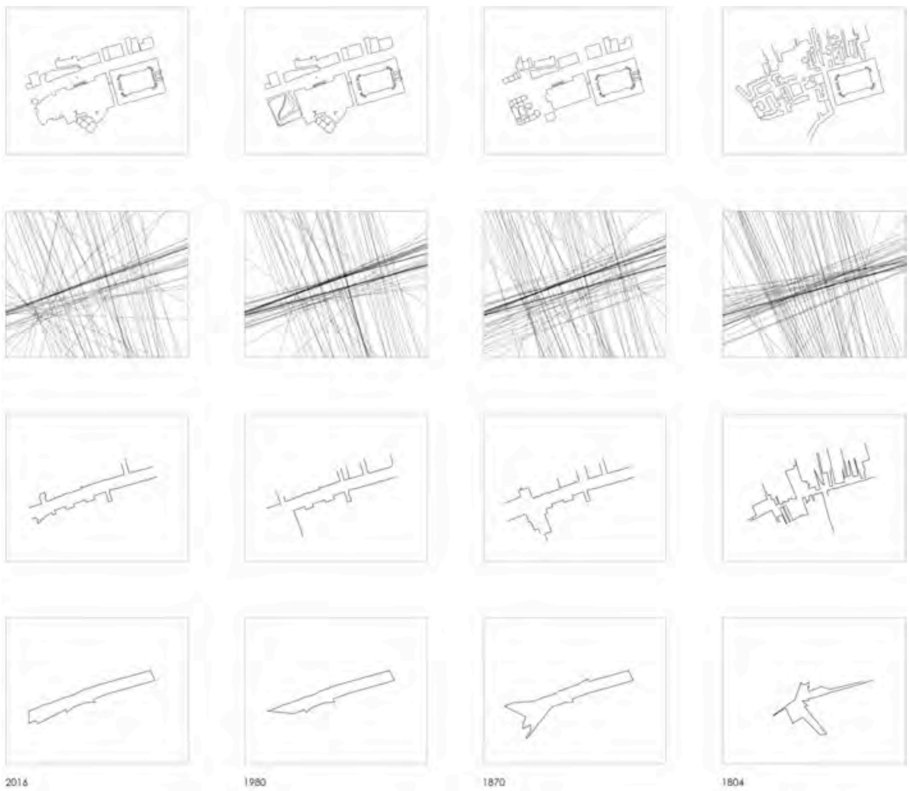

Figure 1. Chambers Street transformation. The maps illustrated here as selected parts of an 'urban timeline' reflecting the transformation of Chambers Street from 1804 until nowadays. Only a few key dates are presented here, in a chronological order from right to the left. The drawings from top to bottom illustrate the following: (i) plans, (ii) coordinates of the urban fabric, (iii) urban space between the artefacts, (iv) visual field from the view point of William Chamber's statue (before its relocation on August 2016*)*.

The architectural-tangible scale concerns the buildings as entities, where their morphological and typological characteristics were surveyed and collected in categories within indexes. Indicatively, the details documented involve dates of construction/alterations/demolitions, usages in different periods, decorative details (such as panels, coat of arms, carved inscriptions, incised letters, carvings, statues and busts, name of the buildings, architects and sculptors, and also archaeological findings subsisting on the fabric). The different typologies, surveyed and observed, have been translated to drawings with the aid of QGIS, where different categories were illustrated in one drawing (Figure 2). Every structure presents information about the past condition of its fabric.

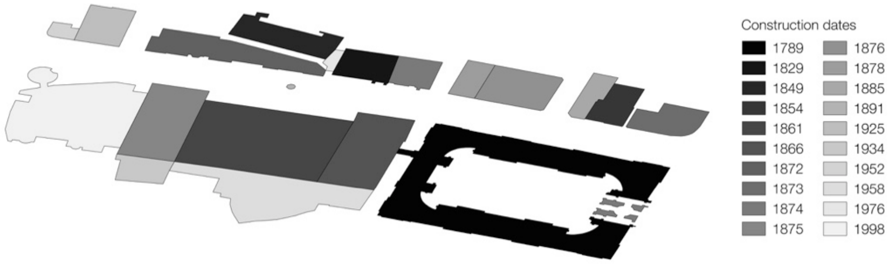

Figure 2. The drawing illustrates the different dates of construction of the buildings in Chambers street. Each building was surveyed separately and the results of the information found concerning their structure are displayed here as an ensemble.

4. Epilogue

Citing Foucault: "The problem is to let knowledge of the past work on the experience of the present. It is not at all a matter of coating the present in a form that is recognized in the past but still reckoned to be valid in the present." (2008, p. 130–131) The analysis above reflects in its majority the artefacts of the site and their tangible characteristics, illustrating Chambers Street's transformation in time. The data gathered from archival sources, in conjunction with site observations, introduce a comprehensive reading of the site and they also reveal multifarious information concerning past conditions of the urban fabric. At the moment, the embodiment of memory is investigated in regards to the morphological alterations of Chambers Street as a tangible historic city site. This investigation provides a step towards the 'non-tangible' dimension of social conditions during the period examined, relating to usages, movements and prominence of the area in connection with the city.

Echoing Aristotle, the *knowledge* of the past can be acquired through the *experience* of the present. Therefore, the immaterial qualities of space, related to the experience of the site by observers, need to be examined further, in order to develop a complete and more coherent view of heritage-memory. These intangible elements, such as melodies, smells, sounds and oral stories, can be revealed with the aid of digital means through a notational strategy, producing a kind of "directed indeterminacy" (Allen, 2008: p. 64), in combination with QGIS based assessment methodologies. The aim is to allow, a step closer, the *knowledge* acquired for the visualisation of the imaginable heritage-memory.

Acknowledgements

I would like to thank Dr Ruxandra-Iulia Stoica and Ms Suzanne Ewing for their most helpful comments. All maps illustrated were reproduced with the permission of the National Library of Scotland and Digimap © 2016.

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PARAMETRIZING INDIAN KARNATA-DRAVIDA TEMPLE USING GEOMETRY

SRUSHTI GOUD
BMS School of Architecture, Yelahanka, Bangalore, India
goudsrushti@gmail.com

Abstract. The Karnata-Dravida temple tradition flourished and evolved for 700 years. The evolution of the typology was demonstrated through the structure. However, as the *Shastras* or ancient texts proclaim, the underlying principles of geometry remain unchanged. Geometry and the unchanging principles of construction made the architects experiment with form, material and ornamentation. Geometry does not only mean shapes or two dimensional diagrams but it is a rule to amalgamate all the elements to form a dynamic form of a temple.
The paper validates the use of geometry through an evolving sequence of Karnata-Dravida temples with the help of an analytical model created using the grasshopper software. The components of the model are based on the geometric rule (the basis for parametrizing) and parameters of the algorithm – plan forms, organizational compositions, *vimana* or superstructure composition – which result in a geometry. Even though building science is an old tradition, the use of computational procedures reveals the predictable nature of temples in the Dravidian clan and enables the analysis of existing temples, development of new possibilities or evolution of interpreted forms. Hence, enriching the existing understandings of previous scholarships in the field of temple architecture with an entirely new system of interpretation.
In the age of technology where analytics plays a crucial role in almost all sectors, ancient temple architecture in India unfortunately falls behind when it comes to computational methods of restoration or reconstruction. This research questions the applicability of computational technology as a facilitator in preserving or reconstructing existing temples while maintaining its creative liberty.

Keywords: Karṇāṭa-Drāviḍa Temple, Geometry, Parametric Design

1. Introduction

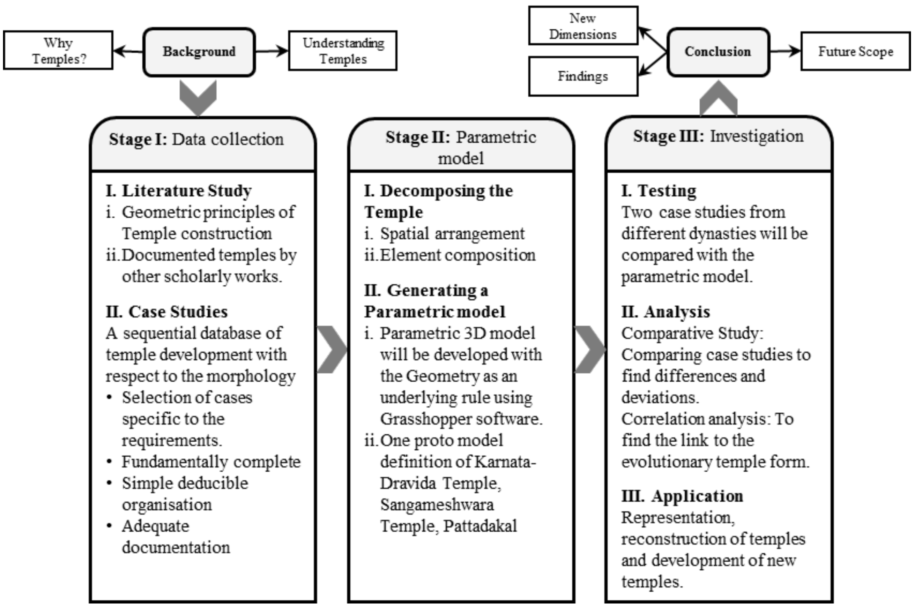
Flourishing rulers of India considered temple construction as a way to exhibit their power and supremacy to the common people as well as their counterparts. The requisite to build temples better than the other rulers led to an evolutionary flow. In political discourse, the grandeur of an era, rule or dynasty was showcased not through the dwellings but through the magnificence of their religious monuments. Developments followed the same ruler or fundamental principles as their predecessors and were thus termed as evolution. The continuity was backed by the fundamental norms that were listed down in manuscripts that were strictly followed. Squares and triangles were the basic units of the principles governing the temple model. The temple form does not seem to have suffered any limitations by following the grid. The question that Volwahsen (1969, p. 3) puts forward, "is it possible that this profusion was only able to develop because it was based upon a grid?". The principles and measurement systems that the temples cohesively used for construction were listed in manuscripts even before this typology started. Without the knowledge of parametric processes, temple construction used complex geometries and evolved with time. Today, we are trying various permutations to interpret the transformation seen in the centuries of temple development may it be visual, social, political, geographical or more.

Indian temples were mainly classified in three styles namely Nagara (north Indian), Dravida (south Indian) and Vesara (hybrid). This research limits itself to only one style, i.e. Dravida, especially in Karnataka, one of the reasons being the availability of well-documented information and drawings. This study will analyse the use of geometry in the design development of Dravidian temples in Karnataka through a timeline. The term morphological evolution can be divided into smaller fragments or components. There are two levels to the understanding of the component composition, the first being a fundamental unit that becomes the primitive article of design. The second level is the use of this fundamental unit and types of geometries to create a complex composition. In totality, the design is a two-way process where on one hand, it has evolved from the most basic elements put together, while on the other the fundamental unit itself has evolved with time with the above mentioned influences (Hardy, 1995). By doing so, the arrangement can be mathematically explained and a formula can be created which serves as a template for all chronological structures. Analytically approaching the study of temple development needs an external instrument. Computer technology shows promising prospects for efficiently analysing as well as periodically documenting the temples.

2. Methodology

This research is taken forward in a qualitative approach with the following components: literature based study initially, case study analysis, generation of parametric model followed by experimentation through computation. The methodology is summarised systematically in Table 1.

TABLE 1. The three-stage methodology of the research.



3. Case Studies

The Karnata-Dravida tradition began and matured entirely during the reign of the Early Chalukyas (Hardy, 1995). A few temples from all three phases are studied in order to justify the evolution and completion of typology, though only two have been detailed here since one was built during development phase (Upper Sivalaya Temple, Figure 2) and the other during the matured phase (Sangameshwara Temple, Figure 3). The later temple forms the proto definition for the type and is used to develop the script. However, typology remained unaltered during the Rastrakuta rule but a strong influence of the Nagara temple is observed in temples constructed by the Later Chalukyas and Hoysalas (timeline shown in Figure 1).

Note: Only Shiva temples are chosen throughout the tradition in order to maintain the uniformity in sculptural ornamentation.

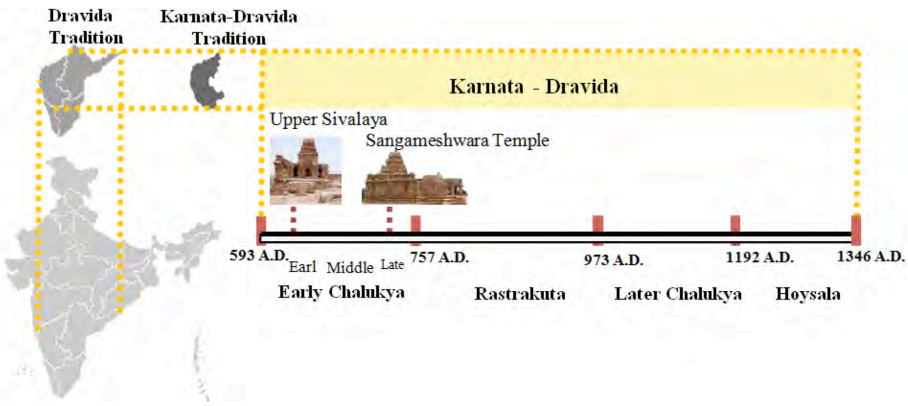


Figure 1. Timeline of Karnata-Dravida Temple tradition under various dynasties.

3.1. UPPER SIVALAYA, BADAMI

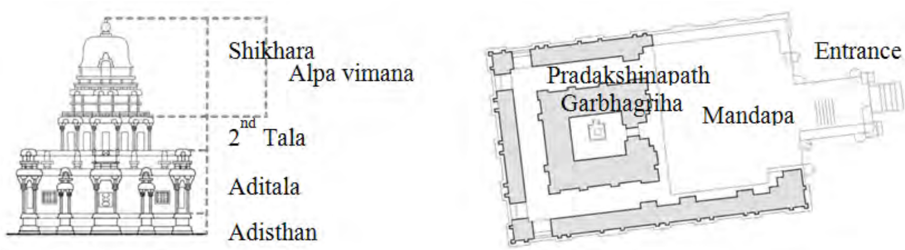


Figure 2. Upper Sivalaya.

Plan Forms: Square plan with shallow projections of aedicules

- Sandhara(with an ambulatory) temple

Organization Composition: Consists of the garbhagriha or sanctum with an ambulatory path and an attached mandapa (pillared hall, seen for the first time) and porch

Vimana Composition: Dvi-tala(two floors) topped with alpa-vimana(monolithic temple)

- Kuta(K)-Sala(K)-Kuta Projection System, seen on first tala Adisthana(plinth) is primitive

3.2. SANGAMESHWARA TEMPLE, PATTADAKAL

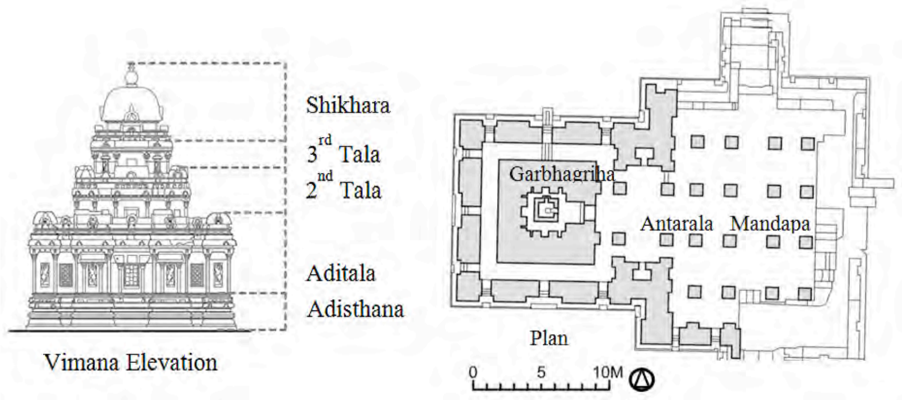


Figure 3. Sangameshwara Temple.

Plan Forms: Distinct projections

- Sandhara temple
- Antarala or vestibule with 4 pillars

Organization Composition: Consists of the garbhagriha, a developed antarala and mandapa consisting of 4 rows of pillars

Vimana Composition: K-S-S-K Projection System is seen on aditala (ground floor) and K-S-K on the second tala

- Adisthana consists of developed parts

TABLE 2. Inferences from Case Studies.

Facets of the temple	Attribute	Parameter of the attribute
1. Temple in two dimension	Garbhagriha as the focal point	Vastumandala, Nirandhara or Sandhara, Projection system in plan
2. Temple in three dimension	Height and components of Vimana	Talas, Shikhara, Adisthana
3. Arrangement of spaces	Composition of temples with respect to the functional spaces	Vimana, antarala, mandapa, entrance porch and nandi mandapa

4. Analytical Parametric Model

The model is developed in 3D using the inferences from the cases (Table 2). For easier understanding it is briefly explained under three headers, i.e. plan form of the garbhagriha, organizational composition of the temple and the Vimana (superstructure), with its associated geometrical rule.

4.1. PLAN FORM

Application of Vastumandala: A suitable grid is selected from the thirty-two mandalas available of 4, 9, 16, 25…1024 squares or padas (Figure 4).

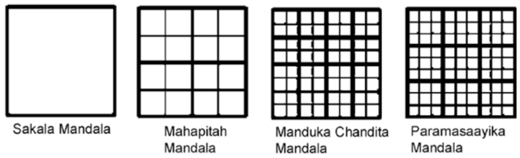


Figure 4. Few types of mandala (Rian, 2007).

Ad-quadratum: The method to determine the walls and its thickness around the garbhagriha where the length of wall is M and length of exterior wall is √2M (Figure 5).

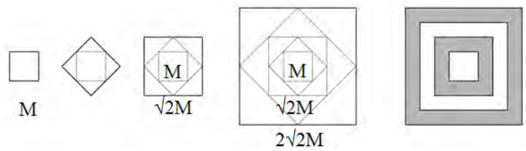


Figure 5. Determining thickness of walls.

Projections on Aditala: Different possible arrangement of aediculer arrangements with three types of aedicules Sala, Kuta and Pajara (Figure 6).

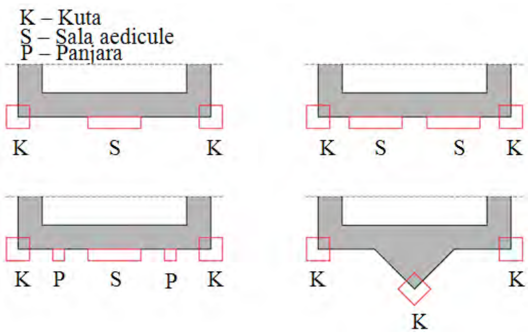


Figure 6. Aedicular Projections

4.2. ORGANISATIONAL COMPOSITION

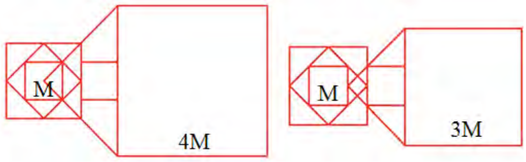


Figure 7. Proportioning the Mandapa

The size of antarala, mandapa, Nandi mandapa etc, are all proportional to the cella length (M) (Figures 7 and 8).

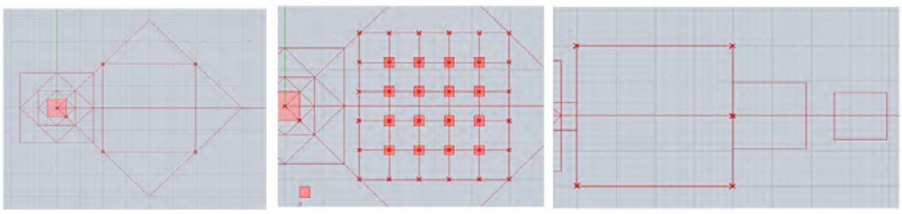


Figure 8. From left; Sizing the mandapa; columnar arrangement inside the mandapa; axially arranged entrance porch and Nandi mandapa.

4.3. VIMANA COMPOSITION

The typology was fundamentally complete by the construction of Sangameshwara temple therefore it forms the proto model definition to be parametrized. The adisthana (Figure 9) and talas (Figure 10) are developed in concurrence to the prescriptions suggested by Hardy (2009: p. 43).

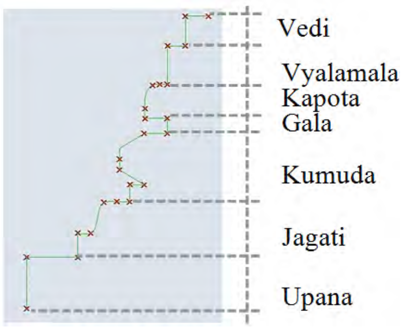


Figure 9. Parametrically developed parts of the adisthana of Sangameshwara temple, Pattadakal (Hardy, 2001).

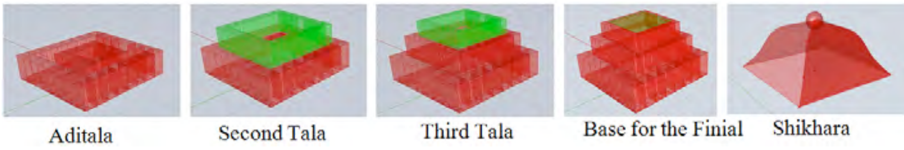


Figure 10. Development of Vimana using prescribed widths and heights of the temple in accordance to the number of storeys (Hardy, 2009: p. 43)

4.4. PARAMETRIC REALIZATION OF SANGAMESHWARA TEMPLE

The various components of Sangameshwara temple are parametrized and the results are shown in Figure 11. In a similar manner all the temples with equal or lesser complexity can be represented through this model.

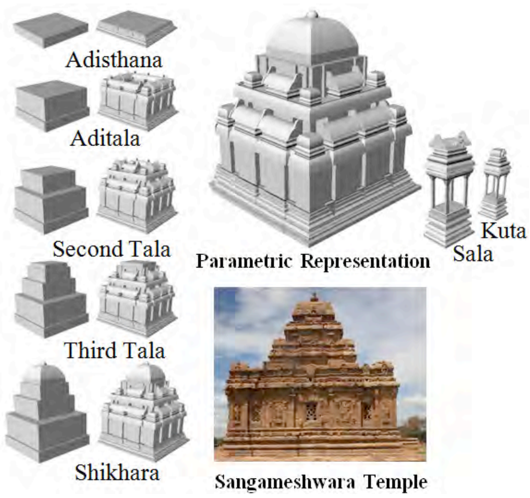


Figure 11. Stages of temple development shown through the parametric model.

5. Application of the Model

See Figures 12 and 13.

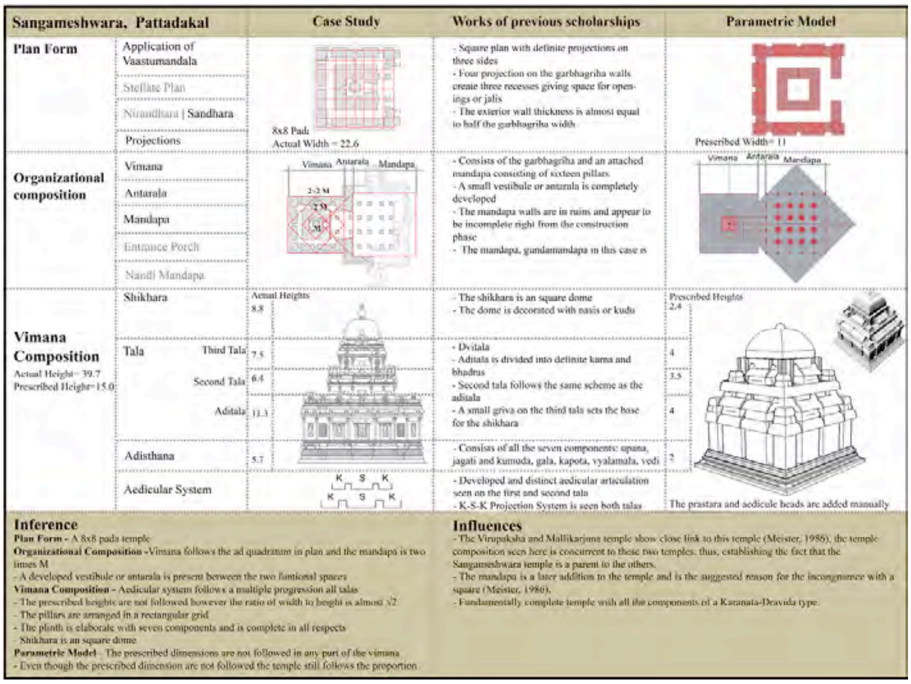


Figure 12. Comparative analysis of Sangameshwara Temple, Pattadakal

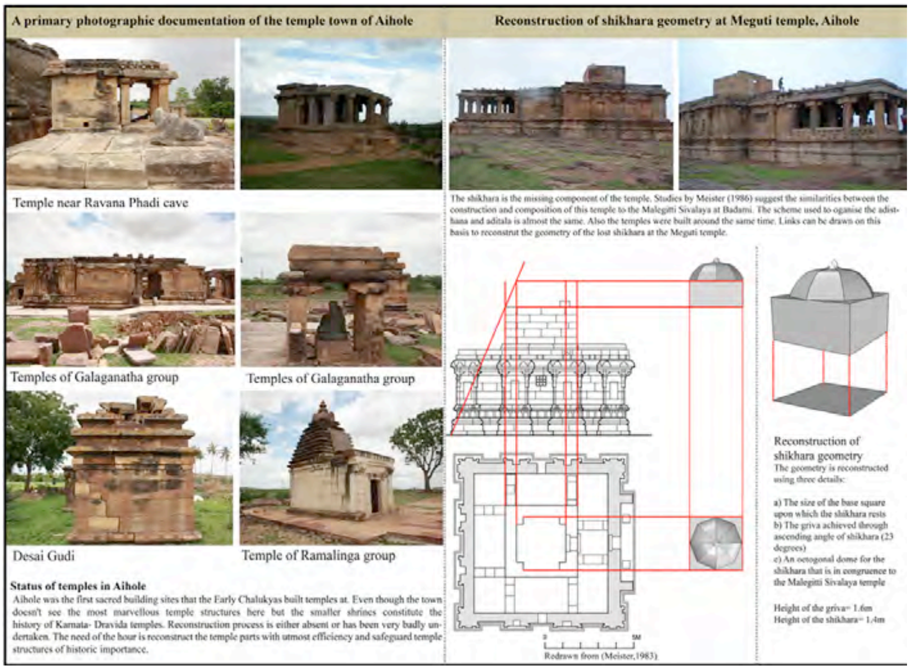


Figure 13. Reconstruction of temple parts.

6. Discussion

Geometry's major role and contribution according to various literary works, such as the Samaranganasutradhara, was in establishing a relationship between width of the innermost shire and elevation of the temple. A mathematical relation was inferred from the existing designs between the width of the garbhagriha, the total height of the vimana and the individual heights of various independent components composed together to form the vimana. Though, not concretely justifying its role in the evolution, the inferred relation would act as a boon in the restoration and reconstruction of Karnata-Dravida temples. Hence, application of geometry and its computation can open a plethora of opportunities in not only studying the existing but also in creating a new paradigm. The interesting factor that can be derived from the above statement is that the study of the elevation shouldn't be confined to its elevation characteristics, but should be studied in conjunction with the plan, of which it is a translation. Therefore, the question or the possibility that needs to be explored is the effectiveness of the parametric model in the restoration of existing designs. This research definitely raises a few pertinent questions considering the rich culture and heritage that India exhibits and they are:

1. Are we doing justice to the current scenario of reconstruction of temples?
2. Can computational technology act as a facilitator in preserving or reconstructing existing temples and still maintain creative liberty?

7. Conclusion

The parametric model shows sufficient results to understand the role and relevance of geometry in temple evolution. The chronology of the evolution of architectural components and sculptural decorations or aedicules can also be tested from the model. The deviation from the manuscripts seems to come across as very subtle, with not much disturbance to fundamental geometry. Weighing each of these inferences individually and later amalgamating their contextual translations clearly shows geometry's significance in typology evolution.

7.1. SHORTCOMINGS AND FUTURE SCOPE OF RESEARCH

Considering the severe levels of complexity seen in the design of ancient Dravidian temples constructed during the later stages of tenth century, the parametric model raises concerns about its application in the analysis and applicability on ornamentation being the torch bearer of this complexity. This research can be further developed with enhanced attention to detail, at both macroscopic as well as microscopic level. Successful establishment of a script which could also help in generation of the aedicules, would not only be path-breaking but also revolutionary, as it would change the way Indian temple architecture is currently preserved and documented.

Acknowledgements

This research was a part master's thesis submitted to CEPT University, Ahmedabad. I am thankful to the University for permitting me to present it at an international forum. I express my sincerest and heartfelt gratitude to my research guide, Prof Nitin Raje for his constant guidance and support. I would also like to thank Prof Krishna Shastri, Dean of SID, for being a constructive critic and for pushing me hard to believe in the ideology of excellence.

Whatever I am and whatever I will be is all because of my family's love, care, patience and sacrifice. My family has been extremely supportive and has always encouraged me to chase my dreams and pursue my passion. Thanks alone would be insufficient to acknowledge them.

I would also like to thank Nikita, Vinay, Rishabh, Kriti, Shilpy and Mayuri for their valuable and memorable friendship. I thank them for being there through thick and thin.

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COMPUTATIONAL INTERPRETATIONS OF 2D MUQARNAS PROJECTIONS IN 3D FORM FINDING

SEMA.ALAÇAM AND ORKAN. Z. GÜZELCİ
Istanbul Technical University, Istanbul
semosphere@gmail.com | *orkanguzelci@gmail.com*

Abstract. In the scope of this study, we developed an algorithm to generate new 3D geometry (interpretation) of a given or generated planar projection of a muqarnas in a digital 3D modelling software (Rhinoceros), its visual scripting environment (VSE) Grasshopper and also the Python programming language. Differing from traditional methods, asymmetrical form alternatives are examined. In other words, 2D projections of muqarnas were only used as an initial geometrical pattern for generative form finding explorations. This study can be considered an attempt to explore new relations, rules and vocabulary through algorithmic form finding experiments derived from 2D muqarnas projections.

1. Introduction

As an architectural element, it is possible to come across Muqarnas in a wide geographical zone from Spain to India. There are different opinions about the origin and development of it, tracing back to the 4th or 10th century (Dold-Samplonius, 1992). One of the earliest, major and written resources on muqarnas is Al-Kashi's "Key of Arithmetics" book, which covers arithmetic and geometric definitions of muqarnas construction for artisans/ master masons (Al-Kashi, 1977 [1472]). Harb's (1978) study provided another basic foundation for researchers in this field. The focus of the related studies increased from early 1990s and can be read in three decade-based directions: 1990s as descriptive- and typology-based approaches, 2000s as geometrical decoding and 2010s as exploratory computational studies.

The common denominator of most of the studies on muqarnas is its decorative potential. A few recent studies examined the structural, functional and performative potentials (Hensel, 2008; Abbasy-Asbagh, 2013) and algorithmic reconstructions (Yagdan, 2000; Harmsen, 2006) of muqarnas. Another common tendency in muqarnas studies is using pre-redefined typology and definitions. However, 3D muqarnas formation might provide new insights to the mathematical understanding of form beyond its aesthetic and ornamental qualities in the digital age. In other words, muqarnas formation has potentials to be decoded by a series of rules, algorithms or topological relations instead of only considering the pre-defined components.

In traditional construction practice, artisans/master masons have been gaining the practical knowledge by constructing on site or from definitions in manuscripts. There were constraints derived from the material selections, construction methods and building on site. The 2D patterns were designed firstly and then used as a base for 3D constructions. A collection of these 2D drawings can be found in Notkin's (1995) study. Dold-Samplonius (1992) also mentions the usage of predefined elements and their assembly. These constraints and reasons might have affected the emergence of limited amounts of novelty in muqarnas formations. We acknowledge that in the scope of this paper we neglect the material usage and the technique in historical muqarnas construction.

2. Related Studies on Muqarnas

It is not possible to approach studies on muqarnas in separated periods with concrete properties. Keeping this in mind, in order to gain a comprehensive understanding, our goal is to investigate the related studies in three decade-based periods: Description (1985–1995), Decodification (1995–2005) and Interpretation (2005–2015). A property, method or approach that we introduce might be seen in all three periods; however, we made assumptions based on the distinction of the characteristics.

In the first period, manuscripts of Al-Kashi and his calculations were studied (Özdural, 1990; 1991). These calculations and definitions constituted a basis for the further study (Harmsen, 2006). Some 2D (Figure 1A) and 3D (Figure 1B) geometric relations by Al-Kashi were introduced by Özdural (1990). Those typological definitions are helpful for explaining the production process in detail. On the other hand, the aspects of design and compositions were neglected in Al-Kashi's concrete descriptions (Özdural, 1990).

The construction process of muqarnas has usually been started by drawing the plane projections (Harmsen, 2006). Plane projections of muqarnas can be considered as simple un-interlocking patterns. In these cases, the arrangements of muqarnas elements were mostly symmetrical and the niches were also equal.

TABLE 1. Decade-based thresholds of muqarnas studies.

periods	approaches	dominant characteristics	studies
1985-1995	-Descriptive Approach	-Attempt to understand through measuring - Al-Kashi calculations on the muqarnas became popular	Tabbaa (1985); Özdural (1990); Özdural (1991); Dold-Samplonius(1992); Notkin (1995)
1995-2005	- Component-based modulation	- Decoding through pre-defined elements - Cells and filling elements - 3D interpretations from 2D patterns	Yaghan (2000); Yaghan (2003); Dold-Samplonius and Harmsen (2005);
2005-2015	- Panelling - Layering - Diagramming	- Graph-based representation; - Decoding by algorithms; - Exploring performative and structural potentials.	Harmsen (2006); Hensel (2008); Abbasy-Asbagh(2013);

Another categorization by Al-Kashi, which has been used in many muqarnas studies, is the assumption of “cell” and “intermediate elements”. The upper part of each cell involves “roofs”, vertical surfaces involve “facets” and the filling elements complement the compositions (Occhinegro, 2016).

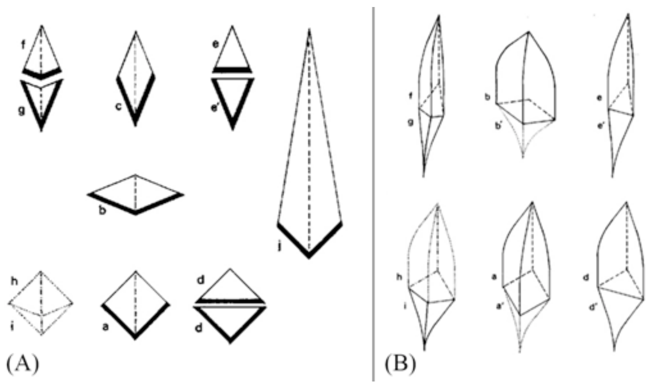

Figure 1. (A) Ceiling elements drawn according to Al-Kashi’s decriptions;
(B) 3D elements of muqarnas (Özdural, 1990, pp. 38–40).

Dold-Samplonius and Harmsen’s (2005) study can be considered as a 3D interpretation of the second period. They examined how different combinations of cell elements might constitute a row from the pre-defined elements such as square, intermediate half rhombus, intermediate biped, rhombus.

3D interpretation samples of muqarnas can be seen in Figure 2.

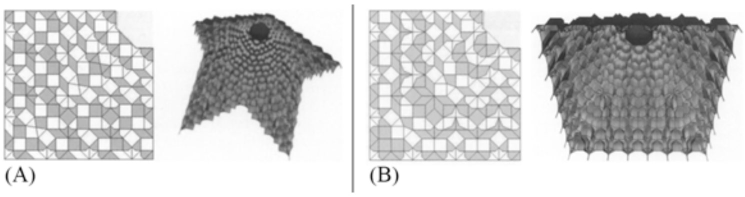

Figure 2. Redrawing and interpretation of muqarnas based on the plate found by Harb (Dold-Samplonius and Harmsen, 2005: p. 91–92).

In relation with the muqarnas codification, some categories such as scale, level of complexity, cornice or vault, the place that muqarnas settle (square-base/central column/eight arch), form of the niche were used by Notkin (1995), and point based-line base assumption, number of the layers and elaboration tools were studied by Yaghan (2003).

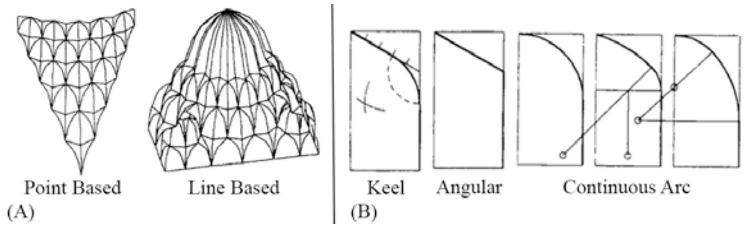

Figure 3. (A) Base type of a muqarnas; (B) Elaboration Tools (Yaghan, 2003: p.75).

3. Investigating Computational Potentials of Muqarnas

In this section we introduce our explorations on muqarnas in three parts. The first part focuses on the digital and physical modelling and encoding exercises; the second and the third parts focus on exploration of 3D form-finding algorithms, which have been derived from outcomes of previous exercises.

3.1. ENCODING MUQARNAS – MODEL-BASED EXPLORATIONS

Further to investigating the studies in the literature, we exercised with physical models. We modelled a scale-free line-based muqarnas located in Friday Mosque, Isfahan. The model starts with an octagon frame. Operations such as selection of midpoints, translations in Z direction, adding new points and connecting the vertices were used. Translation of the 3D model's information into a computer environment involved some reductions and interpretations (Figure 4).

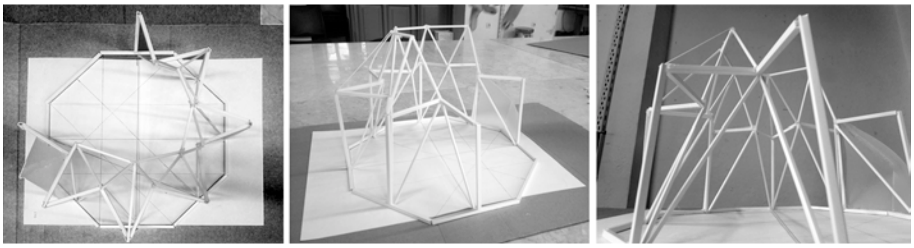

Figure 4. Contour model of a muqarnas of Friday Mosque, Isfahan.

In the translation process from physical model into digital we focused on defining parameters of a muqarnas unit (Figure 5). Instead of ‘keel’ with proper proportions, we used ‘angular’ and/or ‘continuous arc’ (See Figure 3B for the terms).

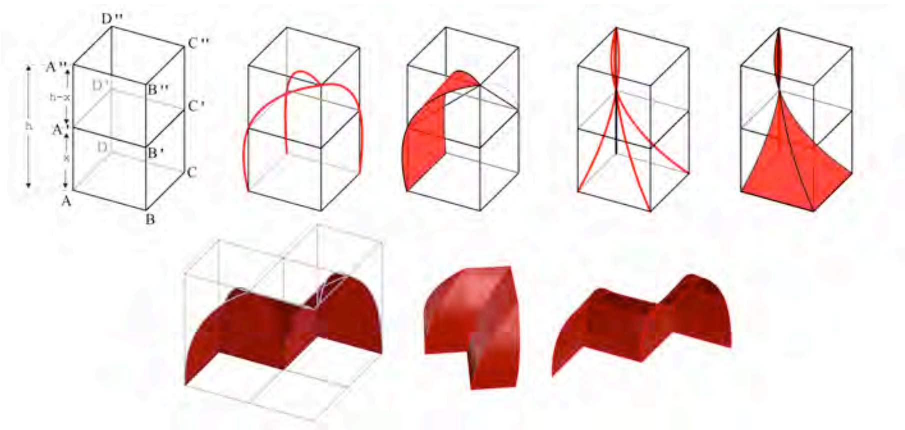

Figure 5. Modelling exercise of a muqarnas unit.

Apart from the representation of an assumptional muqarnas unit in a digital environment, the rotational and linear compositions were examined. The compositions shown in Figure 6 starts with one square. With 45 degree rotation the second square is constructed. Extracting the octagon from the two intersecting squares, adding circles to the sides of the octagon and extracting new intersection points, the following steps can be seen in Figure 6 in detail. This production was constructed manually in combination of 3D modelling and VSE. To achieve a laser cut model, the digital model was unfolded by using Pepakura interface (Figure 6).

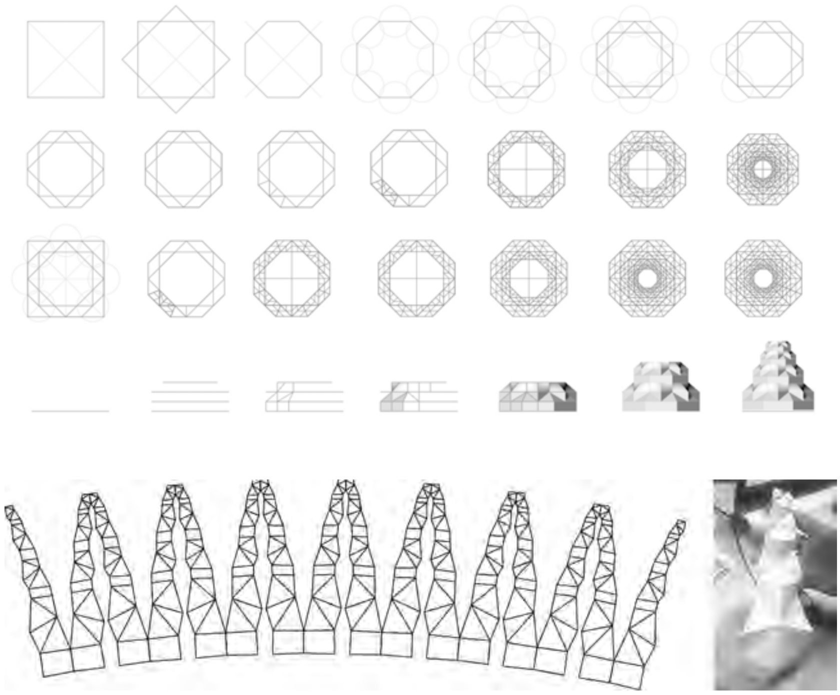

Figure 6. Modeling steps and fabrication process of a muqarnas composition.

3.2. ADAPTIBLE PATTERN MAPPING AND 3D PANELLIZATION

This approach both involves top-down (starting from a 3D surface geometry) and bottom-up (generating a unit pattern) processes. A sample generation process, in which the output was sent to the Pepakura interface and unfolded, is shown in Figure 7. This paneling method can be applied in different surface geometries. This logic of the penalization generates new sub-surfaces including new peak points, hill and valleys.

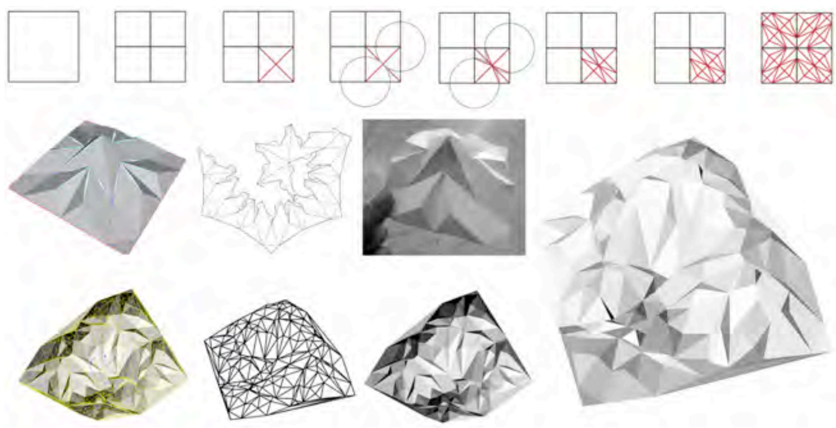

Figure 7. Mapping 2D pattern onto 3D surface.

3.3. INTERACTIVE LAYERING APPROACH BASED ON USER INTERACTION AND THE INITIAL 2D GEOMETRY

This process consists of a generation queue in which there are interactive modules taking input from users. The algorithm takes a 2D plane projection pattern as initial input. Here the critical intervention in form generation is to select points for layer lines. Here the term layer refers to contour lines in the 3D muqarnas. Height parameters for the layers can be dynamically changed from VSE. Further, the python module makes calculations for rationalization of the geometrical data and triangulates the surfaces. This algorithm can be applied to different surfaces however the boundary conditions and exception has not yet been tested.

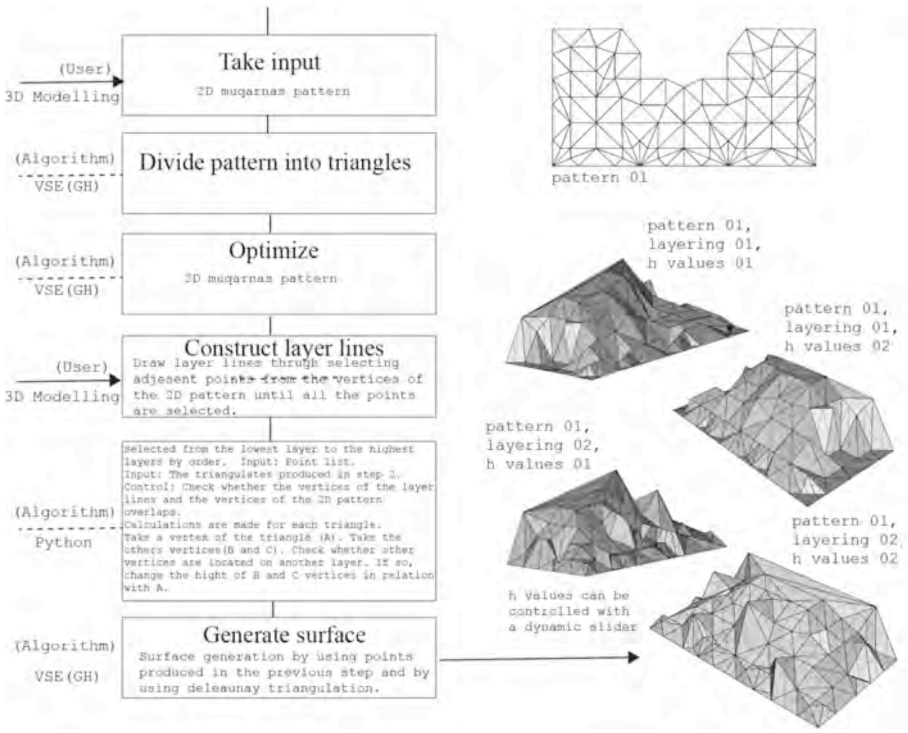

Figure 8. Algorithm schema of the 3D form generation process and samples of 3D surface geometries produced from the same 2D pattern but different layering method.

4. Concluding Remarks

Since the very beginning of its emergence, muqarnas construction had been carrying the potentials to be codified with mathematics, geometry and algorithms. Al-Kashi's (1977 [1427]) manuscripts provide core knowledge for artisans, introducing spatial and geometric relations (angles, dimensions, adjacency), rules (mathematical definitions, construction rule/order), vocabulary elements (units, cells, roofs, filling elements).

Those earliest assumptions and definitions have the potential to be encoded by algorithms. It is possible to claim that the traditional ways of constructing and the constraints derived from material properties resulted in predictable constructions and the novelty in spatial solutions or complexity of the muqarnas geometry have been limited. However, the definition of novelty is still contestable and reading a historical construction technique with today's conception, paradigms and point of view might run the risk of leading to a superficial understanding. Instead, we aim to unfold the tacit potentials of muqarnas as a foundation for today's design environment. The dominant characteristic of studies between 1995 and 2005 was approaching muqarnas with an analytic and a descriptive perspective. Component-based categorization, deterministic models and defining the parameters of the muqarnas with concrete hierarchies became common denominator for this period. After 2005, the widespread availability of digital modelling and fabrication techniques triggered the emergence of new perspectives on muqarnas (Hensel, 2008; Abbasy-Asbagh, 2013). On the other hand, we claim that the emerging digital design approaches might contribute more to exploring the unvisited potentials of muqarnas through stochastic models, topological relations, algorithmic definitions, generative design approaches, material studies or structural performance experiments. In this sense, this study can be considered as an empirical attempt to understand and interpret muqarnas through algorithmic form-finding experiments with the aim of providing a layout for the further systematic studies.

We observed that unit-based assumptions resulted in similar outcomes both in a physical and digital environment. In addition to these, the hands-on modelling and fabrication with laser cutter provided a better understanding on the geometrical organisation before/during preparation of the algorithms. The form exercises in which visual and verbal scripts were used together generated diverse results. Despite the developed algorithms being defined and closed, the selection of the initial pattern and the user decisions during the layer definition enriched the outputs with unexpected results. Moreover, the study in which only VSE was used, generated a kind of paneling method, which can be applicable to both planar and non-planar surfaces.

In our approach, it is contestable whether neglecting the historical context and the material information would still be called muqarnas studies or not. However, the focus of this study was to capture new principles and relations, which can be adapted to different contexts instead of merely developing a reconstruction, which has been achieved.

Acknowledgements

The authors would like to thank İnanç Şencan and Furkan Tüzemen for their precious contributions in developing computational interpretations.

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UNDERSTANDING INTANGIBLE CULTURAL LANDSCAPES

Digital tools as a medium to explore the complexity of the urban space

SIMONE. GARAGNANI, JAMES ARTEAGA, LUISA. BRAVO
Department of Architecture - University of Bologna, Italy
simone.garagnani@unibo.it
Carleton Immersive Media Studio - Carleton University, Canada
james.arteaga@carleton.ca
City Space Architecture, Italy
luisa.bravo@cityspacearchitecture.org

Abstract. The cultural heritage landscape (CHL) of the urban space in cities is the result of multiple layers of complexity, encompassing both the tangible built environment and intangible cultural values that together influence the living heritage that forms the spirit of place. This paper explores the gap in the intangible and living heritage documentation of CHLs by using a section of public space in the medieval historic centre of Bologna, Italy. Digital technology is used to propose a new paradigm in the study of the complex link between the tangible, intangible and living cultural heritage, co-existing in public spaces of a city's cultural heritage landscape.

1. Introduction

Heritage, which has traditionally been recognized as the architectural legacy from the past (*tangible*), is also made up of traditions and expressions of living societies that are difficult to measure (Radovich and Boontham, 2015), temporary and unpredictable (*intangible*). The cultural heritage landscape (*CHL*) formed by the urban space of cities, and their *spirit of place*, is the result of multiple layers of interconnected complexities, encompassing both the tangible built environment and intangible cultural values.

As this paper will further discuss, professionals are currently able to recreate the tangible built environment of a CHL with increasing accuracy by using digital photogrammetry and terrestrial laser scanning (*TLS*); yet, current processes for documenting the intangible dimension that contributes to the urban complexity and *spirit of place* of CHLs are often lacking a comprehensive approach. To explore this gap, a section of public space in the medieval historic centre of Bologna, Italy, was chosen as a case study to test and validate an interdisciplinary, collaborative process that the private and public sectors could use to produce innovative outcomes on the understanding of urban spaces and the *spirit of place* in cities; thus, digital technology is used to promote a new paradigm in the study of the complex link between the tangible and intangible cultural heritage.

2. Cultural Heritage Landscapes, Public Space and Intangible Heritage

UNESCO defines a cultural heritage landscape as, "*a concrete and characteristic product of the interplay between a given human community embodying certain cultural preferences and potentials, and a particular set of natural circumstances; it is a heritage of many eras of natural evolution and of many generations of human effort*" (UNESCO, 2008). In 2005, UNESCO's World Heritage Convention (WHC) adopted the *Declaration on the Conservation of Historic Urban Landscapes* that identified cities as intricate cultural heritage landscapes that result from multiple layers of complexity, encompassing both *tangible* and *intangible* values (UNESCO, 2005).

The declaration, which was a direct response to the challenges faced by professionals to conserve non-static '*urban heritage*' in living cities, further pushed traditional considerations of heritage from the architectural legacy of the past (*tangible*) to a more holistic understanding, including traditions and expressions of living societies that continuously changed and were linked to the built environment, even if difficult to measure (*intangible*). This was, of course, influenced by UNESCO's 2003 *Convention on the Safeguarding of Intangible Cultural Heritage* that recognized and defined intangible cultural heritage as, "*the practices, representations, expressions, knowledge, skills – as well as the instruments, objects, artefacts and cultural spaces associated therewith – that communities, groups and, in some cases, individuals recognize as part of their cultural heritage*" (UNESCO, 2003). Public space, which forms part of the complex urban space making up the cultural heritage landscape of a city, encompasses the tangible and intangible values of a community that in effect influence the living heritage of these places (ICOMOS, 2008). The *Charter of Public Space* (Biennial of Public Space, 2013) describes public space as "*a key element…of a community's collective life…and a foundation of their identity…*". The public space of a city becomes the domain where the tangible, intangible and living heritage of the city's CHL can be found (Goetcheus and Mitchell, 2014). Living heritage, which is formed by both tangible and intangible heritage, is understood as the actions of doing or practicing intangible cultural heritage (culture) or the process of, *"[transmitting] intangible cultural heritage…from generation to generation, [that] is constantly recreated by communities and groups in response to their environment [(tangible)], their interaction with nature [(living)] and their history [(intangible)], and [which] provides them with a sense of identity and continuity..."* (UNESCO, 2003). Living heritage moves away from focusing on the preservation of the past to a focus on how the past is used in a contemporary context, which becomes the essence of the *spirit of place*.

3. Experimental Methodological Framework

This paper describes the experimental work-in-progress that explores the development of a specific digital framework able to store, visualize and analyze public space in 3D models, inclusive of tangible, intangible and living CHLs as identified by UNESCO. The case study area for this work was selected through investigations on the architectural and urban context and preliminary "*on-site"* visits to the city centre of Bologna. This area, which is made up of two major piazzas and a public street, was used for this experiment to plan a coordinated process on how the documentation of intangible and living cultural heritage could be integrated into a digital tool.

A preliminary investigation into the *state-of-the-art* of CHL representation from a human perspective was completed following a well-consolidated scientific literature review, in order to produce an experimental tool that was able to digitally visualize elements representing the CHL of a place. The workflow began by prearranging a GIS map of the case study area and its surroundings. This first step was determined to be the traditional and primary way to approach and visualize a site in the context of Bologna. This became the basis for embedding additional information into the database. However, two-dimensional cartography was not a sufficient medium for representing the complex dynamics produced in the urban space by multiple people with intersectional identities (i.e. age, gender, sexuality, ethnicity, nationality, etc.). Users could gain knowledge about the shape and morphology of the built environment in a specific time through two-dimensional cartography with hyperlinked geotagged images, panoptic panoramas or video clips, but they still could not fully experience the potentials interactive 3D models could provide for understanding place (Bravo and Garagnani, 2013). C. Baudelaire (1995) describes how people living in the city are just like painters that are freely designing their own lives, continuously sketching on canvas. This artistic perspective illustrates the idea that places are characterized by dynamic flows; intangible and living cultural heritage could be indicators of changes, yet many spatial representations are needed to understand the relationship between the intangible, living and flows of change. Three-dimensional models were therefore chosen as the graphic media that could be linked to open *WebGIS* maps, in order to let users easily identify places with representations of intangible and living heritage. Three-dimensional models were authored using digital photogrammetry, terrestrial laser scanning techniques (*TLS*), and point cloud *DataViz,* combined to replicate the cultural heritage landscape of the selected case studies in the digital domain. In more general terms, this reproduction was meant to allow the contextualized perception and analysis of specific intangible resources that belonged to the place, but that were not so easily understandable from traditional maps, image databases or site visits (Figure 1).

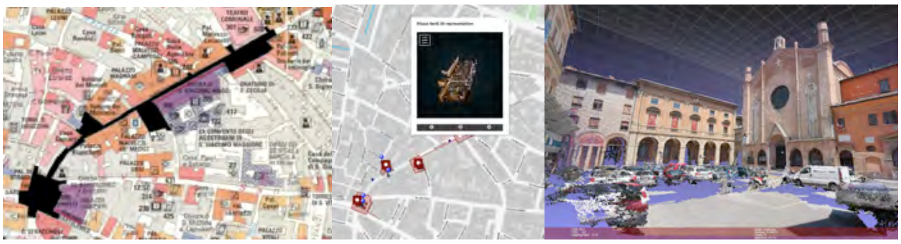

Figure 1. Bologna, Italy case study area, WebGIS interface with classification of hyperlinked intangible elements, and point clouds representing public spaces in Bologna: the ephemeral geometry is a valid metaphor to represent intangible elements (3D digital photo-models by J. Arteaga).

Due to the ephemeral nature of intangible and living elements, 3D models made of *point clouds* (unstructured representations of shapes generated with *TLS* or digital photogrammetry) were considered to be the best compromise in terms of fast production and actual morphology capture. Accuracy of the tools and procedures, even if well qualified by the scientific literature (Singh et al., 2014), was not mandatory at this stage, since simple coloured points were mainly used to represent unmeasurable entities without being precise site surveys. Taking advantage of *Structure from Motion* (*SfM*) algorithms and terrestrial laser scanning, some streets and squares in Bologna were *photo-modeled* and replicated, outputting point clouds that were connected to a general *WebGIS* map. Well-known existing software applications, such as *Agisoft Photoscan*, *OpenStreetMap*, *Potree*, *Meshlab* and *CloudCompare*, were chosen to perform this workflow's stage. This tool, which is in the developing stage, was primarily made of a *WebGIS* framework (based on *OpenStreetMap*) with vector entities related to WebGL pages (Martinez-Rubi, 2015) that hosted interactive *point clouds* (generated using *Potree* software by Markus Schuetz). Data was layered on the shared map, ordered in layers based on contents' taxonomy (the building's age, popular legends, people's perceptions, etc.) then linked to point clouds that were produced through the processing of substantial images and movie frames with the *SfM* algorithm.

These 3D models can be edited (with colors, hyperlinks, etc…) in order to visually represent intangible perceptions in their context. Some analysis could be performed on maps, while several users can dynamically integrate contents. The digital map, augmented by 3D models, can be explored using mobile devices, with specific links leading to stereoscopic representations that can easily be implemented in cheap 3D viewers, such as *Google Cardboard* for smartphones (Figure 2).

Figure 2. The 3D point cloud, visualized into a cheap, immersive environment using a simple smartphone.

4. Conclusion

The developments that are likely to come from the proposed framework can be refined with the application of interoperable contents: data can be exported to more complex GIS systems or 3D viewers, while intangible elements, of the public space studied, can be understood or represented with an improved working pipeline aimed at their identification and choice. This kind of framework has significant potential in the fields of architecture, urban planning, and design. Based on an innovative approach, it can facilitate the planning and design process in both the public and private sectors by providing a way of not only understanding the significance and value of public spaces and CHLs, but also providing a way to better understand, at the human scale, spaces and landscapes as reproduced in a virtual environment. Also, this framework is able to foresee and better understand the effects of potential designs in the cultural landscape of the city. Yet, this work is still under development and a systematic analysis on the advantages and disadvantages of the applied technology is still being investigated, even if the potentials are very promising.

Acknowledgements

This preliminary research work was possible thanks to the SSHRCC funded internship training program *New Paradigm/New Tools for Architectural Heritage in Canada* coordinated by the Carleton Immersive Media Studio (CIMS), Carleton University in Canada, directed by Prof. Stephen Fai. The internship was hosted at City Space Architecture, a non-profit organization based in Bologna, Italy. The authors would like to thank all the people involved in this international program.

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Section

VIII

THEORIES OF DESIGN & CONCEPTUAL MODELS

THE FOUR FS OF ARCHITECTURE

A Conceptual Framework for Understanding Architectural Works

SALEEM DAHADREH[1] AND RASHA ALSHAMI[2]
[1]*Department of Architecture, University of Jordan, Amman, Jordan*
saleem.dahabreh@ju.edu.jo
[2]*90 Degrees Design Studio*
rashaalshami@hotmail.com

Abstract. This paper presents a conceptual framework for understanding architectural works. This framework provides an understanding of an architectural building through qualitatively discerning the complexity of issues involved in its design and enabling their systematic integration into a theoretical construct. The premise behind this framework is that in design a better understanding of 'what' to design leads to a more informed base to 'how' to design. Using a grounded theory method, the paper postulates an ontological framework that recasts the Vitruvian triad of *utilitas*, *venustas*, and *firmitas* into spatial, intellectual, and structural forms respectively, and more importantly expands the triad to include context and architectural thinking as formative ideas, as integral components in any architectural work, thus closing a gap that existed in many frameworks dealing with architecture. The paper concluded that this framework offers a level of robust understanding of architecture that can be used in structuring the generation of architectural form as well as the description and analysis of existing works of architecture. Its value exceeds theory framing and extends towards architectural pedagogy as a theoretical framework in teaching design studio.

1. Introduction

As a social phenomenon, architecture is characterized by complexity and linked to multiple bodies of knowledge; architectural design typifies a multidisciplinary design domain where architecture, engineering and construction come together as one, each dealing with a particular feature of the building design and each with its own concepts and interpretations (Rosenman & Gero, 1997). Furthermore, architectural design is an integrative and interdisciplinary process with complex requirements that calls for a deeper understanding of 'what' to design in order to better inform 'how' to design (Friedman, 1992; 2003). A better understanding of such complex phenomena requires a multidisciplinary approach that distills concepts across domains and organizes them into a coherent structure. This requires the development of a conceptual framework that elucidates the basic concepts of architecture, develops an essential common language within and provides uniformity leading to a better understanding. This paper postulates such a meta-level conceptual framework. This framework facilitates the understanding of architectural form through expounding its underlying constituents and integrating them into a coherent whole, thus allowing for a more structured description, interpretation and generation of proposed works of architecture, and consequently leading to a more structured discourse of architectural design.

Many researchers and theoreticians have attempted to formulate a definition for architecture through determining its ruling principles; however, most of these attempts are traced back to the three enduring sets of architectural principles proposed by Vitruvius in his treatise De Architectura in the first century B.C: venustas, firmitas, and utilitas – translated respectively as beauty, firmness, and commodity. Researchers emphasized one or more of these aspects as bases for understanding architecture (Semper, 2011: p. 1851) emphasized the technical aspect of architecture focusing on four distinctive elements of architecture: hearth, roof, enclosure and mound. Frankl (1973; 1914) proposed analyzing architectural styles based on spatial composition, treatment of mass and surface, treatment of optical effects, and the relation of design to social functions. In design research relevant to architecture; Stiny and Gips (1978) presented an 'aesthetic algorithms' machine for the analysis and generation of designs in art and design. Stiny and March (1981) presented 'design machines' as an algorithmic schema to model the design process. Gero (1990) presented function–behavior–structure (FBS) framework as formal representations of a designed object. In characterizing architectural designs, Tzonis (1992) developed the P.O.M. system defining performance, operation, and morphology as representation of information contained in precedents. Economou and Riether (2008) presented 'Vitruvian machine' that mapped Vitruvius' triad into formal studies of architecture.

However, most of these models did not account for two crucial constituents; first, as a building's symbolic performance is inseparable from time and place (Piotrowski, 2001), the relation of the work of architecture to its context and the dynamic role the context plays in shaping architectural form and influencing design thinking necessitates the inclusion of context as an integral component in understanding 'what' an architectural design is. More importantly, architectural design is a reflexive process that involves critical reflection of the constituents of a design situation (Peponis, 2005), thus framing it in a different manner that goes beyond beauty, firmness and commodity. Accordingly, design reframing makes it imperative to introduce design concepts as part of 'what' an architectural work is and an integral component of any architectural design framework.

Through qualitative description, this paper aims to develop an architectural framework. By no means is the framework intended here meant to be a fully detailed account of what architecture is; rather, it lays out the key concepts and constructs and posits relationships among them. These concepts are the building blocks through which designers reason about architectural form schematically. Besides clarifying concepts and relating them, such a framework structures and frames academic debate about architecture in terms of basic taxonomy of concepts, relationship between concepts and propositions, and accordingly allow sensible debate to take place.

2. Setting the stage: definition of a conceptual framework

Jabareen (2009: p. 51) defined a conceptual framework as *"a network, or 'a plane,' of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena."* The aim of the conceptual framework is to provide an organizing scheme for a phenomenon through the organized structuring of concepts that constitute that phenomenon (Shields & Nandhini, 2013). Of interest to this paper is the formation of an ontological conceptual framework. In the field of design computing, ontologies are structured conceptualizations of a domain in terms of entities in that domain and their relationships (Gero & Kannengiesser, 2007): they present a knowledge set about a subject, and they describe individuals as the basic objects, classes as collections or types of objects, properties and characteristics, and the relations between objects (Aksamija, 2009).

One of the strongest features of conceptual frameworks is that they assimilate knowledge from multiple disciplines and integrate them into a theoretical construct (Jabareen, 2009). As such, for a multidisciplinary domain such as architectural design where art, theory, engineering and construction, among others, come together, conceptual frameworks become an excellent mechanism for relating different concepts and structuring them as a conceptual construct. As conceptual frameworks are formed through qualitative analysis, they do not provide knowledge of 'hard facts' but rather 'soft interpretations of intentions' or concepts (Levering, 2002) that aim at neither providing explanations nor predicting outcomes that address questions of 'how' and 'why', but rather providing an understanding of 'what' constitutes a certain phenomenon.

3. Understanding Architecture: Identifying Concepts

According to Ulrich (1988) the ability to reason about any artifact rests on the ability to abstractly categorize that artifact and provide a minimal description of its structural or salient aspects. For Tzonis (1992) the core of any intelligent design system describes how artifacts work, how they are made, what they do in respect to what is expected, how they fit into the surrounding environment, and how all these aspects are related to each other. Hillier *et al.,* (1984) defined buildings as cultural artifacts that can be regarded as material constructions, spatial organization, and objects in a particular style. According to Markus (1987) for any building to function effectively, it has to accommodate function/s required by an institution occupying the space of the building. The fundamental function of the spatial organization defined by a material structure, labeled by Frankl (1973) as spatial form, is to accommodate human activities.

Spatial form is governed by explicit rules about how people, objects and activities are disposed in space (Markus, 1987). In that sense, spatial form is both trans-spatial and spatial: "the trans-spatial aspect defines purposes, activities and roles for different groups of people. In this sense, program can be understood as a social script. The spatial dimensions of program refer to the ways in which this social script is embedded in space through a pattern of distribution, affordances and labeling." (Capille & Psarra, 2013: p.18).

The material construction or structural form of a building shapes space and signifies how to construct the physicality of the building. It involves structural engineering to address stability and support of the building, mechanical and electrical engineering to address the operation and serviceability of the building in terms of the provision of suitable conditions for the functioning of the architectural building, and the materialization of the building via construction utilizing existing engineering knowledge and technical know-how (Rosenman & Gero, 1997).

At the same time, this material construction has visual qualities, e.g. materials, color and surface texture, as well as construction detailing including moldings, grooves and change in materials etc., which characterize space, thus adding cultural significance and aesthetic appeal. This becomes the perceptual form of the building that transmits social meaning through its physicality. Yet, the formal attributes of the material construction have a cognitive, conceptual and affective dimension (Peponis, 2005); the material construction has an abstract and architectonic aspect, usually expressed geometrically (Unwin, 2003). It signifies how to logically and formally structure the materiality of the building. In that sense, there is/are underlying conceptual system/s (Unwin, 2008) that structure design elements and organize the material construction, thus generating the formal properties of the building. This distinction between the abstract and the material was made

500 years ago by Alberti in the 15th century in his Ten Books on Architecture. Alberti distinguished between geometry and material construction of the building where the function of geometry, lineaments in Alberti's terms, is to "prescribe, and appropriate place, exact numbers, a proper scale and a graceful order for whole buildings and each of the constituent parts" (cited in Dahabreh, 2006).

Consequently, the form of the material construction can be read as: a structural form of utilitarian nature that supports the building and structures space, a perceptual form related to the articulation of surfaces and pertaining to sensory perception and experience, and a conceptual/logical form that orders the elements and regulates the material form. The former three types of form related to the material structure correspond to Vitruvius' structural, sculptural, and geometric forms respectively, as identified by Agudin (1995).

Spatial form (SF) of an architectural building along with its structural (SF), perceptual (PF), and conceptual forms (CF) are interrelated and cannot be separated; each affects and conditions the other and all exist simultaneously in every work of architecture. It should be noted that the categorical distinction between spatial and physical form or between the two aspects of the physical form i.e. structural and intellectual, is not treated as one intended to capture two or more kinds of organization, but rather as one of recognizing the different aspects of building that become important depending upon the kind of question one asks. Hendrix (2012) made a distinction between the functions of form in architecture; a 'communicative' function in terms of expression and representation fulfilled by perceptual and conceptual forms, and an 'instrumental' function in terms of utility and technology as performed by spatial and structural forms respectively. Accordingly, the constituent forms of architecture can be regrouped into three forms: spatial form (SF) related to utility, intellectual form (IF) combining conceptual and perceptual form and related to the agency of the 'intellect', and a structural form (SF) related to technology and construction.

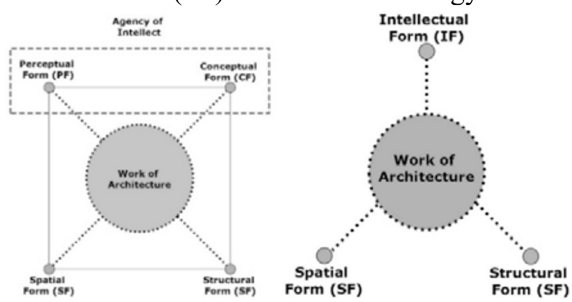

Figure 1. The four forms of architectural form understood as spatial, intellectual, and structural forms

The three forms identified above are synthesized through a design process. This process involves a critical reflection upon that situation that goes beyond its immediate conditions, thus leading to new understanding of it (Dahabreh & Abu Ghanimeh, 2012). This new understanding necessitates the reformulation of design constituents i.e. SF, IF, SF, in an innovative manner to address the conditions of the intellect. This type of thinking utilizes what is referred to as design concepts; they refer to "how the various aspects of the requirements of a building can be brought together in a specific thought that directly influences the design and its configuration." (McGinty, 1979: p. 215). As such, design concepts are formative ideas (FI) designers use to influence or give form to design (Clark & Pause, 1996). Furthermore, formative ideas include additional aims, or inflections of aims brought about by designers themselves, in the course of design as well as the aims of design as intrinsic to the designed object that cannot be initiated before the design process itself (Peponis & Wineman, 2002). According Schumacher (2011) it is this type of theoretical reformulation and innovation that differentiates architecture from mere building. Consequently, an architectural building has an abstract and conceptual aspect i.e. formative idea (FI) that integrates spatial, structural, and intellectual form into a unified whole, providing a logical order that governs and organizes its material construction and expressing how a designer reasoned about the design situation, including what they added. Thus, the diagram of architectural form in Figure 3 can be recast to integrate formative idea (FI) as the heart of any architectural work (Figure 2).

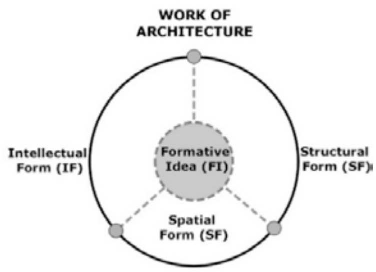

Figure 2. Intellectual form as the integrator of architectural work

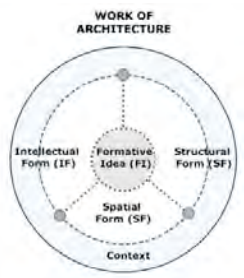

Figure 3. Architectural work as an integration of the five concepts

Kolodner (1993: p. 13) defined a case as "a contextualized piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner." Conferring with Kolodner that reasoning about any case cannot be separated from its context i.e. the situation under which the case evolved and took place, the final constituent of the conceptual framework is the context (C) under which architectural work is conceived and in which it exists. When the conditions of the surrounding environment – natural-physical we exist in and socio-cultural we operate in – do not meet the aspirations of humans, humans create new artifacts that belong to a techno-physical environment (Rosenman & Gero, 1998). Thus, the surrounding context defines the requirements that state what properties, functional or constructional, an artifact should have (Greefhorst & Poper, 2011). Additionally, the context plays a proscriptive role in architectural design, where through being constrictive in terms of its physical or techno-physical nature, e.g. topography and climate, or being controlling through setting rules and regulations for design, e.g. building codes and zoning, context constrains the design by saying what should not or could not be done. Furthermore, the building operation and performance are conditioned by the circumstances of the surrounding context. But most importantly, context defines the theoretical framework of any work of architecture. As such, understanding 'what' a work of architecture is cannot be complete without understanding under what conditions conception, formation and materialization took place. The final conceptual framework is presented in Figure 3.

Within the conceptual framework presented in this paper, an architectural building can be understood as a material construction molded though a formative idea (FI), structured by intellectual requirements (IF) that regulates functional requirements (SF), and mathematical and physical necessities (technology and construction) (SF), all within the constraints of a context (C). In order to elaborate on the practical application of this framework, a case study will be described and analyzed using the main components of the framework.

4. The Bhāva: A Case Study from the University of Jordan 2015

The conceptual framework proposed in this paper was used to structure the work of fifth year students at the University of Jordan in 2014–2015. Two of the projects won international regional awards, and one of them won another international award and was published in several respected architectural websites. This project, the Bhāva designed by Rasha Al-shami will be presented as case to elaborate on how this framework can be used in teaching an architectural design studio (Figure 4).

The project was to design a Community Technology Center (CTC) in downtown Amman. The thesis started by reformulating the design situation and researching a deeper theoretical context. Theoretically, the project was based on the premise that humans occupy a multiplicity of worlds, e.g. from the physical to the abstract, and from the real to the virtual. Nevertheless, gaps and clashes exist between these worlds. Researching a narrative that acknowledges the parallels and divides between the physical and abstract worlds and brings them together became the theoretical context of the design (C).

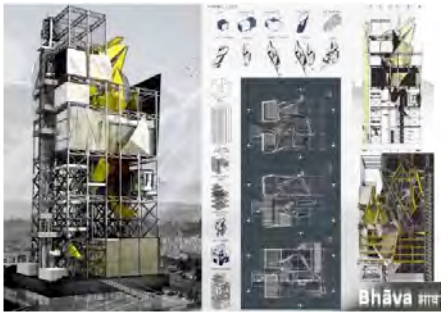

Figure 4. The Bhava

The basic conception behind the design was to collapse real and virtual worlds into one through the creation of a gaming universe that is a hybrid of virtual elements and physical objects (HVP). In this universe, the outer world of reality merges and interacts with the inner world of the mind. Such a designed universe creates a state of spatial immersion, a state of being physically present in a non-physical, non-abstract world giving rise to the state of multidimensional consciousness where one is conscious on more than one dimension and more than one level. In such a universe, the concrete and abstract, the real and virtual, no longer constitute a duality; rather the two become one. To design this state of becoming, of transition, of transcendence is to design a Bhāva. As such, the design of a CTC is conceived as the design of orders in collision: an order of existing reality confronted and challenged by an order of the new materialized virtual, nevertheless forming a Gestalt. That became the formative idea of the project.

Formally, the design of the project became the design of field conditions in which a Cartesian system of modular elements establishes structure and boundaries of materials echoing the memory of the site are disrupted by a parasitic tectonic structure that moves and transforms portraying a world in a perpetual state of change. Geometrically, the design is seen as interplay between the Cartesian grid and deformed tectonic structure that disrupts and challenges the omnipresence of the Cartesian grid and launching towards the fourth dimension (Figure 5). The geometry of the tectonic structure is scripted by mathematics of space and time as demonstrated by Lorentz transformations, i.e. stretch and squash. More pertinently, the curvature and breaking of the structure is stirred chromo dynamics and lattice theory to calculate the rotation, coupling, and splitting of the various components of form. The interaction of the ideal vs. monstrous, script vs. form, and proportional vs. recursive produces a heterogenic masterpiece that acts as frozen frame in a continuous process of variations. The in-between interior spaces become contour spaces freed from the constraints of historical reality and of any predetermined meaning and purpose, functionally ambiguous and conceptually open; they aim to expand the scope and depth of users' experiences (Figure 6). Moreover, these spaces are transformational; they show the transformation of one system to another.

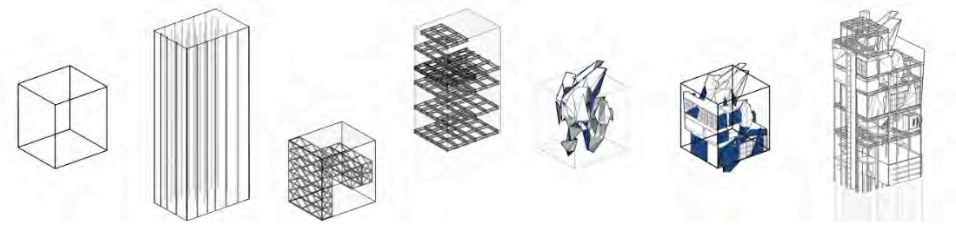

Figure 5. The formal manipulation of the two systems (conceptual form)

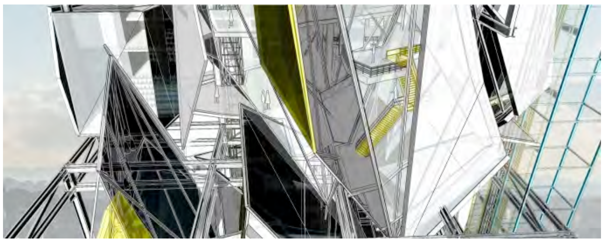

Figure 6. Interior spaces

Structurally, the Cartesian system is made up of modular columns and beams forming the main structure. This system of beams and posts is made of Architecturally Exposed Structural Steel (AESS). The parasitic system based on a lattice division that disrupts and challenges the Cartesian system is a kinetic structure that constantly evaluates its surroundings and reconfigures according to changing site conditions. The insertion and location of the lattice grows according to varying site conditions and functional needs bringing a dialogue of hierarchy and tectonics. The initial module of the lattice is made of flexible carbon tubes and holds elastic ETFE panels incorporating photovoltaic cells to generate electricity.

The overall design is a dynamic constructivist composition of ordered structure and splintered surfaces and twisted wiry forms creating a fantastical scene depicting an alternative world that glimpses into a parallel universe. This composition is not without merit; it is governed by the interaction of *faktura*, the particular material properties of an object, *tektonika*, its spatial presence and underlying laws of physics, chromo dynamics, and lattice theory.

5. Discussion

As can be seen from description above, the theoretical density and repleteness of the Bhāva can be made discrete through the application of the conceptual framework. The constituents of the framework provide an explicit and systematic review of specific concepts that form the bases of the design. They frame and structure the qualitative description and stipulate the type/s of representation/s needed to express it. Furthermore, the conceptual framework has two added values: firstly, the use of spatial form instead of function or utility shifts the focus towards the quality and geometry of space in terms of 3D volume and visual articulation as can be seen from the figures. Secondly, the transferal from aesthetics as appreciation of sensible characteristics of an object or as emotional response to these characteristics to the intellectual form of an object signifies an intellectual shift towards seeing beyond the sensible appearance and accessing the principles of creation and underlying logic through the application of intelligence. Accordingly, the description and generation of the project is more concerned with identifying its elements of design, their relationships and principles governing these relationships, than providing a description of the physicality of the project.

More importantly, if the description and analysis of the project was based on the Vitruvian triad alone, the concept behind the design of the project would not have been addressed. As we have seen, the concept of Bhāva guided the design of the house, structured the interaction of the intellectual, spatial and structural forms, and united them in the final form of the building. Through its main constituents, the framework answers the four basic questions pertaining to analyzing, synthesizing or evaluating any architectural work: what a building does and the logic of it spatial organization, how a building is physically constructed, how a building is intellectually, i.e. formally structured, and why a building took its final form and under what conditions.

6. Conclusions

This paper proposed a conceptual framework for understanding architectural works. The conceptual framework made up of a spatial form, intellectual form, structural form, formative idea and context, bridges the gap between the different domains to present a structure of different concepts making up an architectural work and enables the understanding of ‘what’ a work of architecture is. The main thrust of this framework is that it expands the traditional triad of *venustas*, *firmitas*, and *utilitas* of ‘what’ architecture is, which deals with what to design, how to design it and how to construct it, to include how to conceptually think about it, and reintroduces context as an integral concept in understanding 'what' a work of architecture is.

This framework, through the clarification of concepts, depicts the underlying status quo of an architectural work and enables its communication between interested communities. By explicating the status quo, a platform is offered for structured debate concerning the nature of architecture and architectural works. Further, shortfalls within existing bodies of knowledge can be depicted accordingly, opening up venues for further reflection and investigation. Such a framework is of a pedagogical value where it can be used as a priori framework supporting architects in the conceptual stages of design, as can be seen from the presented case study. Furthermore, it can act as a posteriori framework that can be used in architectural analysis and criticism through providing a systematic description and interpretation of built works of architecture. In that sense, it can be used as a didactic tool whether in teaching in design studios or in the field of architectural morphology.

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RADICALISM VS. CONSISTENCY

The Cyber Influence on Individuals' Non-Routine Uses in the Heritage Public Spaces of Cairo

REEM ALBARAKAT AND GEHAN SELIM
Queen's University Belfast, Northern Ireland, UK
ralbarakat01@qub.ac.uk

Abstract. Since the emergence of the concept of user-generated content websites – Web 2.0, Internet communications have developed as a powerful personal and social phenomenon. Many Internet applications have become partially or entirely related to the concept of social network; and cyberspace has become a space about 'us' not 'where' we are. This paper investigates the theoretical grounds of the effect of cyber experience on changing the individuals' uses of the public spaces, and sustaining this change through maintaining the ties and reciprocal influence between actions in physical and cyber spaces. It aims at examining the impact of cyber territories on the perception, definition and effectiveness of personal space within different circumstances; and its role in changing the uses of spaces where people used to act habitually. The personal space, here, will be represented as the core of both: change and consistency – the space of bridging the reciprocal effect of cyber and physical counterparts, which is transformed through the experience of physical events mediated into the cyberspace. The paper is part of a study which looks at the case of Tahrir Square during the Egyptian political movement in 2011. We will compare the activists' actions and practices in the Square during different events of non-routine use of the square and its surroundings. The case study will show the level of consistency in the features of the produced personal space within different waves of the revolutionary actions for all that different circumstances, motivations and results.

1. Introduction: The Cyber influence on Individuals' Practices in Physical Public Spaces

Since the emergence of the concept of user-generated content websites "Web 2.0" [1], the Internet has developed as a powerful personal and social phenomenon. Many Internet applications have become partially or entirely related to the concept of social network (Park 2009) and cyberspace has become a new home of the mind (Hunter 2003). The term *'space'* generally conceptualizes the ability to move, act, create and describe (Krippendorff 2010). Breaking the physical borders, Klaus Krippendorff (2010) argued that space is about 'us' not 'where' we are. 'It exists only for actors who recognize possibilities and act in them: changing the location of their bodies, interacting with one another, or creating new artefacts' (ibid). Cyberspace, here, is an example of this abstracted space. It is based on the communities of actors who exceed the physical boundaries through mediated communication.

The number of studies on cyber communities has significantly increased in five perspectives: social, business, development, application and methodology issues. According to its multidimensional approach, all five perspectives, especially the social perspective, appeared unable to produce a conclusive definition of cyber communities (Li 2004). The social perspective of virtual communities addresses the definitions into two main approaches. The first one is the sociological definition of Tönnies community of mind, where virtual communities are defined using the elements of bonding and culture (Etzioni & Etzioni 1999). According to Tönnies definition, there are three types of communities: (1) community by kinship, (2) community of locality and (3) community of mind. Virtual communities resemble a community of mind but through an electronic communication medium (Rothaermel and Sugiyima 2001). The second one considers virtual communities as the opposite concept of 'offline community of place' or proximal community (Scott et al. 2005), where the offline face-to-face interaction is converted into mediated one (Park 2009). Offline communities are defined as a group of people who share common ties and social interaction through an area physical space for a specific period of time (Hamman 2001, p.75)[2]; while virtual communities are *"mediated social spaces in the digital environment that allow groups to form and be sustained primarily through ongoing communication processes"* (Bagozzi and Dholakia, 2002, p. 3); or a group that shares thoughts or ideas, or works on

[1] It includes social networking sites, blogs, wikis, video sharing sites, hosted services, web applications, mashups and folksonomies. Source: Wikipedia.com

[2] Hamman, R. (2001) Computer Networks Linking Network Communities, Source: Al-Saggaf and Begg: Online Communities versus Offline Communities 2004

common projects, through electronic communication only (Digital Future Project 2007).

The motivations of participants in virtual communities include: daily-life needs (Bakardjieva 2003), online friendships (Coon 1998)[3] and the desire to obtain and exchange information (Ridings et al. 2002); but, mainly, the intention of participants is determined by the social identities of the individual (Bagozzi & Dholakia 2002). The theory of 'uses and gratification' is used to explain this argument. The theory hypothesizes that different consumers use the same media messages for different purposes, depending on their individual needs and goals (Sheldon 2007, p. 40[4]); and users meet their motivation within three main categories of virtual communities: Blogosphere, Wikis and social network sites. The world now faces new forms of association which are called social networks. It is a rich source with several dimensions, which mobilizes the flow of resources between countless individuals distributed according to variable patterns (da Costa 2005).

2. Literature Review: Virtual Communities V. Cyber Space

Based on different platforms, motivations and ways of interaction, Cyber communities represent the virtual version of the real counterpart. Coon (1998) was among the first to suggest that the virtual communities resemble real communities and that people can form communal relationship through computer-mediated communication on the Internet.[5] Therefore, involvement in virtual communities/ cyberspace leads to offline actions: in social activism, daily use, members' interactions, social links and posting information. Space and cyberspace are roughly equivalent, at least in the sense of sharing the four common notions of place, distance, size and route (Bryant 2001). These four items reflect: locating specific targets in cyberspace, time value and its relation to distance and size, and finally the description of the movement within the space. Terms like 'visiting' a web 'site', typing its 'Uniform Resource Locator' and 'entering' chat 'rooms' are indicators for this approach.

Places in cyberspace are, in fact, software constructions which create environments of interaction. These places (cyber objects) are dependent on cyberspace, while the opposite is untrue. Cyberspace can exist in the absence of all information; the potential to transmit does not disappear along with the information. Actually, cyberspace depends on human use of these potentials. It is not only a matter of investigating cyber objects within cyberspace, it is about the responsibility for creating and protecting those cyber objects and the space in which they exist. Without these ongoing human activities, cyberspace and cyber objects would

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[3] Source: Li H. (2004)

[4] Source: Katherine K. Roberts (2010) Privacy and Perceptions: How Facebook Advertising Affects its Users, *The Elon Journal of Undergraduate Research in Communications,* Vol. 1, No. 1, 24-34.

[5] Source: Li H. (2004)

become meaningless. Networks provide platforms for media resources to be shared among nodes, resulting in the flow of information – which activate cyberspace. Since then, a direct relationship is standing between existence and actions. For example, even users enter and leave cyberspace whenever they please, the point for users is not just to ‘be there’, as traditional meeting places, but to ‘present’ themselves and to interact with others.

Individuality, the effective factor in changing the concept of community, has its reflections on the cyberspace. Cyberspace has been divided. People hold rights of exclusion to a property, and millions of tiny land-holdings appeared (Hunter 2003). Taking into consideration the self-defining and self-regulated structure space, cyberspace "embodies the liberal democratic goals of individual liberty, popular sovereignty, and consent of the governed" (Hunter 2003). People hold the responsibility to define the space through their properties *(territories)*, shape it into networks and sub-networks, enhance it while contacting and, continuously, reshape it by eliminating people and posts.

Territory, also referred to as personal space, is defined as more distant, somewhat removed from the immediate person, and it involves use of places and objects in the environment (Daskala and Maghiros 2007). Although boundaries are not always very clear, people are aware of their existence and act accordingly. This starts with the territorial behaviour which is a boundary-regulation mechanism of: marking of a place or object, communication that it is owned, regulating interpersonal interaction and to achieve a desired level of privacy.

In the physical space, personal space is literally ‘attached’ to the self; and in the cyber milieu, personal territory is stands for the cyber personal space. It includes all the cyber personal data of the individual, as well as the online activities. According to Daskala et al. (2007), the use of the notion of territories and personal space may provide us with a better way to map out and conceive the personal space and the management of personal data and privacy in the cyberspace. Within this space, the individual controls all data and actively decides on who and what part to access.

The personal territory is shaped by a dynamic data-sphere (bubble), whose size varies according to its content, the type of interaction and the level of trust to the interaction milieu. This bubble set as the nucleus of a two-way interaction, where any taken action is applied to: the direction of the movement of data, the classification of the personal data (level of privacy) as well as time and spatial factors – either physically: personal or public device, or virtual: the type of used website. This bubble sets adaptable borders, which change according to its will of increasing or decreasing them, and represented by markers to convey the idea of ownership (for example: Log-in screens). The last dimension is the built up bridges which provide links between physical and cyber milieus.

Frequent logging into cyberspaces converts them to online stages for interaction, which affect the offline counterpart. Internet has increased the number of people to contact with; and as the related apps and devices are developed, the number of virtual communities' members who keep in contact with their cyber world increased steadily. While logged in, people post and receive information from their communities. This interaction is considered to have a positive impact on the world, according to the Digital Future Project Reports, which shows an increase in the positive responses 2013-2015, even for those who do not use Internet.

Such participation affects the behavioral patterns within the physical spaces (offline communities), on one or more of the following dimensions:

Social activism: Participation in social causes through the Internet has increased, even for those who were not familiar with such activities (Digital Future Project Reports 2007).

Social links: a) cyberspace helps the users to find growing numbers of online friends, as well as friends they first met online and then met in person, 5 friends on average (Digital Future Project Reports 2015); b) cyberspace users show an increased regular stay in contact with online friends. This indicates a belief in the use of internet for maintaining social relationships 58%, with 62% specially using texting (of mobile phone users).

Daily life activities: a) Using mobile phones for functions other than talking has increased for a wide range of internet based actions: access the internet, send/receive pictures/video/messages, use apps, GPS mapping services, use social networking sites, watch/listen to streaming video/music, instant messages, personal digital assistant functions, download ringtones/music/mp3/videos and check into locations; b) Online purchasing for 78% of the adult internet users, who became more confident about their personal and security information while shopping online (Digital Future Project Reports 2015).

In parallel, political life was affected by the cyber experience. First of all, people almost trust in Internet. 43% of Internet users said that most or all of the information online is reliable. The percent increases to 74% when users talked about websites which they visit regularly, 76% of the information posted by governments and 69% of the information posted by established media (DFP 2015). On the other hand, information posted by individuals on social networking sites do not have the same reliability for users.

A small percentage of respondents said that governments should regulate the Internet, this real involvement in the cyberspace as a source of information has a significant impact on the political campaigns, knowledge and freedom to respond towards governments actions. In spite of that, in compatibility with Fox and Roberts (1999)[6] argument of the complementary relationship between virtual and real communities instead of completely replacing them, the majority still do not consider virtual communities as the only tool to gain political power.

This impact of cyber experience inspired examples of protesting around the world, as a means of public contribution in political life. Social media was the driving force behind the swift spread of revolution throughout the world during the last six years, as new protests appear in response to success stories shared from those taking place in other countries (Skinner 2011). Through social media, protestors create communities to: organize their movements, share insights, news and support; and, finally, learn from the experience of others, which is essential for activists' success.

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[6] Ibid.

* See: Skinner, J. (2011). "Social Media and Revolution"

Significant examples are drawn around the Arab spring uprisings since 2011; in Tunisia, in response to oppressive regimes and a low standard of living, and in Egypt, the case of public participation affected by cyber-physical relationship. These cases reflected on the political movements in other countries of the region in several forms in Libya, Yemen, Bahrain and Syria; in addition to minor reflections in Algeria, Iraq, Jordan, Kuwait and Lebanon. Some spaces appeared as the physical spaces of these movements. Tahrir square of Cairo was the biggest example with successive waves of events. A smaller example was of Pearl Roundabout (Lulu Roundabout) in Manama-Bahrain. Inspired with the Arab spring (Skinner 2011), the Occupy movement instigated in USA[7] 2011; called together by groups like Adbusters and Anonymous. The online organized protesting was transferred into physical public spaces, which were occupied by protestors, of both Arab Spring and Occupy Movement. The longest period of continuous occupation, the Hong Kong version of Occupy Movement (15 October 2011 - 11 September 2012), as well as other examples all over the world, transferred the protesting into physical spaces. This has created reactions and impacts on social and political dimensions within their countries. These cyber-organized, physical-applied movements led to several impacts, such as regime change (Tunisia and Egypt), passing of various laws (Spain) and alerting some economic issues (USA).

In all cases, social media played a major role in motivating protestors. Hashtags converted the scattered tweets into public discussions; Facebook allowed people to express their support; Skype was used to hold conference calls with participants of different locations; and multi-media was used for documenting and publishing events. In conclusion, it was a tool to connect protestors and send their messages to the world. On the other side, governments also recognized the role of social media in such movements, since then took actions like shutting down specific sites, blocking Internet service, and accusing active users of unrelated crimes. In parallel, physical spaces of protesting were places of clashes between protestors and police, while trying to clear them even with force.

3. The Case Study Background

The Egyptian revolution that took place in *Tahrir* Square in 2011 continuous to provide evidence on the frequent movement of the activists between cyber spaces, like Facebook, blogs, twitter and YouTube, and the public spaces, like squares and streets. Facebook was elected as a space which was able to represent the physical counterpart. It was the main turning point which has transformed social communication in the history of social network sites (Roberts 2010). Facebook, the republic of 1.59 billion monthly active users (Facebook, December 2015) all around the world, stands as the most popular and influential social networking website (Di Capua 2012) - in comparison with WhatsApp (500 million population), Twitter (284 million) and Instagram (200 million) (Source: CNBC) [8]. 1.04 billion People who log

[7] This movement which began in Manhattan to protest corporate greed as well as the performance of elected officials, encouraged protestors around the United States and then around the world.
[8] Source of statistics: https://zephoria.com/top-15-valuable-facebook-statistics/ and

into Facebook every day spend 20 minutes in average per visit (Source: Infodocket), upload: 136,000 photos, update 293,000 statuses and post 510 comments every 60 seconds (Source: The Social Skinny). Statistically, it is vital and big enough to represent the community, with sufficient hours of interacting on a wide range of interests through a wide variety of verbal and non-verbal expressions: symbols, words, photos and videos.

Tahrir square stands for the most important public space in the Egyptian experience of the Arab spring. The square, originally named "Ismailia Square", was part of the political movements in Egypt and well connected to its revolutions since 1919 – when it was informally named "Tahrir Square" (Salama 2013) until officially being renamed in 1960. The square, then, became surrounded by several public and governmental buildings; such as: the Egyptian Museum, the House of Folklore, the National Democratic Party-NDP headquarters building, the Mogamma government building, the Headquarters of the Arab League building, the Nile Hotel, Kasr El Dobara Evangelical Church and the original downtown campus of the American University in Cairo. All these have converted the square to become a part of the concept of *melk el hokomoa* (property of government) which occupied the Egyptians' conception of public space for the following six decades. This notion started to change gradually since the 1970s, when socialists started to consider public spaces as places to protest against capitalism. The government contracted these actions through police surveillance. Therefore, the cyber alternative was established and got tied to the public spaces like Tahrir Square.

This paper is part of a study which aims to analyse the individuals' cyber and physical practices during political movements in public spaces, and through their personal spaces – the building unit of space. Through a case study analysis, the study attempts to provide evidence on the relationship between defining cyber and physical personal spaces, through users' inputs – whose communities represent the space.

The case study will be conducted in the city of Cairo, namely in Tahrir Square and its surroundings. A series of major events will be selected as key events of the political movement within the defined three years scope. The events are all non-routine acts which have made: a) a significant change in the actions took place in the selected public spaces and b) a direct impact on the community engagement in this movement and its results. Two events are considered turning points of regime change, while the others established for these changes. The selection criteria is that: a) the event is caused by a physical action which motivates the protestors b) the event took place in a public space which is geographically inside the selected case study and within the defined timeline, c) the event was mediated in the cyberspace, d) the event has been initiated with collective effort; and finally e) had a significant impact on the political movement of the selected case (see figure 1).

The series of event starts with the death of Khalid Sa'eed under police custody. The memorial Facebook page "We are all Khaled Said" stands as a nucleus of change, which started online and moved to the streets of Cairo. Second is the major wave of Jan.25th which sparked with online demands to protest against the

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https://newsroom.fb.com/company-info/ . Last visit: 24/04/2016 deterioration of political, economic and social conditions; as well as a reflection of Khaled Sa'eed death. The third event was under the rule of the Supreme Council of the Armed Forces when Mohammad Mahmoud Street hosted the protestors who moved to speed up the transfer of authority. This has resulted in changing the government team and announcing a timetable of the authority transfer. The fourth event took place in August 2012, following the state declaration of a new a constitutional to enhance its power, followed by the Rebellion movement; and finally, the turning point that took place in Tahrir Square in June 30th, 2013.

The selected events, within the three phases, display variety in the circumstances and motivations of actions; while the relationship between the cyber and physical spaces of engagement keeps constant. The activists' inputs – virtually and physically, will be tracked through documented writings, archives, newspapers and visual materials which are saved either as hardcopies, soft copies or on cyberspace. The sample and its aim of engagement will be the constants of the study, while the circumstances will vary upon the several parts of the analysed case. They, all, have an active social media account (Facebook, twitter etc.) and have participated in all selected events of the study as indicated above.

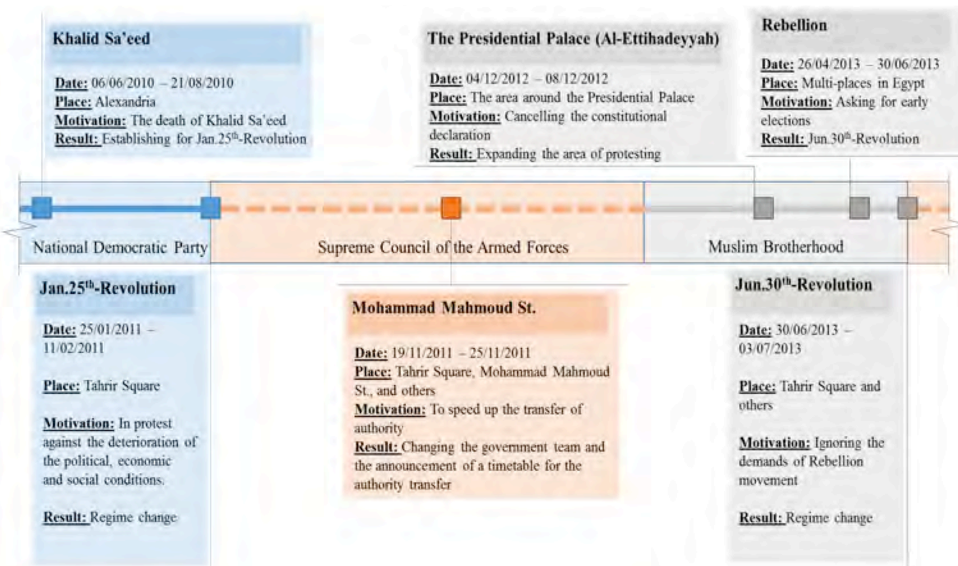

Figure 1: The Case Study Timeline

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TRAINED ARCHITECTONICS

JOSÉ ALGECIRAS-RODRÍGUEZ
CAAD DARCH, ETH Zürich Switzerland
josealgeciras@gmail.com

Abstract. The research presented here tests the capacity of artificial-neural-network (ANN) based multi-agent systems to be implemented in architectural design processes. Artificial Intelligence algorithms allow for a new approach to design, taking advantage of its generic functioning to produce meaningful outcomes. Experimentation within this project is based on Self-Organizing Maps (SOMs) and takes advantage of its behavior in topology to produce architectural geometry. SOMs as full stochastic processes involve randomness, uncertainty and unpredictability as key features to deal with during the design process. Following this behavior, SOMs are used to transmit information, which, instead of being copied, is reproduced after a learning (training) process. Pre-existent architectural objects are taken as learning models as they have been considered masterpieces. In this context, by defining the SOM input set, masterpieces become measurement elements and can be used to set a distance to the new element position in a comparatistic space. The characteristics of masterpieces get embedded within the code and are transmitted to 3D objects. SOM produced objects from a population with shared characteristics where the masterpiece position is its probabilistic center point.

1. Introduction

Trained Architectonics explores design processes relying on the use of nonlinear procedures to produce architectural geometries. Taken from the Artificial Intelligence (AI) field, specifically from Artificial Neural Networks (ANN), Self-Organizing Maps (SOMs) are used in this project to produce specific new geometry according to an input set of geometry.

ANN are use in machine learning processes and SOMs, as part of this group of algorithms present the self-organizing feature that allow the algorithm to develop itself with no external supervision. This characteristic is based on fully stochastic functions that imply an amount of randomness and uncertainty during the process development.

"The SOM may be described formally as a nonlinear, ordered, smooth mapping of high-dimensional input data manifolds onto the elements of a regular, low-dimensional array" (Kohonen, 1982). There are two vector sets involved in the mapping process: the codebook set – which is the actual ANN – and the input set playing the role of the signal space. The model in the original definition of the SOM is associated with a one- or two-dimensional array of nodes, defining a certain topological connectivity between the model vectors according to the node configuration.

SOMs are commonly used for clustering and visualization of high-dimensional data, to support theoretical analysis or as non-human supervised optimization algorithms in machine learning. The aim of this project is to take advantage of SOM behavior and topology-preserving features to produce architectural geometry. Thus, the discussion should not focus on its functioning or optimization.

2. Indices

2.1. INPUT SET QUANTIZATION

The *input set* in a SOM defines the target of the learning process. As in a human learning environment, the input set acts as an example of exceptional craftsmanship to lead the direction the learning moves towards. For the purpose of this project, in the architectural field this role is performed by architectural masterpieces. However it is a pretty much subjective issue whether a building is or is not a masterpiece. What is important here is the ability of masterpieces to stand out with their own architectural characteristics, becoming unique buildings that are worth to use as study cases.

The case of Le Corbusier's Chapel of Notre Dame du Haut in Ronchamp, is used here due to its characteristic geometry. Its iconicity will allow the reader to place a virtual image of the building and establish a certain relationship of proximity with every outcome (index) produced by the SOM. The other selected buildings – Venturi's Vanna Venturi House; Eisenman's Guardiola House; Van Der Rohe's Farnsworth's House – allow the establishment of different positions in an architectural comparatistic space.

The several outcomes produced in this project act as a *resemblance* (Deleuze, 1994; Eisenman *et al.*, 1995) rather than as a *representation* (Deleuze, 1994; Eisenman *et al.*, 1995) of the aforementioned masterpieces. The code transmits information from the masterpieces – as information sources – in an *indexical operation* (Carpo, 2011) to the outcomes that become *indices* (Figure 1) of the previous masterpiece.

Figure 1. Indices of Le Corbusier's Chapel of Notre Dame du Haut in Ronchamp; Robert Venturi's Vanna's House; unbuilt Peter Eisenman's Guardiola House; Mies Van Der Rohe's Farnswoth's House, produced by stochastic SOMs.

Architectonics are transmitted from geometrical inputs to geometrical outputs through topology, producing a population of individuals that resemble one another, and where the masterpiece becomes the probabilistic center point as the model of learning.

The masterpiece architectural geometry determines the SOM input space. Two operations are required to bring geometry to topology. The first operation consists of modeling a mesh model of the building. This mesh becomes a three-dimensional continuous region in Euclidean space (Figure 2a) acting as the information signal space. The second operation quantizes the previous region into a finite collection of three-dimensional vectors (Figure 2b) rendered as a point cloud and performing as the input sample set. The input set then is defined by quantization of a continuous signal.

Figure 2. (a) 3D region as continuous domain in Euclidean space, (b) vector quantization of the region. The 3D region must be modeled as an error-free closed three-dimensional mesh.

2.2. CODEBOOK MAPPING

The initial codebook set values have been defined by random initialization as a uniform random distribution of three-dimensional vectors spanning within the domain of the input vectors, adapting the codebook point-cloud size to the input point-cloud size.

The way the codebook vector set adapts to the input set is widely described in mathematics and computer science publications in papers. It is not the intention of this project to offer further details on the SOM functioning. Generally, the SOM produces the codebook vector set adaptation to the input vector set by mapping the input values to the codebook values or neurons. Both codebook and inputs are defined as points in a Euclidean space. In the pure form, the SOM defines an "elastic net" of points – neurons – (or model set or codebook) that are fitted to the input signal space to approximate its density in an ordered fashion (Kohonen, 1982). The SOM maps the input values to the codebook producing the adaptation. The code parses the codebook for every input vector in several iterations. The accuracy of the adaptation depends upon the number of iteration but mainly upon the number of input samples (Figure 3).

The input set defines the information to be transmitted, hence to be instructed. The codebook conforms to the neural network itself. It is initially defined as a set of random vectors in a specific topology. Its initial state is generic by definition, thus it is considered as *pre-specific* (Bühlmann, 2008). The masterpiece input set provides specificity to the outcomes that no longer remain generic and become architectural by acquiring architectonic features. The process of learning consists of the approximation of the neurons to the input set values by stochastic algorithms.

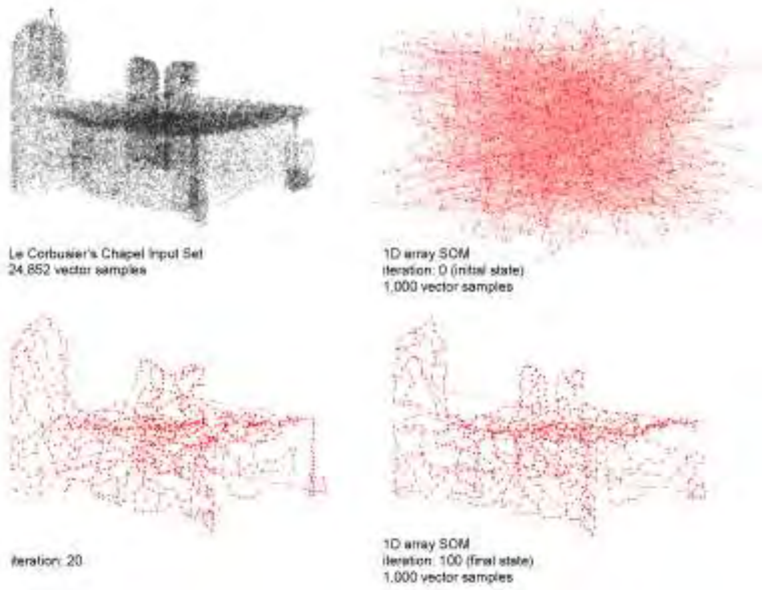

Figure 3. Selected iterations of a one-dimensional array codebook (red) adaptation to the input set (black).

3. Conclusions and Results

SOMs as stochastic procedures differ essentially from deterministic procedures. The production of indices by SOMs allows for the creation of a population of fully independent individuals by always using the same function and keeping exactly the same parameters. Differentiation becomes an intrinsic value of the production system where, in these cases, allows for the transference of form information without the reproduction of structural components. Every produced object is able to perform to a certain degree as the original object, due to their relationship of proximity.

Design in this research is not taken as a process of final shapes definition but as a process of instruction. The final output is not the product or the result of a design or fabrication procedure. It is not linked to any material system. The produced form lacks structure or else, it is provided with an amorphous structure, and still it results in a meaningful object. The role of the designer here is the role of an instructor of learning machines.

Due to the lack of structure, 3D printing is a natural fabrication process able to produce structureless objects. However, 3D printing methods (laser sintering in this case as in Figure 4) still based on post-processed printing must be developed in order to achieve real-time processes, fitting the stochastic SOM behavior.

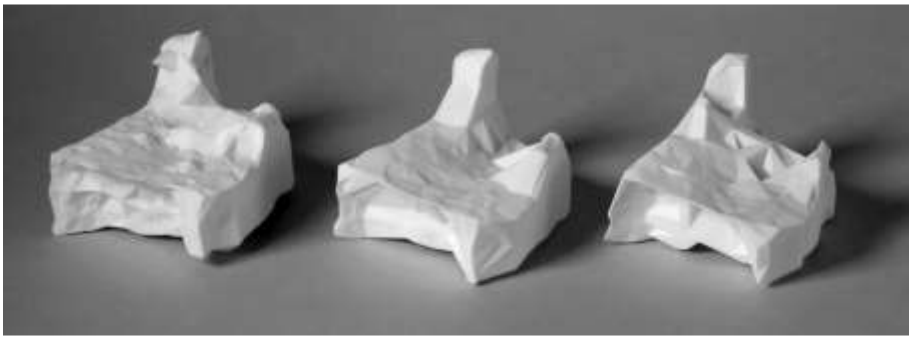

Figure 4. Printed meshes on Le Corbusier's chapel generated by α-shapes from one, two and three-dimensional array SOMs (from left to right).

Acknowledgements

I would like to thank Prof. Ludger Hovestadt and Prof. Vera Bühlmann for their support and the rich background provided within the framework of the MAS in Architecture and Information at the Chair of CAAD at ETH Zürich, starting point of this research. Thanks also to Despoina Pippa for giving me a title.

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ARABIC CALLIGRAPHY AND PARAMETRIC ARCHITECTURE

Translation from a calligraphic force to an architectural form

BASSAM AL SHIEKH
Edinburgh College of Art, The University of Edinburgh, UK
bassam@aaschool.ac.uk

Abstract. This paper describes an on-going research that unites two distinct and seemingly unrelated interests. One is Arabic calligraphy and the other is parametric architecture. The effort is to integrate these interests and, in doing so, balance cultural issues with technological ones, traditional with contemporary and spiritual with material. Moreover, this paper is inspired by Arabic calligraphy and its influence on Zaha Hadid's designs; it is invigorated by parametric systems and their capacity as a source of architectural forms. This paper will observe the rising importance of computation technologies to architecture, which has always been a form of negotiation between 'function and fiction' and 'force and form'. The paper proposes a Parametric Calligraphic Machine that simultaneously produces, connects and separates calligraphic surfaces, calligraphic images and calligraphic reality. Therefore, the goal is to examine this hypothesis in order to produce a set of techniques, tools and methods that inform the three-dimensional design process of Arabic calligraphy's contemporary possibilities by addressing a process description rather than a state description of creating calligraphic images and calligraphic surfaces. The theoretical approach highlights issues pertaining to *calligraphy, spatiality, translation, generative systems, parametric design, visual structure, force and form.*

1. Introduction

The motivation for this multidisciplinary research (Fig. 1) can be traced back to thoughts, speculations and ideas developed during several years of engagement in architectural design and theory at the University of Edinburgh and the Architectural Association, as well as during the author's professional work at Zaha Hadid Architects in London. The research's cross-disciplinary main propositions unite the interests of Arabic calligraphy and parametric architecture, and have a mutual understanding of speculation analysis that deals with discovery and predictive theory, as well as a creativity synthesis that deals with the experimental explorations and invention of both disciplines.

Arabic calligraphy is one of the most typical expressions of the Islamic spirit and a fundamental decorative element of all forms of Islamic/Arabic art, ranging from architecture to decoration design. Calligraphy integrates a cultural language with the language of geometry and combines sacred meaning with creative making (Moustapha & Krishnamurti, 2001). Therefore, there has been extensive interest in the study of Arabic calligraphy as a medium for design from an objective and/or subjective point of view.

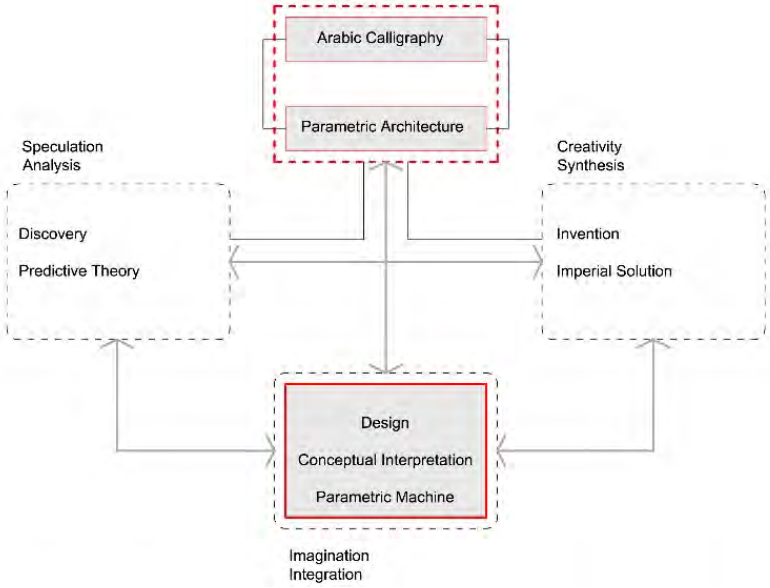

Figure 1. The research’s cross-disciplinary main propositions (adapted from Philips, 2000).

Furthermore, calligraphy is a *visual structure* and has a visual order, and has shown an impressive ability to regenerate itself. A calligraphic composition is composed of components (letters) and formational rules (letter arrangement rules), defining an overall *visual structure* where letter flexibility and fluidity present indefinite possibilities for designing two-dimensional calligraphic expressions. Arabic calligraphy’s visual structures and its conceivable spatial dimensions make it a dynamic and versatile language for the conveyance of form and space as well as meaning. During the calligraphy compositional process, letters and their relation arrangements are formed, and the visual system transformed and redefined. There is a rhythmical and poetic interpretation of calligraphy in Arabic culture, which demonstrates itself in architecture through the decorative surfacing of sacred architecture with the complex patterns displayed in Arabic architecture and arts. However, this interpretation and representation occurs only in two- dimensional visual structures. The challenge, therefore, is to determine how to translate these calligraphic visual structures into three-dimensional objects and how to inject them into the real context. The challenge of translating these calligraphic visual structures into three-dimensional objects is associated with the current state of architecture in the Arabic region; this indicates that there are serious challenges at different levels, which are affecting both the 'making' of Islamic/Arabic architecture and the 'meaning' of its cultural identity. However, this research, by using Arabic calligraphy as a catalyst, will attempt to identify and discuss briefly the challenge of integrating and interacting the culture identify of Islamic/Arabic architecture with global contemporary and avant-garde movements in architecture.

2. Translation from a *Force* to a *Form*

In his book, *Notes on the Synthesis of Form*, Christopher Alexander (1964) examined ways to infer form from the diagram of forces. This concept, borrowed from D'Arcy Thompson who referred to the form as a 'diagram of forces', was later further advanced in Alexander's article 'From a Set of Forces to a Form.' Questions asked in this article included, 'Given a system, how can we assess the forces which act upon it and arise within it? Given a set of forces, how can we generate a form which will be stable with respect to them?' (Alexander, 1966: 98). Alexander believed that the concept of force had the potential to articulate the complexity of a given system. He defined force as "an inventive motive power which summarises some recurrent and inexorable tendency which we observe in nature" (1966: 96). Alexander argued that the notion of force allows us to summarise and outline all forces embedded within a given system.

D'Arcy Thompson, in his book *On Growth and Form*, analysed variations in the morphology of animals' shapes using deformable grids, which shaped curvilinear lines according to changes in any given form (Fig. 2). These terms relate to the influence of a force on a form through a natural *system*. In this context, the term 'deformation' indicates a system that regulates and orders an object through a combination of forces (Lynn, 1999: 29).

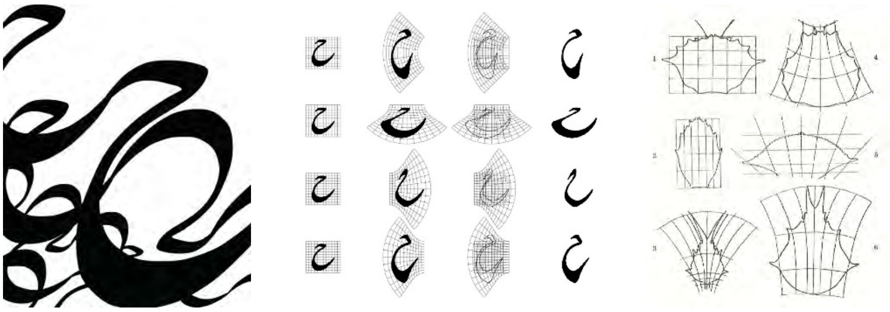

Figure 2. Study of the transformation of Arabic letter 'Haa' through the deformation of a flexible grid. Inspired by Thompson (1992) (right).

The present paper will focus on the concept *translation* between forces and forms in the Arabic calligraphy *visual structure*, by translating calligraphic expression into architectural spaces based on algorithmic means through computational experimental studies. In his article, 'Translations from Drawing to Building', Robin Evans stated, 'It can be argued on the common antilogy that would have architecture be like language but also independent of it. All things with conceptual dimension are like language' (Evans, 1996: 154). According to Evans, buildings are translations of drawings. However, Arabic calligraphy as a source of drawings could be described as a diagram. Furthermore, the importance of translation and representation becomes increasingly apparent in architecture; moreover, much research has been undertaken in the area of non-symbolic, especially diagrammatic, representation systems. Evans identified translation as 'the interpreting of the meaning of a text and the subsequent production of an equivalent text, to translate is to convey. In another words, it is to move something without altering it' (Evans, 1996: 154). In general, diagrams are important representations of design thinking and design communication in the design disciplines, and drawings are considered the principal form of representation; they translate ideas from conception to completion.

A diagram of Arabic calligraphy visual structure is a form of representation that involves a high level of visual abstraction with a low level of visual perception that does not affect the informative dimension. Alexander characterised design as matching program requirements with a corresponding diagram (Alexander, 1966). He called a diagram 'any pattern which, by being abstracted from a real situation, conveys the physical influence of certain demands or forces' (1966: 85). Furthermore, Deleuze and Guattari (1988) described diagrams as abstract *machines* that haved embedded within their structure the ability to generate potential forms – physical or visual. "They are not representations; they construct the process through which the generation of form will be possible. Therefore, they are the visualisation of a mechanic process, which combined with territorialised elements (such as program, regimes of signs, and regimes of bodies) produces form" (1988: 142-144).

By understanding and reflecting this methodology in the process of translating calligraphic forces into architectural forms, it is noted that *Calligraphic Information,* required for producing the *Calligraphic Formation* that is susceptible to *Calligraphic Transformation,* could be associated with generative and parametric systems used to produce two- and three-dimensional paradigms. The paper will present a Parametric Calligraphic Machine that supports a novel approach to calligraphic compositions by manipulating and controlling the algorithmic script *'Calligraphy of the Algorithm',* based on an actual Arabic calligraphy preference, *'the Algorithm of Calligraphy.'*

3. The Visual Influence of Calligraphic Forces on Zaha Hadid's Forms

The author observed, during his professional employment at Zaha Hadid Architects, that Hadid's thinking and creativity had been heavily influenced by the place of calligraphy in her Arabic culture. Arabic calligraphy inspired Zaha Hadid's architecture; for example, she allowed Arabic calligraphy to influence her design strategy and style. Hadid stated that she realised there was a connection between the logic of maths in architecture and the abstraction of Arabic calligraphy, and mentioned it in the press as a fertile subject for scholars to investigate, with consideration given to creating forms and surfaces based on contemporary design elements that employ algorithmic means.

Hadid and her partner, Patrik Schumacher, share a design goal to achieve spiritual meaning with aesthetic making in their buildings. It can be argued that during the past two decades, the defining feature of avant-garde architecture has been the media representations and design processes pioneered by Zaha Hadid, which have resulted in the production of spectacular paintings and drawings. Her curved gestures, influenced by Arabic calligraphy, allowed her paintings and drawings to reflect the notion of deconstruction and fragmentation in space (Schumacher, 2002). The influence of Arabic calligraphy on these drawings and paintings challenged the sensibilities of Hadid's contemporaries, who found them hard to interpret. Some scholars felt they were merely graphics (2002). But this dilemma around two-dimensional drawing has been a predicament of architecture ever since its inception as a discipline distinguished from construction (2002). As Robin Evans pointed out, '[A]rchitects do not build, they draw.'

One of Hadid's significant moves was to translate the dynamism and fluidity of her calligraphic hand into equally fluid tectonic systems, producing controversial relations between angular and curved forms (2002). Using her calligraphic skills, she shifted significantly from isometric and perspective projection to literal deformations of space. The curvilinear contours of Hadid's designs echo the cursive flow of Arabic calligraphy.

Both Hadid's designs and contemporary calligraphic visual structures share design principles with space and landscape design, since all have common visual design guidelines. The influence of calligraphy on Hadid's designs is apparent; both Arabic calligraphy and Hadid's designs have several strengths as a form. These include changing relationships between curves and lines, the ability to stretch or compress elements and the ability to fit equally well into large or small spaces. The concept of 'scale' is vital in both phenomena; they are highly flexible and full of dynamism, energy and sometimes rhythm, which makes Arabic calligraphy, as well as Hadid's designs, a responsive device for aesthetic expression. They both have the quality of adapting to all purposes and moods.

Both Arabic calligraphy and Hadid designs have creative tension, where boundless flexibility combines and meets with the following of rules. The flexibility and dynamism of the written sensibility of Arabic calligraphy, as well as the visual sensibility of Hadid's designs, offered an exceptional probability for the malleability of constituent letters and the elements of a word or design. Moreover, the flexibility of the written language of Arabic calligraphy and the visual language of Hadid's designs allows designers to stretch letters and design elements almost in any direction, which creates a work of art. Indeed, both Arabic calligraphy artists and Hadid follow the same rules in their use of space and surfaces.

4. Understanding Arabic Calligraphy as a Surface

Continuous surfaces play a significant role in Hadid's design principles. In Islamic/Arabic architecture, calligraphy and geometric patterns flow through the interior surfaces of sacred buildings, establishing this *continuity* (Blair, 2006). These surfaces become the visual ornamentation that convey the meaning of the text; they are particularly noticeable in most sacred buildings, providing the comprehensive decoration that seems to cover every surface of the building. In such architecture, surface and calligraphic ornamentation are responsible for representing the building's meaning and making. These surfaces, covered with calligraphic ornaments, deliver a timeless message about the society's belief system.

Traditionally, the technique of producing Arabic calligraphy emphasises a two-dimensional surface, not a three-dimensional form, and horizontality rather than vertical order. The main principle of calligraphic visual structure is *continuity*, rather than interruption or disconnection. This continuity in shape and geometry has been noticed in the continuous evolution and development process of the art of calligraphy; Hillenbrand stated that it could 'well be argued that the art of beautiful writing – for that is what "calligraphy" means – has, alone of the major Islamic visual arts, continued its creative evolution without a break from the first Islamic century until the present day' (Hillenbrand, 2006). As a metaphor, this *continuity*, either as a state description of *continuity* of surface (in space) or process description of *continuity* as calligraphy development (in time), is very important in understanding calligraphic continuous surfaces, which could constitute a new era of design in Islamic/Arabic architecture.

For the author, such concepts hint towards a different and more contemporary approach to the appearance and representation of Arabic calligraphy in architecture, one in which the surface of calligraphic ornamentation is not a representation of reality. Instead, calligraphic ornamental surface effects have constructed a different reality, a virtual reality that has become a significant aspect of architectural creativity. In other words, Arabic calligraphy is not considered an inferior simulation of reality, but rather a creative and symbolic reproduction that produces a unique reality of its own. When such calligraphic ornamentations are re-interpreted as ornamentation applied to the surfaces of buildings, the non-hierarchical simulative operation continues to affect different mediums. Consequently, it is possible, as a creative act, to argue that the design elements will merge and integrate to form a folded continuous calligraphic surface. The surfaces of calligraphic ornamentation are visual boundaries between the inside and outside of the form. In order to identify this virtual reality, a new approach should be followed and computational thinking should be implemented.

5. Parametric Architecture and Computational Exploration

The rapid development of the computational design technologies of mass reproduction has been an important issue for this paper. This ongoing research is derived from two fields, *Arabic Calligraphy* and *Parametric Architecture,* and the awareness of the crucial role that parametric design plays in exploring new boundaries for architecture and space making. Today, Muslim/Arab architects and artists are formulating different responses to image, surface and their (re)production in the information age, and parametric design plays a significant role. Many theorists in architecture have discussed the notion of expressiveness and representation in architecture through the use of computational and parametric methods.

'Parametricism' is an avant-garde architecture and design movement introduced in 2008 by Patrik Schumacher. However, there is a difference in computational thinking between *Parametric Design* or *Parametric Architecture* and *Algorithmic Architecture* or *Algorithmic Design*. Scholars may also argue that there is another field, called *Generative Design* or *Generative Architecture.* The author shares the opinion of Wassim Jabi, who defines *Parametric Design* as a process based on algorithmic, mathematical and logical thinking that enables the expression of parameters and rules that together, define, encode, clarify and control the relationship between design intent *force* and design response *form,* which differentiates it from both algorithmic and generative design.

The fact that it is a *process* is clear (Fig. 3). It is a strategy of thinking, not 'just a tool', and it should not be the *purpose* of a design. It is actually a fundamental shift in thinking of the process of design. The main shift is from a high fidelity in the manifestation of design concepts to a high fidelity in the expression of the logic of design concepts. It is also a shift from a focus on the shape of a given form to a focus on the internal mechanics and forces that define the form (Jabi, 2013).

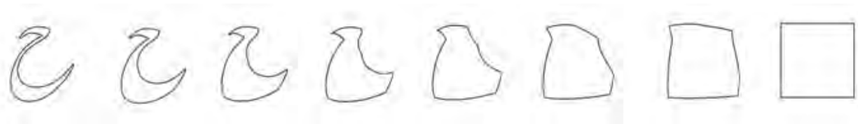

Figure 3. Abstract translation of transforming the Arabic letter 'Haa' to a square.

The relation between architecture and its integration with Arabic calligraphy, as well as the rise of the information society and digital culture, stresses again the role that architecture plays in Islamic/Arabic culture. The question then follows: what can Islamic/Arabic architecture achieve today and in the near future by merging parametric thinking with Arabic calligraphy as a catalyst? The use of parametric architecture to produce new and spectacular forms is only one aspect of a larger picture that later leads to unfolded perception, just as 'the invention of the perspective at the Renaissance was linked to broader issues than the mere research of geometric regularity' (Picon, 2000, 55). What should be the exact scope of parametric architecture's involvement with architectural design and Arabic calligraphy?

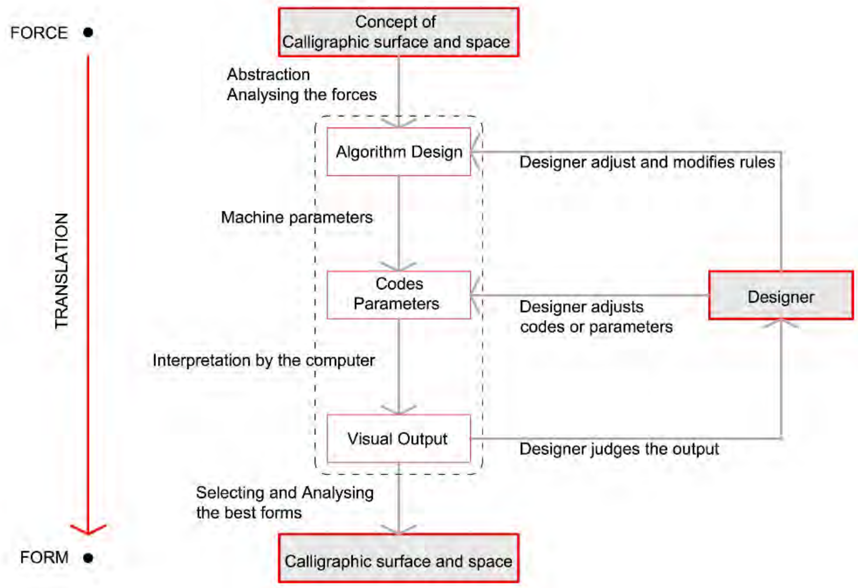

Figure 4. Parametric Calligraphic Machine design process and methodology.

The author's ongoing research will unify these polar opposites through the hypothesis of 'architecturising' Arabic calligraphy and the theory of parametric design, which have both been widely used to produce two- and three-dimensional forms, and will use this new design thinking and new design outcome in architectural contexts. The scope of this paper is to explore the intentions and influences underlying the argumentative relation between *Parametric Architecture* as a design system and *Arabic Calligraphy* as a design medium within the framework of architectural design generally and algorithmic design specifically (Fig. 4).

In his book, *Notes on the Synthesis of Form*, Alexander examined way to deduce form from a diagram of forces; his question of how to generate a form that will be stable with respect to a set of forces (Alexander, 1964) could be answered using a parametric machine that represents the influence of specific forces in any given context on a design. The outcome – a Parametric Calligraphic Machine for designing and visualising calligraphy-based forms – will be a significant contribution to the design process and will influence the way people create new forms of architectural spaces. This machine will translate Arabic calligraphy forces into architectural forms. The concept of the machine also supports transformations of Arabic calligraphy visual structures, thus producing new, yet arguably visual forms.

6. Parametric Calligraphic Machine Design Framework

In order to design the Parametric Calligraphic Machine, a series of experimental computational studies have been designed. In these experiments, Arabic calligraphy is applied as a design medium for conceptual inspiration; this inspiration began with the idea of defining a parametric architectural language. Investigations and explorations started with an exploration of the different visual possibilities within a single letter from its two-dimensional abstraction, proportion and perspective quality into three-dimensional interpretation.

The next step is to apply algorithmic means to the design process, which will be based on a series of algorithmic design experiments. In this sense, the proposed parametric system can be a completely automated process or a user-controlled one. John Frazer (1995) in his book *Evolutionary Architecture* discussed that we are inclined to think that final transformation should be process-driven, and that one should code not the form but rather precise instructions for the formative process. As such, the MEL (Maya Embedded Language) programming language was employed to create the Parametric Calligraphic Machine by designing specific programming scripts. Moreover, the basic structures and processes of MEL scripting will be introduced in order to understand, clarify and illustrate some of the mechanisms, relationships and connections behind the forms generated.

This process involves designing the algorithm of a certain calligraphic letter (rule) that enables the expression of parameters and rules that together define, encode, clarify and control the relationship within the calligraphic letter by adjusting the initial parameters and shapes, steering the derivation process and finally selecting the best variant (Fig. 4). A distinct machine was created for each case study. The machine introduces, explains and articulates the use of scripting in creating a space based on calligraphic visual structures. However, experiments examine the intellectual power of an algorithm and consequently parametric architecture (Terzidis, 2003).

7. Machine Design Review

This paper does not address the MEL scripts and code used in creating these machines, since the experiments are still ongoing. The machines and their visual outputs represent and constitute the beginning, rather than the end, of a narrative. Later research will be conducted in order to determine principles or a strategy to work with complex parametric systems using a more sophisticated method. The proposed Parametric Calligraphic Machine supports novel approaches to calligraphic compositions by manipulating and controlling algorithmic scripts based on actual Arabic calligraphy preferences (Fig. 5). The main concept surrounding the Parametric Calligraphic Machine can be attributed to the abstraction of the algorithm versus the concrete of form (Fig 6); therefore, most experiments ended up producing abstract forms.

Furthermore, adjustments had to be made to constrain the algorithm, which subsequently reduced many qualities of the spatial feature (Fig. 5); the experimental process was begun without precise knowledge of the way it would develop. On the other hand, producing an algorithmic project cannot be approached in the same way as an architectural project (Terzidis, 2003). From the outset, it demands a fundamentally different way of thinking. Parametric calligraphic surfaces and spacers are nevertheless a stimulating intellectual exercise. Moreover, the experiments examine the ability of an algorithm to encode and respond to new types of data and information, and to extend certain limits of the design process. The machine’s scripts create parametric design processes. They give an indication of the potential and a point of reference for assessing the value of algorithms in the design process.

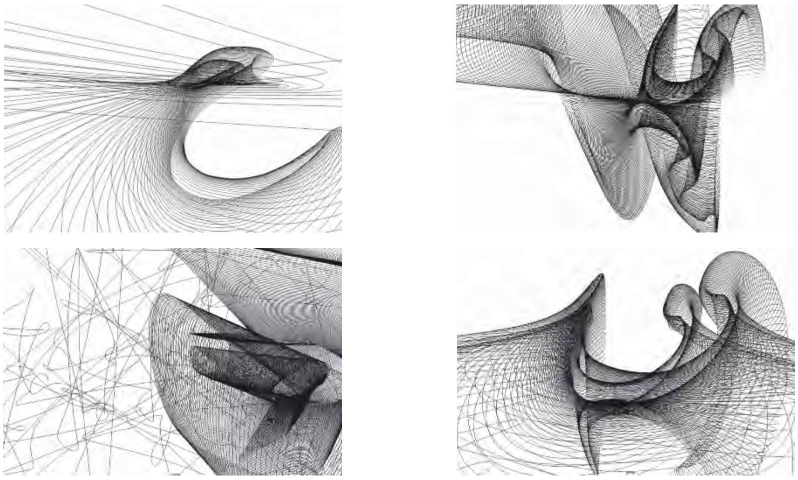

Figure 5. Forms and surfaces produced by the Parametric Calligraphic.

Figure 6. Ongoing three-dimensional calligraphic experiments to produce forms and surfaces.

The algorithms for these experiments were designed based on calligraphic letters' formational rules through a systematic development of the algorithm; the algorithms for these experiments allowed swift and accurate exploration of many variations. The machines translate the dynamism and fluidity of calligraphic context into equally fluid tectonic systems, producing controversial relations between angular and curved forms. Moreover, these algorithms are seen as linguistic expressions. An expression in a computer language is arguably a description of the desired behaviour of a virtual machine. 'The basic linguistic elements used in algorithms are constants, variables, procedures, classes, and libraries and the basic operations are arithmetical, logical, combinatorial, relational, and classificatory arranged under specific grammatical and syntactical rules' (Terzidis, 2003: 38).

Although algorithms in some experimental studies are effectively controlled, the final result was limited to a repetition of elements. However, it must be stated that algorithms offer many precise variations on a theme, though the main problem with them is that some designers find the numerical relationships too limiting (Terzidis, 2003). Parametric machines as diagrams can be understood in two ways, as a descriptive device and as a generative device (Eisenman, 1998). The machines produced designs different to what architects had designed previously, generating a process description form based on algorithmic calligraphic forces.

The questions still to be answered after completing these experiments are:

- How can these calligraphic forms and surfaces be utilised in real architectural designs, and how can they be handled spatially?
- What kind of design strategy and principles will calligraphy as a continuous surface offer? What kind of spatial possibilities might such a surface create?
- Did these calligraphic machines extend the designer's vision into a spatial design? Will the machines suggest a cognitive inventive process?

8. Conclusion

The author concludes this probationary part of the ongoing design experimentation as its theoretical basis; this preliminary investigation has, perhaps, raised more questions than it has been able to answer. The challenge that has persisted throughout the process is ascertaining how to crystallise this relationship with the abstraction of mathematically generated forms. Nevertheless, this ongoing research is in a position to formulate a contemporary hypothesis about the relationship between Arabic calligraphy and parametric architecture and will be able to develop studies further and provide a better insight into the relationship between the theory and application of the Parametric Calligraphic Machine.

Acknowledgements

I would like to thank Prof John Lee, Dr Tahl Kaminer, Dr Alain George and Prof Richard Coyne for their support and great insight.
I would also like to thank Dr Patrik Schumacher, with whom I discussed the emergence of this research, for his silent creativity and vision.

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IMPACT OF USING STRUCTURAL MODELS ON FORM FINDING

Incorporating Practical Structural Knowledge into Design Studio

INAS ABDELSABOUR[1], HEBA FAROUK[2]
Department of Architecture, Helwan University, Cairo, Egypt
[1] *inas.abdelsabour@yahoo.com*
[2] *heba_farouk2007@yahoo.com*

Abstract. Physical Models as an architectural design tool, had major effect on architecture learning process. In structural form finding, it helped in improving visual design thinking to track form creation processes during form finding design stage. The aim is to study the impact of using physical models for second year architecture students in design studios learning. By analyzing and comparing students' performance and progress; to clarify the effect of using physical models as a tool for designing progression, followed by analytical study on the students' structural models, in order to investigate the influence of models on their design educational progress. Research achieved that there were three basic phases the students pass through during form finding process when used manual physical models that improve the students' design capability.

1. Introduction-Scope of Work

One of the significant goals in any design studio, is helping the students to transform theoretical thoughts into drawings through architecture education. To develop design knowledge process, most students in the early design studio begin their architectural education without or with limited expertise in understanding the structural system of various spaces and forms. Whereas, an architect needs full understanding of structural principles in order to effectively communicate with structural engineers. Each design stage requires a specific way of visual design thinking and perception that varies from one medium to the other and from one designer to the other. It is necessary to develop manual abilities to improve imagination and design capabilities of the architect, specifically in the early stages of the design process.

1.1 CLASSIFICATION OF DESIGN CAPABILITIES

Design capabilities of an architect could be classified into five main types: Conceptualization, Form Giving, Representation, Decision-Making and Knowledge Building and Retrieving, Abdelhameed (2005). This research reports on the form giving stage, which can be described as the capability which enables architects to translate their concepts /or conceptual frameworks into actual formal architectural propositions and compositions, Abdelhameed, (2002).

Students of architecture in this stage need to visualize the structural elements at work, because their understanding during the early learning stage depends mostly on visual and oral communication rather than imagination, so forms had no meaning and are not realistic.

1.2 REASEARCH AIMS

Physical modeling allows designers to move easily between, form properties, abstract representation, component assembly and material shaping through a single design activity. So, physical models were chosen as a design stage tool, which students must learn manually during the 2nd year at the department of architecture in order to overcome the gap between what was taught in the theoretical structure courses and its application in the design studio. Physical models help in understanding, or validating structural system in the design process.

Architectural students must understand the structural systems during their projects, in order to identify when a system or a structural member is not appropriate fit for an idea by using physical models to display the structural principles during the design process.

To explore the physical model's value as a conceptual design tool of structural studies, the study aims to instruct students on how to build an environment through optimal design, by choosing the suitable structural system and most suitable materials during the design studio classes, and ultimately to help them test the form constructability and material choice. Getting feedback during design classes, help them to enhance their model and upgrade the design to the next level by transferring the physical model into 2 dimensional drawings.

1.3 LITERATURE REVIEW

Various studies had been conducted to explore the optimal way of teaching essential structural engineering knowledge to architecture students. One focus is placed on the act of manual modelling and its influences on studio design.

Abdul Aziz, (2010), Indicates that physical model at an early stage of design, enables the student to visualize the structural elements clearly to show more space planning and the materials selection. In addition, Abdel hameed (2011) described how physical modeling helped in studying the components assembly and construction aspects. Then, the student's awareness of the structural properties and form component assembly by hand is definitely increased.

While, Fahmi (2012), discusses the reason architectural students face difficulties in integrating structural knowledge into their design. He emphasizes the importance of coordination and communication between classes of structure and design studios, particularly, in studio projects to improve the integration ability with structural topics.

Moreover, Yazici, (2013), shows that design has a unique learning environment based on the principle of "learning by doing". Where all architectural knowledge is obtained and put into practice, so the supplement of the classroom teaching with active experimentation could help the structural concepts integration in the design studio work. Besides, Vrontissi (2015), argues that there is an actual lack of conceptual structural design studies in architecture education when discussing the presence of physical model in generating a structural concept process at early design process stages, and how it could offer a rich field for exploring conceptual structural design studies.

2. Methodology

2.1. MAIN PROCESS

The proposed framework uses physical models in the form finding stage through the design process, to study their impact on the students' progress in developing their design concept to clearly visualize structural elements. The main target is to study the complex structural systems with wide span projects. So it enables students to have a better understanding of the building structural system, and increased awareness of space and form impact, as well as space making.

The design studio of 2nd year students in its first semester (2015-2016) were selected as a case study for the application, after their studies all structural systems in the first year for two subsequent semesters. Aiming to link between what had been studied theoretically and raise it to another level in the design process, to understand the fundamental concepts of used structural materials, which related to structural design during the undergraduate education level.

2.2 PROCESS STEPS

The process is divided into three phases, at the first phase; a pilot study is conducted on a cohort of students, to investigate their awareness of using physical models during the design process. More than half of cohort confirmed its importance. The second phase is a 3-stage project for the design of a "Pavilion for Expo Dubai 2020". The stages are: 1- concept, 2-sketching, then 3-physical modeling for five weeks, ending with complete plans, sections, and facades drawings. The project takes into account students' desire to select their materials and modeling techniques (as strings, paper and cardboards), while maintaining the possibility of ease of assembly and installation model, to allow for changes during the weekly evaluation process. An assessment was done at each stage, to record the students' progress during the design stages. Scores are been recorded and compared with the earlier scores in the previous weeks, to measure the student education progress.

In the last phase, a questionnaire was carried out utilizing both qualitative and quantitative methods of analysis. The Qualitative part explored and propped into the role of physical model in form finding phase. With quantitative analysis, an attempt was made, using the statistical analysis programme SPSS to analyze the outcome of the survey questionnaire. The aim was to find correlations, the criteria for correlations that could highlight the importance of the physical model, which would ultimately lead to obtain the important affective factors in the form finding process.

3. Results and Discussion

3.1 STRUCTURAL FORM FINDING AND PHYSICAL MODEL CRITERIA

In the second phase, during the first week, students' ability to generate the structural system forms varied, and their skills in predicting stable structures without calculations became known to tutors. Whereas, the second week, saw variations among students in ability to integrate structural information within the design idea. While some students managed to produce many structural alternatives for their projects as in cases (1, 4), a majority of students experienced a decrease in their performance in the second week than in the first week as in cases (2, 3). Average performance improved in "merging structural element criteria" for most students who used the manual model in different stages, and a noticeable development was observed in the structural form with the design idea. In the advanced stages of the project, students' performance improved more than in former weeks, through developing the generated form and manipulation using the model. Figure (1) shows the progression of a random selection of students from a sample of 40 through the five weeks.

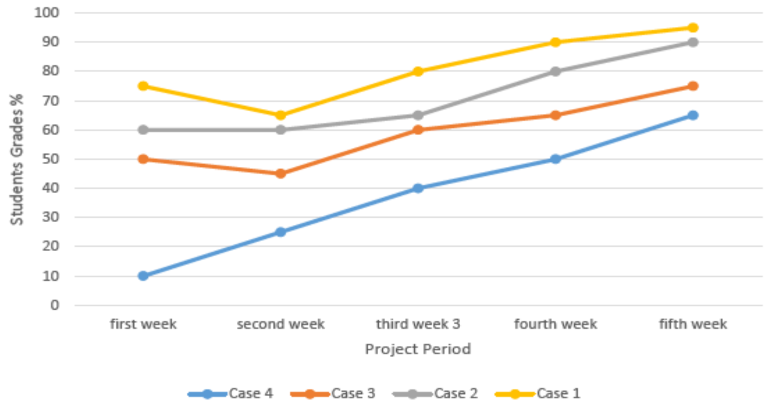

Figure (1) Assessment of Students progress during the design process.

In addition, figure (2) showed the student's physical models (case 1) as an example, during five weeks, to highlight the major progress that happened in his model, during the design process, as following. At first week, several ideas for long span structures were presented, then in week 2, design parameters were identified and some alternatives were displayed. In week 3, the best idea was selected, and then the architectural and structural drawings were fulfilled in the fourth week. Finally, the final model was completed in week 5.

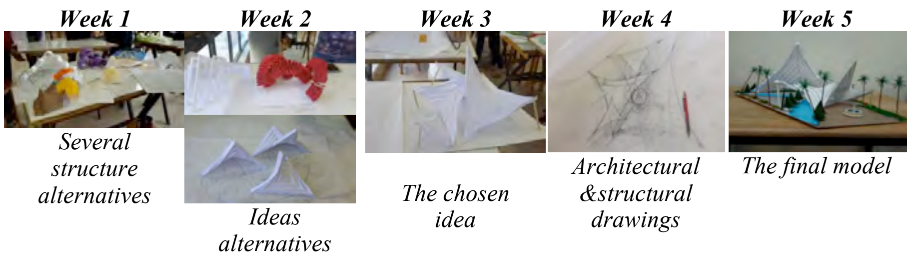

Figure (2) Example of a student' models through five weeks.

3.1.1 Frequencies

Finally, after conducting the main questioner in phase three, most of the students found that physical models helped them to think realistically in the structural design stage, while more than half of them confirmed the importance of physical model in the structural form finding process. The importance of the physical model was reflected in the increase in using it as a tool to "produce multiple alternatives of different structural systems for the proposed design, generating creative ideas based on structural concepts, and to help in choosing the best structural form".

Most students agree, that physical models help in discovering errors, choosing and evaluating the proposed structural concept, "creating ideas in a visible way – building, merging experience between structural and design elements". Figure (3), shows the response of students on the investigated criteria from the main survey, which were unimportant, semi-important, or important.

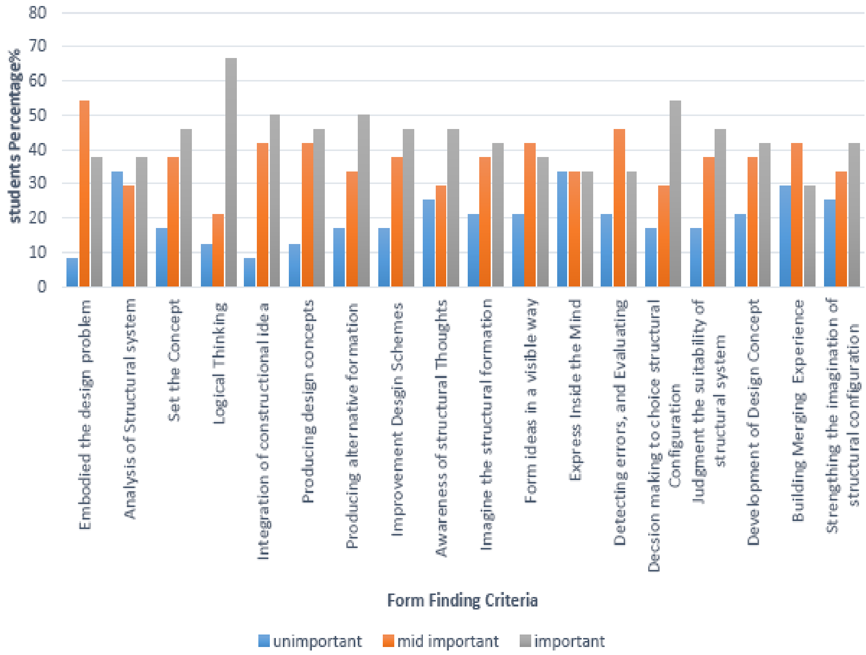

Fig (3) The Importance of Physical Model Related to Form Finding Criteria.

3.1.2 The Correlation

As shown in table (1), there was a correlation network with a strong, statistically significant relationship between "creating ideas in a visible way" criterion that related to the structural forms and their elements, and "building, merging experience between structural and design elements" criterion, and "generation of structural forms", that confirm the important role of using manual physical models during form finding design stages.

There is a direct correlation between thinking in a realistic way and visual form generating, with the structural thoughts awareness, and structural form generation all while being integrated in the design idea. Students' ability to produce alternative design ideas related to structural aspects increased, with an observed improvement in their decision-making skill, selecting optimal configuration and forming a sound opinion on the suitability of a structural system. Finally, their ability in "Merging Structural Experience of Knowledge into Design Studio" improved.

TABLE (1) Shows SPSS Output for the Spearman's Correlation Coefficient between Criteria.

	(!) Embodied the design problem	(2) Analysis of Structural system	(3) Thinking in logically way in structural system in project	(4) Integration of structural idea	(5) Awareness of structural Thoughts	(6) Imagine the structural formation	(7) Form ideas	(8) Detecting errors, and Evaluating	(9) Development of Design Concept	(10) Imagination of structural configuration
A) Producing design related to structural concepts	0.165	0.385	.573**	.537**	0.322	0.265	0.136	0.334	.424*	.506*
B) Producing alternative structural formation	0.244	0.222	.528**	.495*	.434*	-0.049	0.223	.462*	0.318	0.326
C)Better Decision making for suitable form	0.124	0.288	0.088	0.367	.619**	.517**	0.334	0.295	0.299	0.311
D) Judgment the structural system suitability	.460*	.424*	.418*	.539**	.455*	0.338	.596**	0.401	.486*	.485*
E) Development of Design Concept	.674**	.858**	.564**	.505*	0.399	.499*	.672**	.706**	1	.627**
F) Merging Experience	.625**	.649**	.696**	.597**	.602**	.659**	.572**	.677**	.644**	.751**

**. Correlation is significant at the 0.01 level (2-tailed).
.*Correlation is significant at the 0.05 level (2-tailed).

3.1.3 Factor Analysis

Through analyzing the criteria by using the factor analysis, the criteria show, that there are four major factors in the form generation stage by using the physical model:

First: express and generate structural ideas in a visible way.
Second: ability to combine structures and architectural design.
Third: producing alternative systems and forms.
Fourth: decision-making ability in choosing the best structural system and form of the project. Table (2) shows the main factors merging the structural knowledge in form finding stage.

TABLE 2. The Main Factors merging the Structural knowledge in form finding stage.

	Rotated Factor Analysis			
Criteria	**First Factor** Express and generate structural ideas in a visible way.	**Second Factor** Ability in combining structural info with architectural design.	**Third Factor** Produce structural systems alternatives and forms.	**Fourth Factor** Decision-Making ability in choosing the best structural form for the project
Express Inside the Mind	.838			
Embodied the design problem	.829			
Development of Design Concept	.828			
Analysis of Structural system	.818			
Detecting errors, and Evaluating	.708			
Form ideas in a visible way	.633			
Integration of constructional idea		.70		
Logical Thinking		.672		
Building Merging Experience		.670		
Imagination of structural configuration		.602		
Producing design concepts			.814	
Producing alternative formation			.749	
Decision making to choice structural Configuration				.909
Awareness of structural Thoughts				.750
Imagine the structural formation				.641
Judgment the suitability of structural system				.543

3.2 DISCUSSION

The learning methodology, especially in the first week, was leaving students to explore structural form freely, to help them easily connect with what was studied in structural courses. As a result, students developed a better awareness in form finding stage, and gave unexpected results, also they were able to gain benefits from using simple materials, and gave variation in using structural form ideas. They also developed a sense of understanding structural loads without the need for mathematical calculation.

During the second week, number of students faced difficulty in finding a structural form suitable to the nature of their projects, despite of their good performance in the first week. More experimentation needed, which was achieved by producing more alternatives for the same design proposal, and then selecting the best one after assessment. This suggests that a comprehensive design process can account for development much better than separate stages.

4. Conclusions

Physical models offer students a method of embodiment to their vision, and examination to their structural ideas, which eventually enhances their skills in choosing the best structural concept to develop their design ideas. The ability to produce design based on structural systems, produce design and structural alternatives, improve decision-making, and offer better judgment on structural system suitability to a project, all ensure the quality and skill of integrating structural info into design.

After correlation and factor analysis, there are three basic phases that students pass through in form finding process by using manual physical models, namely: generating ideas stage related to projects' structural elements, generating structural forms related to design stage, and developing their ability to choose and to evaluate the best structural form. Also, "Incorporating Practical Structural Knowledge into Design Studio" criterion exhibited a strong correlation with all the other criteria elements.

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*Program SPSS "Statistical Package for the Social Science", version 16

MORPHOLOGICAL TAXONOMY AS A METHODOLOGICAL TOOL OF FORM MANIPULATION

ASMA. GHARBI[1], FERDAWS. BELCADHI[1] AND
ABDELKADER. BEN SACI[2]

[1]*National School of Architecture and Urbanism, Tunisia*
asmagharbi2013@gmail.com
ferdaws.belcadhi@yahoo.fr
[2]*High School of Architecture, ENSA Grenoble, France*
bensaci.a@gmail.com

Abstract. The paper presents taxonomy as a methodological tool which serves to better understand the architectural morphose (act of giving shape), and its contribution to form manipulation, produced through a morpho-digital combination. The interest is to exploit digital processes to decipher an underlying architectural grammar. It is thus a matter of releasing the morphological knowledge in conformations (observed forms' system). This orientation stipulates that the produced shape results from a system of morphose which we can formalize and understand by the identification of the structural attributes and the organizational logic, as well as the inherent morphological laws of generation. We stipulate that the interest of our morpho-digital method is the characterization and the development of a constructive morphological model governed by internal relations. Thus, a collection of dwelling buildings is characterized by both the morphology decomposition and the morphometric study. Based on the questions about the form produced, the method promotes a creative situation in the field of architectural design.

1. Introduction

The paper proposes, with the help of the epistemological paradigm (methods and surrounding areas of morphological characterization), a model of management and processing of the morphological information. It is about a proposed new understanding of the produced shape on the basis of the underlying postulates of the architectural shape. The stake is to characterize a morphological taxonomy (1) by the exploitation of processes moved forward in artificial intelligence, allowing observing the laws of regularity, which characterizes a given morphological system. This article defends the necessity of an intermediate positioning which is joining the phenomenal representation of the shape to that digital technology to understand the genesis. The latter is a matter of formalization in both complementary dimensions. On one side, it is a question of revisiting the phenomenological foundations of the morphological similarity; On the other hand, it is about digital characterization's foundations of the architectural shape. The epistemological formalization gives operating results which are leading to a parametric development of the architectural morphology. This work adopts a methodological purpose concerning the laws of identification and manipulation of the forms.

The domain of knowledge of the shape goes through three paradigms mainly: i) phenomenological paradigm bases, the superiority of the physical dimension. A phenomenological experiment does not show the structure interiorized by the shape. It is rather about a description stemming from the perception's experience. It is about representing the shape by its eminent physical properties. M. Heidegger defines the shape as portion of the space limited by an edge which its harmony conveys the reason (1982); it is a figure on a bottom as asserts Gestalt-theory also; ii) empirical paradigm believes on the superiority of the rational experiment allowing to annihilate explanations based on the perception. An empirical discipline maintains its reports with the experiment and the observation (Popper, 1988), as unifiers of objectivity. So, a field of experiment applies digital operating tools on a variant specifically treated for a given architectural corpus; iii) digital paradigm enables to localize the recurring morphological properties, to qualify them, to quantify them to optimize the importance. It is based on new properties of artificial intelligence.

But, a fundamental qualification of the shape is deduced from the integration of the digital tool to check the operations of perception. H.l. Dreyfus asserts the complementarity of two epistemological and 'ontological' indubitable presuppositions (1991) to establish an objective knowledge. Its interest is to overtake the epistemological obstacles put by both previous paradigms (2). He displays an approach which combines the phenomenological definition of the shape in the purely experimental definition. We develop a dynamic conception of the shape which federates within a qualifying and forward-looking combined reflection. The morpho-digital modelling articulates qualificatives and quantificatives purposes. We agree that the morphological formalization reveals two degrees of understanding: i) the analytical morphology displays a qualifying moment, using digital investigation on the shape phenomenologically studied; ii) the morphometric method constitutes a quantifying moment which pleads the conversion of every shape studied in numerical values regulated by means of internal frequencies. Those support the comprehension of the produced shape and the projection of the shape to be produced.

2. Morpho-digital Method For The Architectural Forms' Analysis

2.1. CORPUS AND STUDY MATERIAL

Our methodological investigation concerns a collection of 95 facades of residential buildings constructed between 1990 and 2015. It is about a new district on the periphery of the capital Tunis, *Ennasr*, whose buildings respect specific rules and regulations of town planning in the zone. The facades, included in our study, present on the morphological plan a source so rich with morphological combinations. We do confirm the release of the morphological values interiorized in the conformation of the facade. What allows to report combinations' rules which govern an underlying morphological system. B. Duprat defines the façade's addresses as a rich support which supplies multiple analycities (capacities to be analyzed), being a matter of an autonomous morphological structure (1999). Facades reveal an underlying morphological knowledge to be clarified. We work on the basis of statements of facades reproduced in linear mode then codified in levels of grey, and handled by specific software to the study of the architectural shape.

TABLE 1. Exemples of current facades

2.2. FORMALIZATION OF MORPHO-DIGITAL COMBINATORY

2.1.1. Patterns of Morphological Composition

The morphological analysis and the morphometric modelling constitute two analytical models of the produced shape. The morphological analysis is a first operation of morphological objectification. The decomposition sets up a system of interstitial morphological relations between parts and parts and the whole. It is necessary to observe the morphological obvious discontinuities of the objects; decompose (through reflection) each of the specimens of the collection into different segments. The morphological segments of the whole are definable because they are bounded (and their perceptible limits are the discontinuities forming borders between adjoining segments). It is what, b. Duprat considers as a source of legitimacy of the method (1999). Those considerations reduce the relations possible for a very small number, and eliminate the weak relations between objects and their segments. A morphological structure is stopped further to operations of comparisons inter and intra-specimens. So, to decompose the facade, it is necessary to go through 1) the location of the recurring obvious discontinuities by the various conformations; and with regard to a hypothesis of homology; 2) the Transport / Coupling of the discontinuities, which we appoint by segments, to reveal or deny homologies; 3) the definition of structural model (s). The comparison between the whole and its parts and between the parts themselves trains an operation of control and validation of the most convincing morphological hypotheses.

The morphometric modelling proposes the second pragmatic objectification. It imputes within a model of morphic information (quantified morphological information); where it becomes possible to measure the shape, calculate its morphic potential and estimate its contribution regarding morphic information. The morphic experience displays tools of mathematical calculation. The digital measures are governed by an energy description in a field of variable frequencies distributed on 15 frequencies' domains. Every frequency domain constitutes a frequency band BF which corresponds to an elementary morphic composition. The shape is defined according to: a topological space (corresponds to morphic information retained on first morphic strata corresponding to the primary frequencies), and a configurationnel space (informs about levels of frequential stabilizations of morphic strata). The frequential analysis displays specific digital tools. On the software 'Matlab', the 'Morphique' application reveals the behavior of the shape according to the variation of the frequencies. The 'Morgex 'application is used to measure codified images and translates them into a series of digital values defining variables in columns of an Excel table. The tool ' Wad ' allows the statistical processing of the digital data.

2.1.2. Structural Matrix

In the process of characterization, the parameters of position and depth set up two matrixes of comparison and structural control. The matrix of position allows clearing the laws of morphological stability according to the horizontal pile of the parts. However, the deep matrix clarifies the origins of the volumetric stratification. According to its position, obviously, each party corresponds to a segment. It is possible to project the latter according to its position from a specimen to the other one. This is what we call a projectable property.

2.3. MORPHOLOGICAL OPERATORS

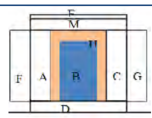
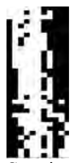
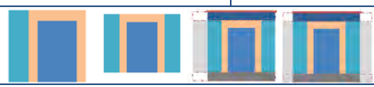
A visual operator is deducted from the of the position's matrix on specimens. The comparison's operations and structural control are based on the parameter of linear positioning. A digital operator results from the application of the depth matrix. It is translated in values of variable frequencies which we indicate by energy descriptors.

3. Results and Discussion

3.1. MORPHOLOGICAL ANALYSIS AND DATA PROCESSING

We proceed to the analytical decomposition of the facades' specimens. We choose the position as mode of apprehension of the structure, locating the discontinuities or the segments, defining the homologies of position as descriptor of constitution (equivalent segments from a specimen to another one). Then, we establish a comparison based on those visible structural homologies. This allows the validation of structural models by the formalization of its intrinsic morphological relations. This method calls on the digital tool 'BSK' to facilitate the classification and the data processing of decomposition, comparison and morphological control. The segments of strong importance constitute the morphological attributes of comparison inter-specimens; which leads to their categorization in families of the morphological structures, according to the eminent attributes. The elaborated work asserts that the conformation of facade is a morphological system which hides two typologies of internal structures. A first category shows a structuring by linear juxtaposition of spans. The second reveals a structuring in main span of order with possibility of presence of symmetric or unilateral side bodies. We do summarize in the following picture the stages of morphological decomposition.

TABLE 2. Structural modelling steps

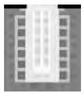
 Elementary decomposition	 Position matrix	 Specimens/Attributes apportionment ('BSK')
		

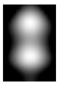
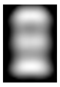
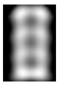
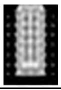
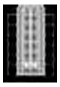
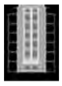
Structuring by linear stacking spans — Structuring by main sequence span

3.2. FREQUENCY ANALYSIS AND DATA PROCESSING

For every specimen corresponds a frequency storyboard. It allows to survey the structural evolution of the form from the embryonic structures on the frequency bands. What clarifies a morphological cycle, and reveals a structuring in elementary morphic skeletons.

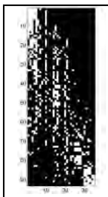
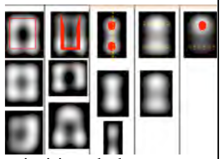
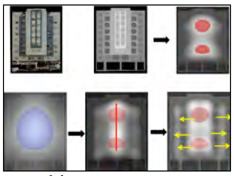
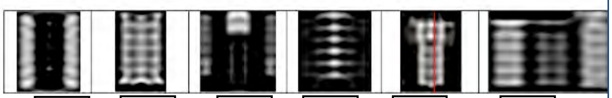
TABLE 3. Example of morphic storyboard.

Codified facade 

BF1-2	BF1-3	BF1-5	BF1-7	BF1-10	BF1-15	BF1-23
						

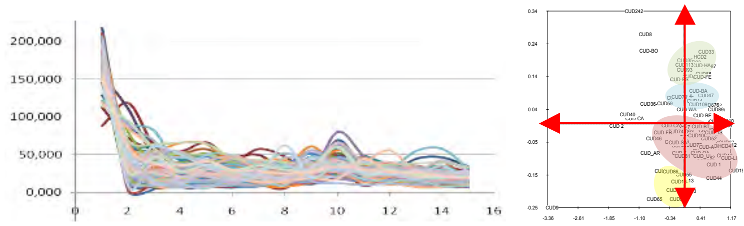
The shape's cycle contains three essential phases: the disturbance (BF1-3, 1-5, 1-10), the temporary stabilization (BF1-2, 1-7) and the refinement (BF1-15, 1-23). It sends back to the parameter of morphic tectonics. 'BSK' reveals categories of elementary morphic skeletons held by the BF.

TABLE 4. Morphic tectonic parameter (follows morphic behavior).

 Evolution	 primitive skeletons	 morphic emergence	Morphic behavior : 1-Monobloc with alveoli 2-Configuration in 'I' + cellular divisions + lateral disturbances 3- Repetitive verticality 4- Horizontal stack 5- Configuration in 'T' + cellular divisions 6- Configuration in 'U'+ cellular divisions + horizontal disturbances
 1 2 3 4 5 6			

With the application 'Morgex', we get frequency curves from each codified facade specimen. The superposition states that specimens in the collection have large structural homologies. The clouds of points table is obtained after integration and processing of values calculated by 'Morgex' on 'Wad'. It shows specimens concentration areas. It is qualified in relation to axes U1 and U2.

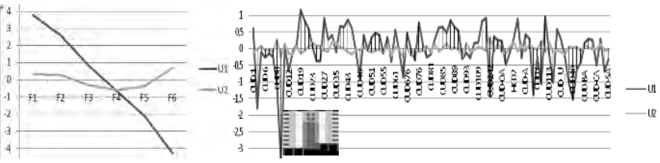
TABLE 5. Superposition of frequencies' curves and point cloud table.



To optimize the interpretation of the data, we proceed to their superimposing (Figure 4); this reveals a main frequency domain where are located the majority of specimens. The general morphic information is situated in the field of frequencies [-1, 0.6]. The more obtained frequency value aims towards 1, the less is the structure's depth. It is governed by a main span of order with regard to a back body. The more the frequency value aims towards [-0.6], the more the structure presents a high quantity of morphic information. So, the morphic potential establishes the second morphic parameter determining the depth. The morphic structure corresponds, in this case, to a complex combination of juxtaposed and superimposed spans of bays, balconies. The morphic depth becomes so remarkable.

TABLE 6. Superimposing of frequencies' axes and localization of specimens' distribution

	U1	U2
F1	3,767	0,335
F2	2,566	0,28
F3	0,808	-0,316
F4	-0,682	-0,598
F5	-2,144	-0,389
F6	4,315	0,687

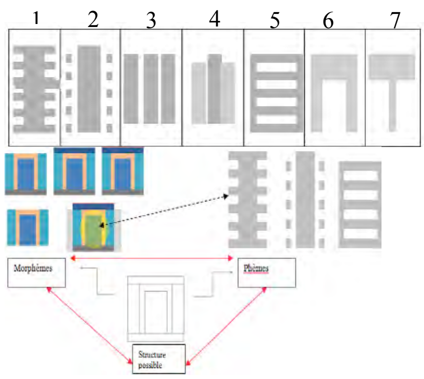


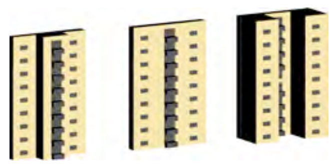
3.3. MORPHIC FACTOR

The morphic factor results in the morpho-digital combinatory. It is projectable by three properties: the morphic tectonic or the morphic depth, the potential of morphic information, and the inter-relation between the parts and the whole. The interstitial laws are summarized at the origin of the structural convergences between attributes: the span of order or simple, the main body, the back body or the side body. The latter are summarized by a taxonomic matrix. The morphic tectonic is underlying to a structural evolution's cycle, made in similar elementary primitive embryonic skeletons. The potential of the morphic information depends on the corresponding structural system. More it is complex; the structure demonstrates an important morphic depth.

Thanks to the evolution of the artificial intelligence tools, it becomes possible to plan the same structures in an infinite way. What supports the manipulation of the shape by its elementary attributes with its own morphic operators. All the morphic relations identify the general morphological matrix. The back body (Ar C) shifts from a main position, in this case we hold the relation Ar C/To, or secondary one obeying the relation To / Ar C. This structural typology governs all the other elementary components, this is applicable for side body (CL), front body or main body (AC). The span of bays (Tb) constitutes the most important attribute of the corresponding specimens. Each can establish in certain cases a span of order. Its central position makes set up a symmetric or asymmetric organization according to the choices of the designer. The span of order (To) respects two morphic topologies: i) simple by superimposing either of bays or set back masses or masses in projections; ii) combined where it shows morphological structure based on the combination of simple span by linear or volumetric juxtaposition; iii) (To) can be associated with the main body (Cp) in projection or set back position. We conclude the following structural relations: T_o=Ar C/T/ (C_p or AC);

TABLE 7. Matrix for morphological manipulation





1- Span in ‘I’
2- Span with lateral detached bodies
3- Repetitive separated spans
4- Span with lateral adjoined bodies
5- Monobloc span with alveoli
6- Simple or composite span in ‘U’
7- Simple or composite span in ‘T’

4. Conclusion

The morpho-digital combination supports the formalization of a theory applied to the domain of the architectural shape. This theory associates two modes to identify the shape. It questions in particular the utility to assign a theoretical knowledge of the shape to a digital field of application. On the epistemological plan, the morphometry reveals methodological tool of ontology of the produced shape; this builds itself from the conversion in objective values of an ‘objectivable’ (capacity to be objective) shape. It is an innovative track which comes to complete a rich structural morphological analysis by its contents and limited by its ways. It adds to the shape's understanding by visual assertions objective mathematical solutions.

The current facade, support of our present study, hides a structure which is able to be formalized through a morphic factor. The latter expresses morphic parameters. A morphological objectivable logic which rests on a knowledge and a know-how and which sets up the laws of generative manipulation is demonstrated. The formalization of an underlying morphological taxonomy reveals the typologies and the laws of the morphological organizations of specimens in question. Thanks to the morphometric tools, the form federates in an objective quantitative definition. The characterization based on the morphological taxonomy contributes to the development of a constructive morphological model. The latter sends back to operations of regulation in a spiral which aims towards the infinity (Le Moigne, 1999). Consequently, the shape possesses double epistemological purposes: epistemic purpose which stimulate the acts of morphological objectification, and the methodological purposes which develop the experimental methods. This work opens new perspectives of computer-aided design. So, it establishes a creative method resulting from a combinatorial morphological strategy. The generation of the shape becomes possible just as we manage to define all the morphological behavior which governs an existing architectural object or to produce. After decrypting its epistemological contribution in a genetic knowledge of the shape, it becomes possible to manipulate it.

References and Notes

1-The taxonomy is defined as the study of the diversity of the human beings and the clarification of its causes of this diversity. The field of the discipline extends the description in the analysis of the relations between types until the expression of the results under a codified shape (Cnrtl.tn, 2016).

2-By ontological, Dreyfus reminds the phenomenological dimension which he criticized at Heidegger; he considers that the latter presents a definition of the existence which is lacking internal articulations contrary to Husserl (1991,p.30)

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Section

IX

SMART CITIES & URBAN PERFORMANCE VISUALISATION

“SELF-HEALING” PROCESSES FOR THE CITYSCAPE

Computationally driven collective initiatives

AIKATERINI PAPADIMITRIOU
AP Design, Stuttgart, Germany
aikapapad@gmail.com

Abstract. The subject of this paper describes a proposal on processes and strategies that a community should inherit towards a collective effort for the improvement of public space, in order to evaluate, preserve or cancel actions towards this scope of their personal, and extended, scenery. This project, within the spectrum of what an era, underlined by (financial) crisis, represents, is an experiment on the active cooperation of the citizens for their own benefit. That affects, amongst others, the social and public management of space, by creating and activating a community’s feeling of “ownership and responsibility” within its neighborhood. It is expected to achieve an intense caring environment both for the public space, and the extended private scenery. Identifying the tools for actions as such, there comes the necessity for them to be able to make the interested parties feel comfortable with the main artifact and challenge them for collaboration. The digital era, the social media power, as well as the need of the individuals towards networking and belonging, shall perform the main attraction to the subject, leading to the creation of a digital tool linking the people actively to the changes they want to see. This paper debates on the development of an application that enables citizens to take part on the well-being of the(ir) public space.

1. Introduction to the Idea

The term cityscape describes the sum of elements that are experienced as the setting of a city as its inhabitants conceive it. The scenery in which one is living, walking, working and operating – a scenery that architects and engineers are responsible for, at a first read – and combines private and public matter. The state of the space that is being inhabited, though, is subject to the users, the citizens. Living in an era where financial and ethical crisis is imminent, a caring attitude from both state and citizens can be limited. The results are obvious within the city tissue, with abandoned-looking areas and mistreated infrastructure, affecting the quality of the citizens' everyday life. Conditions of unstable political situations and protest, may deteriorate the situation, making the government vulnerable while keeping track or dealing with all of the cityscape issues.

The subject of this paper deals with processes and strategies that a community should inherit in order to evaluate, preserve or cancel actions towards the improvement of their personal, and when extended, public, scenery. It is a proposal for emergent actions, with immediate results, both affecting the city image and the inhabitants' psychological health. By taking advantage of the increased communicative applications, the up and coming collective spirit for constant improvement and the spontaneous character of each individual, the creation of a "tank" for action is being proposed. Stimulating the cooperation of the citizens for their own benefit influences, amongst others, the social and public management of space, by creating a community with the feeling of "ownership and responsibility" within its neighborhood.

Identifying the tools for actions as such, there comes the necessity to make the interested parties feel comfortable with the main artifact that will be provided and challenge them to collaborate. At this point the digital era, connectivity and interaction (IoT), the social media power, as well as the need of the individuals towards networking and belonging, shall perform the attraction to the subject, leading to the creation of a digital tool linking the people actively to the changes they want to see. An application that enables citizens to take place on the well-being of the(ir) public space.

2. Background and State of the Art

2.1. COLLECTIVE SPIRIT AND MOTIVATION: THE POWER OF THE MASSES

Current economic and social challenges may result in a crisis of the public sector organizations' ability to effectively provide various forms of public services. Simultaneously, social innovations and, in particular, people's emerging active and collaborative attitude can be among the most promising drivers of change for public services. (Manzini & Staszowski, 2013). The city management often lacks efficiency, while simultaneously an urge of people to belong somewhere, to be active members and to be respected, is noticed. In order to achieve the turn from a self-centered approach to a more global and caring citizen of the city, there needs to be motivation. As declared in research conducted at the University of Australia, the types of motivation can be identified into the following categories: (1) Ideology, by contributing to a larger cause. (2) Challenge, as personal achievement, endorsing knowledge. (3) Career, succeeding and getting recognized. (4) Socializing, the need to have shared experiences and the sense of belonging. (5) Fun, enjoying the process. (6) Reward and recognition, experiencing private or public acknowledgement. (7) Duty, awakening the participation and responsibility notion of the parties. The proposing application will attempt to trigger all of those motivation types as part of the methodology to application process.

2.2. INTERNET OF THINGS (IOT)

The Internet of Things (IoT) is expected to offer advanced connectivity of devices, systems and services that goes beyond machine to machine communications and covers a variety of protocols, domains and applications. (Hoelle, *et al.*, 2014). By definition, it is the network of physical devices, embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. Computational power is the link to the data mining that IoT is producing. This principal, in the case of this project, is used as the tool to connect the participating parties and their actions to the perception of space and the interventions happening in favor of the city life. At this type of network governance […] on the one hand, the efficiency is enhanced through distributed knowledge acquisition and decentralized problem solving; on the other, the effectiveness is improved through the emergence of collective solutions to global problems in different self-regulated sectors of activity. (Dedeurwaerdere, 2007) With smart phones and mobile technology increasingly becoming available to a larger number of people, it should be possible to create inclusive systems which are available to all and change the future of individuals, enterprises, and the public sector. The IoT, for the purposes of this product, facilitates the data flow, makes them accessible to the public establishing transparency in the processes, enables a hi-tech approach for everyday operations and inserts the above to the citizens' everyday life, into their mobile phones.

3. Methodology – Operation Flow of the System

3.1. THE PROBLEM

The public holds the perception that neither their fellows nor the local authorities care enough about the cityscape, the communal areas. It is believed that the authorities do not pay the adequate attention to the needs of their people and that the system is corrupt, and favors certain castes of people or areas of the city. This makes citizens careless about their immediate environment. By achieving meaningful mechanisms of public participation, underlining the collective spirit and feeding the sense of participation and ownership of the cityscape, care is expected to rise as a natural consequence.

The workflow of the idea behind this project hinges on the triptych: Locate–Act–Enjoy. One locates the problematic spots, they act: (a) by recording it and publishing it, (b) by offering services (or hardware) to fix it (c) by enjoying the outcome visually, functionally, raising the quality of life, becoming an active member of society and receiving appreciation for making change happen. The central idea of the project is to alert the authorities to issues within the cityscape and to motivate the citizens dealing with those in theory or praxis. The key point focuses on the development of a network among shorted-out information as a database, activating citizens and companies, to accelerate the state on dealing with public space repairs.

3.2. MANAGING THE SYSTEM – LOOKS AND FUNCTIONS

There are three main types of core facts that shape the application: Profiles, Actions and Rewards. Initially one creates a profile, declaring their interest on the matter, they act and react in different ways regarding the level of engagement they wish to have and regarding the latest, they receive rewards.

3.2.1. Profiles

Individuals, enterprises as well as **institutions** (universities, schools) are welcome to participate in this collaborative action. In order for one to be part of the system, they have to set a profile for action, which will allow them to interact with other people/companies and the authorities as identified entities. The profile can be a combination of existing social profile incorporating additional information. The following data are considered to be necessary: Name and contact details: as a basic feature of the profile and contact channel to the individual, the company or the institution. Age: the age can ensure that, the access on certain actions are restricted. Simultaneously, this would allow the creation and live update of databases. The correlation of age groups and interests, facts and figures, could be helpful for general statistics and future researches. Fields of Interest: stating their hobbies, interests and tendencies, can be a filter on what appears on their info-board and on where they could participate. Expertise: declaring their profession. Stating expertise would allow, or deny, parties take part in later processes. Areas of Interest: locations on their field of action. Where do they spend time, live or work? Reporter or Doer: declaring if they are interested in reporting problems within the city, or if they'd like to take part in the healing process themselves. Enterprises shall note whether they can offer services, merchandise or support on the rewards sector. Tax Number and ID: necessary for the rewarding system. (a) eligible for possible tax reductions (b) verification key for the individuals and companies.

In the case of institutions, the repair of the faults could become a real practice scheme for students, sensing and dealing with reality in real time. Names of supervisors and their contact details should be provided.

Related authorities' departments must be on the platform with active profiles. The official name of the department and the specialization of it shall be declared as well as contact information for those responsible have to be available. This project is setting a live communication portal from the governmental public sector departments to the public. Each department will get notifications when issues addressed to it are referred in the system. The department will have to filter and assign them to the respective group of employees that will get the work done. The contact rate, the response rate and success of the department deal with the issue will be embedded in the platform and available to the public. In cases where the healing action maintains a low level of complication, the citizens themselves will be eligible to be assigned (upon request) for the healing process.

3.2.2. Actions

The way that the project operates will be based on the triptych: (a) record/share (social media effect), (b) react/evaluate (individual initiatives on participation principles), (c) enjoy (reward system).

The process of recording the actions requires: (a) documentation photo, (b) location, (c) evaluation/categorization according to the following characteristics: (1) Level of Complication (how difficult is the implementation of the repair? A scale 1 to 5 declares a low to high level of expertise) (2) Level of emergency (How urgently does the reported incident need to be taken care of? A scale 1 to 5 declares a low to high level) (3) What kind of expertise is required? (Assign the nature of the intervention: built, electric, plumping, […]. This input is going to address the request to the respective department within the state authorities. (4) Aesthetic or Functional? (Is the intervention of an aesthetic or functional nature?).

The actions reported shall include anything that a citizen might want to improve in their surroundings. That is a list that can be continuously updated on the fly, and could include: In small-scale interventions: painting, cleaning, signage, fixing broken tiles, plumping failures, broken lights or even gardening. In large-scale interventions: road elevation issues, gas or water leaks, decaying or broken infrastructure. Regarding the levels of complication and expertise required, those eligible will be logged by the respective departments, and on the platform. Any citizen could declare interest on taking care of those which have low level of complication and apply to their interests and expertise. Upon completion of the intervention, the citizens are then able to evaluate the result. The evaluation scheme can operate as a quality factor for future processes, stored under the profile of the reporter, the relevant state department and the employer/doer, and takes into account accuracy, time for completion and quality, as statuses.

The result of a prim public space improves the quality of everyday life and pushes citizens to maintain it while simultaneously improving their psychological health. Contributing to the well-being of the public space, aesthetically and functionally, enhances the sense of ownership, which can also be seen as an extension of their personal space. Under the scope of the system described, everything operates following principles of the Internet of Things. The data are being processed, stored or cached and the state departments are getting connected with the citizens live. All this information and network connections are available and accessible for future use. Inhabiting those active cities will no longer be just an optical pleasure; through interventions and participation, sentimental relationships will develop and be encouraged by a reward system.

3.2.3. Rewards

The Rewards tab will become unlocked and "points" will be added on the profile of the users, as an extra motivation, once they start reporting issues, or participate in the repairs. Motivation is always a key factor for the success of any initiative. This aspect in the project is covered predominantly by the improvement of the environment that people live in. Still, providing a reward system to the involved parties for their commitment to the public well-being can only lead to a chain effect of constant refinement. Therefore, each valid report and repair adds on the account of the user adequate points. The amount of points added get affected by the levels of complication and expertise of the action taken. Hereby different methods of redeeming the collected points are presented: (a) Recognition: an "invisible" monument is created, underpinning the value of each individual. The picture and/or description of the citizen who contributed, and the way they did, appears on the spot virtually, if they wish. (b) Ethos, Social contribution: aid offered to NGOs. The citizen transfers the desired amount of points to the institution of their choice. (C) Reductions: participating companies (e.g. local super markets, shops, services) offer products at reduced prices. (D) Tax reductions: the state recalculates the tax addressed to each party according to their points/contribution to the cityscape. € ECTS points: in the case of educational institutions, the participants could gain ECTS points for classes relevant to the operations they implemented. Additionally, they could create a productive competition scheme with other schools: whichever collects more points gets, for example, new laptops, new sports equipment, an excursion.

At the case of the authorities, the points system is translated into trust points and to a live evaluation process. They promote transparency in assigning tasks and can showcase the efficiency of their governance.

4. Expected Results

Sounding a bit romantic, but as Gandhi stated, "Be the change that you wish to see in the world." The project seeks to get implemented by two different European cities. One which could be considered without financial problems, and another which is affected by the crisis of the latest times. The comparison of the findings among those case studies is expected to provide material for future consideration, since the processes operated will be conducted in environments with diverse mentalities, financial conditions, and public space management. It will be distributed to the youths, who are familiar with up-to-date technologies and are expected to get engaged actively spreading their visions and enthusiasm, projecting (and creating) a space they 'd love to live in.

Sensing and actuating: sensing the problem and getting the habitants themselves actuated to deal with the issues that arise within their extended private sphere, the(ir) public space. As Carlo Ratti at his Talk in TED 2011 mentions, "as architects, as engineers as designers, we always think of how people will use the things that we design but always reality is unpredictable and that is the beauty of doing things that are used and interact with people." The project is expected to achieve an intense caring environment both for the public space, and the extended private scenery by merging the knowledge of public services and professionals on how to operate in the system (bureaucracy, hierarchy, paperwork), with the citizens' awareness of "in what type of city I want to live in". It is sensible to utilize information and communications technology and increased networking abilities to address urban challenges. "Connections become relevant and add value because the right information is delivered to the right person in the right time in the most appropriate way." (Mitchell *et al.*, 2013)

The future expectations within a spectrum of augmented reality lies in intensifying the social engagement towards a system that would allow a type of self-governance of the public space. Creating bridges between the research, industry and authorities is a gesture that can go the extra mile towards a progressive public sector for the public good. This project is not a way to detour the public sector or authorities, but rather support it with new tools and operation systems.

5. Discussion – Conclusion

The establishment of a live and up-to-date communication system among individuals, enterprises and the public sector is believed to lead to the well-being of a city, and one that can deal locally with its faults. Achieving the creation of an archive that dynamically updates and invites authorities and individuals in raising the quality of the cityscape can only be promising. Increasing transparency, quality and time of execution regarding issues that derive within the city tissue, are factors to motivate and activate people, providing a new perspective on what belongs to the citizens.

Incubating technological innovations in favor of the social good, could lead to long term opportunities, such us enhancing the touristic aspect of an area, triggering research and attracting entrepreneurs and investors in favor of those initiatives. The effective applications of data analytics could enhance the potential to transform business, government and society into a more interactive and efficient mechanism. This chance that arises, turning barriers into opportunities, by placing the energy of the mass to build and create rather than to destroy, seems to be the right tactic for progress.

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LIVING ON THE EDGE

Reinventing the amphibiotic habitat of the Mesopotamian Marshlands

SALLY AL-BADRY, CESAR CHENG, SEBASTIAN LUNDBERG AND GEORGIOS BERDOS
Architectural Association school of Architecture, London, UK
sally.al-badry@aaschool.ac.uk | *cesar.cheng@aaschool.ac.uk*
seb.lundberg@gmail.com | *giorgosberdos@gmail.com*

Abstract. The Mesopotamian Marshlands form one of the first landscapes where people started to transform and manipulate the natural environment in order to sustain human habitation. For thousands of years, people have transformed natural ecosystems into agricultural fields, residential clusters and other agglomerated environments to sustain long-term settlement. In this way, the development of human society has been intricately linked to the extraction, processing and consumption of natural resources. The Mesopotamian Marshlands, located in one of the hottest and most arid areas on the planet, formed a unique wetlands ecosystem, which apart from millions of people, sustained a very high number of wildlife and endemic species. Several historical, political, social and climatic changes, which densely occurred during the past century, completely destroyed the unique civilisation of the area, made all the wild flora and fauna disappear and forced hundreds of thousands of people to migrate. During the last decade, many efforts have been made to restore the marshlands. However, these efforts are lacking a comprehensive design strategy, coherent goals and deep understanding of the complex current geopolitical situation, making the restoration process an extremely difficult task. This work aims at providing strategies for recovering the Mesopotamian Marshlands, organising productive functions in order to sustain the local population and design a new inhabitation model, using advanced computational tools while taking into account the extreme climatic conditions and several unique cultural aspects. Part of the aim of this work is to advance the use of computation and explore the opportunities that digital tools afford in helping find solutions to complex design problems where various design variables need to be coordinated to satisfy the design goals. Today, advanced computation enables designers to use population consumption demands, ecological processes and environmental inputs as design parameters to develop more robust and resilient regional planning strategies. This work has the double aim of first, presenting a framework for re-inhabiting the Marshlands of Mesopotamia. Second, the work suggests a design methodology based on computer-aided design for developing and organising productive functions and patterns of human occupation in wetland environments.

1. Introduction

Historically, human civilisation developed with some connection to natural resources. It is no coincidence that human society developed next to a spring, a river or close to a waterway. It is no coincidence that the great ancient civilisations developed along the Nile River and between the Tigris and Euphrates, where rich silts and fertile soils facilitated agriculture. At the same time, technological development occurred as a need to transport and process resources. The Egyptians and Sumerians developed boats made out of reeds in order to take advantage of the river not only as source of food but as infrastructure and transportation arteries that would start to define the logistical frameworks of advanced forms of civilisation. With this in place, the combination of technological development, social organisation and natural advantage allowed cultivators to produce more than they needed to subsist, which lead to a system of labour division and product distribution. "The cities were the residential form adopted by those members of society whose direct presence at the places of agriculture was not necessary. That is to say, these cities could exist only in the basis of the surplus produced by working the land" (Castells, 1977). For more than 5000 years the land of Mesopotamia has continually been transformed making it one of the most highly engineered environments to be found on earth. It was here where humans began to transform ecosystems into pastures, agricultural land and other engineered environments in support of long-term settlements. In this sense, the land of Mesopotamia is intricately linked to the history of urbanisation and city development.

In an era of intense urbanisation, it is important to re-examine the relationship between urban centres where activity concentrates and the productive landscapes that make this activity possible. In this regard, this work investigates urbanisation from the perspective of its operational and logistical processes. These processes happen in a space of transition. A space that exists between people and resources. A space between the city and the wildlands. A space between natural and built environments (Figure 1). The land of Mesopotamia has always been defined by this condition. Etymologically, Mesopotamia refers to the land between two rivers, a space between land and water. Mesopotamia exists in a transitional space, where ecological systems meet human systems. This work aims at suggesting the possibility of a new form of settlement to re-inhabit the marshlands of Mesopotamia and seeks to re-evaluate the role of ecology, infrastructure and architecture in shaping the countryside. In order to examine this subject, the Marshes of Mesopotamia have been selected as an area of intervention.

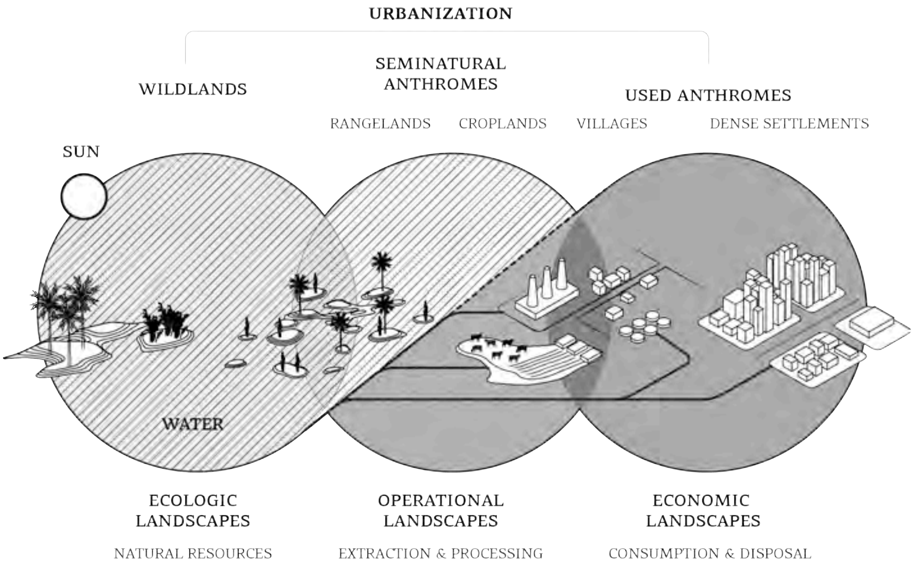

Figure 1. Resource demand and Urbanisation

Throughout history, the Mesopotamian Marshlands have been a significant site where land has been exploited to support human activities and urbanization. Initially and for many centuries, the fertile soil of the marshes was harnessed to support large-scale agricultural activities. During the past fifty years, the character of the site has changed multiple times due to various environmental, political and social transformations in the broader area. Today, this site still serves the urban growth by providing enormous amounts of oil while being populated by nearly one million people who are occupied with small-scale agricultural activities. Unlike previous forms of land use, the oil extraction industry is leaving long-lasting traces, which combined with climate change; pose a big challenge concerning the future of the wetlands and those who depend on them.

After surveying the general features of the Marshlands of Mesopotamia an area of a 30 Sqm spanning between Al-Hammar village and the city of Qurna was selected for the initial design intervention. The area selected is part of the Central Marsh which has been partially re-flooded with water from Euphrates since 2003. The area above Al-Chibaysh contained more than 1,200 artificial islands until the late 70s. During this time, the community of the Marsh Arabs was completely self-sufficient and relied on cultivating a few crops, fishing, hunting and trading with the neighbouring tribes. Back in the 70s Al-Chibaysh was nothing more than a small village along the Euphrates with a relatively important position as a small trading centre because of its proximity to the river (Figure 2).

Figure 2. Mesopotamian marshland.

After the complete draught of the marshes, most of the people living there migrated to either Al-Chibaysh or other small villages along Euphrates, creating bigger semi-urban towns and leaving almost no trace of the earlier inhabitation patterns in the marshes. The partial re-flooding of parts of the Central Marsh (above the Chibaysh area), which started in 2003 and is still in progress, was not a part of a coherent sustainable plan but rather a spontaneous act from some locals. This has caused many problems and challenges that are mostly related with the water quality and with the ability of the marsh area to recover and be re-inhabited by humans and wildlife. This work presents a strategy for recovering and re-inhabiting the Marsh area above Al-Chibaysh village (Figure 3). This initial intervention suggests that the population who would gradually relocate to this area will form self-sufficient community in coexistence with the ecology of the wetlands. The preservation of the Marshes and controlled use of resources suggests a long-term plan for developing the area in a sustainable way. A similar approach could be then expanded to greater areas of the marshes.

Figure 3. Site of intervention.

2. Methods

An important aim is this project is to advance the use of computation and explore the opportunities that these design tools afford. To this end, a design workflow involving various analytical and generative design tools was established.

The workflow initiates with data collection from GIS databases. In order to define the initial parameters for the project, basic spatial, environmental and geographical information is gathered. Starting from the whole area of the Middle East to understand the regional context and moving down to the country of Iraq and marshes of Mesopotamia, various sets of data are collected to inform the design. At the same time, the design goals and the overall design objectives of the project are established and translated into measurable (geometric and numeric) inputs. The collected data from GIS and the design objectives are used as the starting parameters for a parametric model. This model is based on an initial algorithm applied to the defined area of intervention. The algorithm is used to determine the distribution of uses and settlements and the possible configurations that can be achieved in the site. Multiple design alternatives for land-use distribution are achieved by means of an algorithm based on the circle-packing theorem. Simultaneously, clusters of residential units are generated by using a magnetic field algorithm, which works in combination with the results obtained by the circle packing distribution. This results in a number of network configurations that are evaluated through network analysis tools.

The design option that best matches the design criteria is selected to be further developed. Using agent-based simulations (ABMS), the base network is extended to connect all the residential clusters with each other. The design option that has the highest integration and connectivity values between the residential clusters is selected to be further developed.

At this point, the information obtained from the previous processes can be used to inform design decisions for developing specific areas of the project. A sample area of the project is selected to distribute social functions (education, health, recreation, etc.). A network based model (UNA) is used to distribute these functions. The final outcome is a model that comprises all the uses and functions tied together by a network that connects residential units to productive and ecological zones (Figure 4).

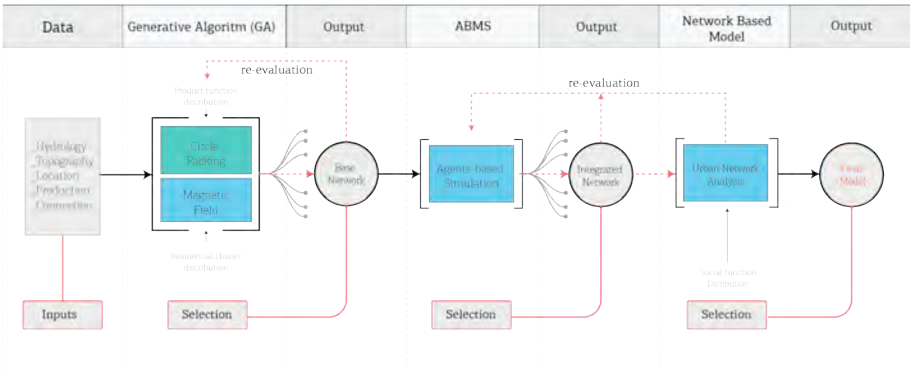

Figure 4. Workflow.

3. Design

For a given area of marsh, the percentage of a certain product needs to meet the demand established to feed a target population based on the average consumption of produce per capita. Production should sustain the population inhabiting the selected area and generate surplus product to generate additional value. These numbers are allowed to fluctuate as long as about 50% of wild marsh is preserved. The marsh ecology needs to be preserved not only for environmental conservation reasons but also because the different products can benefit from interacting with the marsh ecology and its services. Therefore, the distribution strategy aims at increasing the interaction between the various productive functions and the marsh.

Instead of separating and concentrating functions in zones, the goal is to create a semi-random distribution of uses in order to establish the most connections between product to products and marsh to products. This condition can be described as a "field condition" to borrow Stan Allen terminology. A field is capable of unifying distinct elements while preserving its individual identity. Fields are characterised by being permeable and porous. Fields promote interaction between its parts. Fields are loosely bound and its overall shape is less important than its internal relations. In this sense, the field condition offers an ideal arrangement of uses that can extend or contract without destabilising the whole (Figure 5).

Whereas most industrial processes follow a linear behaviour, an alternative designed strategy can be established to promote cyclic and non-linear behaviour by harnessing synergistic relations between the marsh ecology and the set of products that are to be introduced in the site. In simple linear systems, a process constantly utilises the same inputs and produces the same outputs. This results in inputting resources that are extracted from the environment and outputting waste to the environment. Non-linear systems, on the other hand, cannot be explained in terms of their individual parts because their essential properties depend upon the interaction between their parts. These systems are capable of exhibiting emergent behaviour, which means that the outcome from the interaction of their parts produces a result that is greater than the sum of their parts.

Not all interactions are beneficial and not all combinations are possible. All biotic and abiotic elements in an ecosystem have some boundary condition that defines whether synchronised behaviour and cooperation can take place. In order to produce synergies, the main focus of design needs to shift from the parts to the relations. To achieve synergetic relations there needs to be some degree of diversity of processes taking place on different but parallel levels. When parallel action takes place, different components in the system process different resources and it is possible to connect what is waste for one component to what is an input for another. In designing these relations the goal is to make positive sum gains the attractor state. To do this, network relations need to be established. This requires an investment in the infrastructure that sets up the relations through which the different elements of the system would interact. In order to establish productive relations between the marsh ecology and the productive functions a set of rules for combining positive adjacencies was established. Positive combinations were identified in order to use them as rules to inform the distribution of functions across the site of intervention.

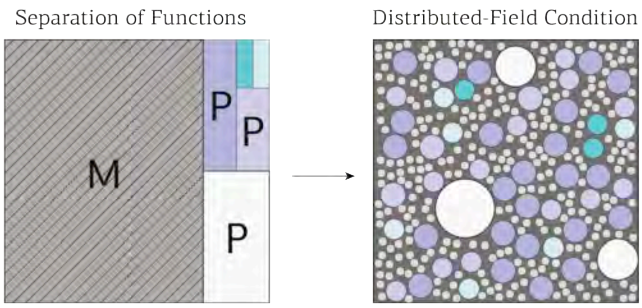

Figure 5. Land-use Distribution.

A series of "key" diagrams will follow that use a generic square as a reference border. The diagrams (Figure 6) are going to explain the process of generating the residential clusters/canals in the selected plot and consequently the complete infrastructural canals network that hosts boats serving productive or residential activities.

The functions have been distributed with different circles containing different productive activities. Furthermore, each circle represents the area for which a water tank (triangle) will store and provide fresh water according to the different production needs throughout the year.

A different intensity is assigned to the centre of each circle (water tanks), according to the intensity of the productive activity that is taking place there. This ensures that there will not be much interruption to the more labour or land-intensive productive activities.

The area of intervention is populated with randomly distributed points. Every point represents a residential unit. The number of points is dependent on the desired population density for that specific area. The amount of inhabitants per unit ranges from 5 to 20 people, according to the residential typologies that will be later placed there.

The field lines/canals are created, starting from the residential nodes placed on the previous step and converging along the periphery of the production areas. The field lines leave enough space for both the productive activities to happen with the least possible residential interruption and for the wild marsh to grow in order to ensure that no large, solely productive zones will be created along the plot.

In this stage a preliminary evaluation of the field paths occurs. The field paths that are not forming clusters (less than four intersecting lines) and those that are interrupting a productive activity are eliminated.

These are the final field lines/canals, which are going to serve as the paths that connect the residential islands with the rest of the network.

The central paths were chosen after counting the number of intersections within each cluster. The curve with the most intersections per cluster was selected as the central path. These paths/canals were wider and deeper than the rest of the canals within the cluster as they have to accommodate more small and bigger boats. Agent-based modelling was used to connect the central paths with each other and form a complete hierarchical network within the site.

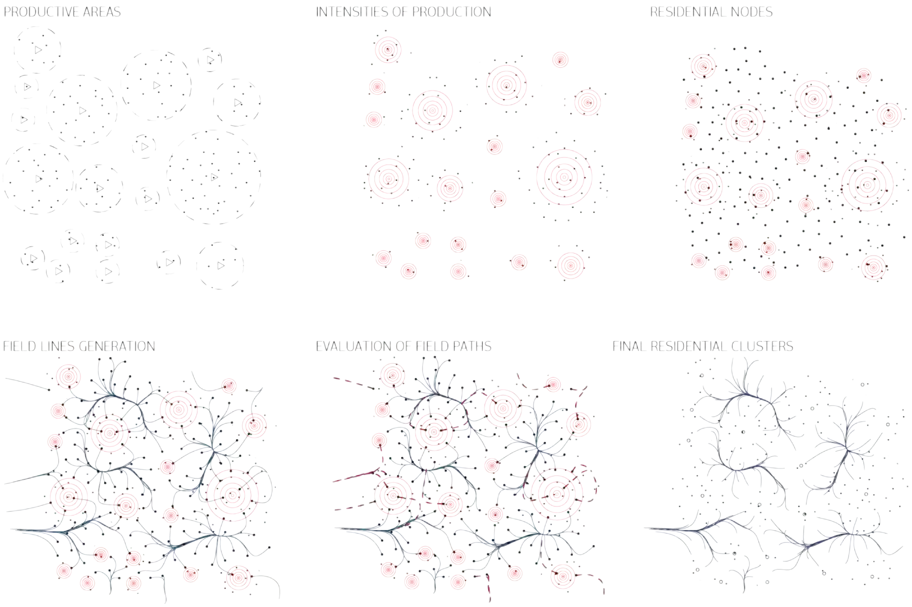

Figure 6. Generating the residential clusters.

In order to generate a complete network, all residential clusters needed to be connected to each other. Each one of these clusters had a common central path formed by the convergence of multiple local paths. To connect the clusters with each other, an agent-based simulation was used, which through a mechanism of indirect coordination, the agents self-organised and generated a network without any need for central planning. The system was based on a set of simple rules. The agents' movement pattern was sign-based and hence indirect, which meant that the agents followed the traces left by other agents. The trace of the agents' movement was left in the environment making an indirect contribution to the task being undertaken and influencing the subsequent behaviour of other agents performing the same task. The mathematical model of the agents' behaviour was developed to follow the basic rules of flocking behaviour. (Figure 7)

After connecting the main paths of the residential clusters with each other (using the aforementioned agent-based simulations), the resulting networks were evaluated and ranked using a network analysis software (integration analysis).

The next step was to position the products' distribution centres. The distribution centres were placed along the most integrated parts of the network, ensuring that they could be easily reached by as many parts of the network as possible. Local and regional parameters such as the position of the distribution centre in relation to the neighbouring productive uses and its proximity to "densely" populated residential clusters further informed the positioning of the centres. After that, the distribution centres were connected to each other (primary canal – distribution path). The canals created were drawn following the existing base network, being within a small deviation from the "optimal" straight connections. Furthermore, the main distribution paths were also drawn in a way that left the main productive areas uninterrupted and therefore some connections between them were discarded.

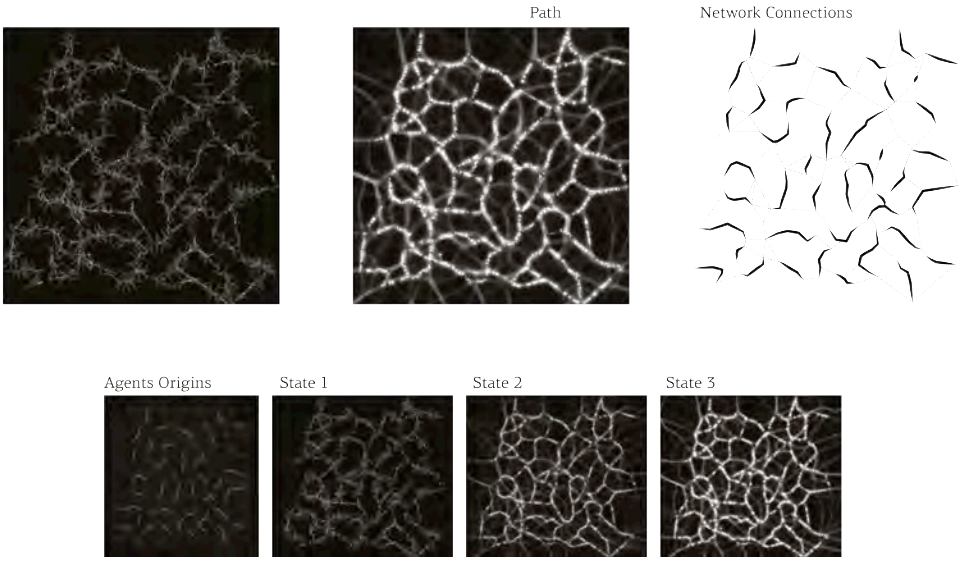

Figure 7. Agent-based simulation.

After analysing, comparing and ranking all the options generated through the program distribution phase the solution that best responded to all the criteria was selected and further designed. Some of the criteria were conflicting and there was no solution that was the fittest according to all the criteria. Therefore, the selected solution was the one that responded the best to all the criteria on average and in relation with the existing context of the city of Chibaysh and its existing main canals-water inlets. The selected individual solution that contained the best integrated network, a large number of residential clusters, high average reach and the deviation of the main distribution path was within the limits (Figure 8).

The expected amount of production fitted in the selected plot exceeds the current consumption needs of the inhabitants of Chibaysh plus the new inhabitants needed to work/live in the marsh area itself. To design a more elaborated version of this plan we further zoomed in, choosing a 3 x 3 km patch, which includes all the different features found in the biggest plot.

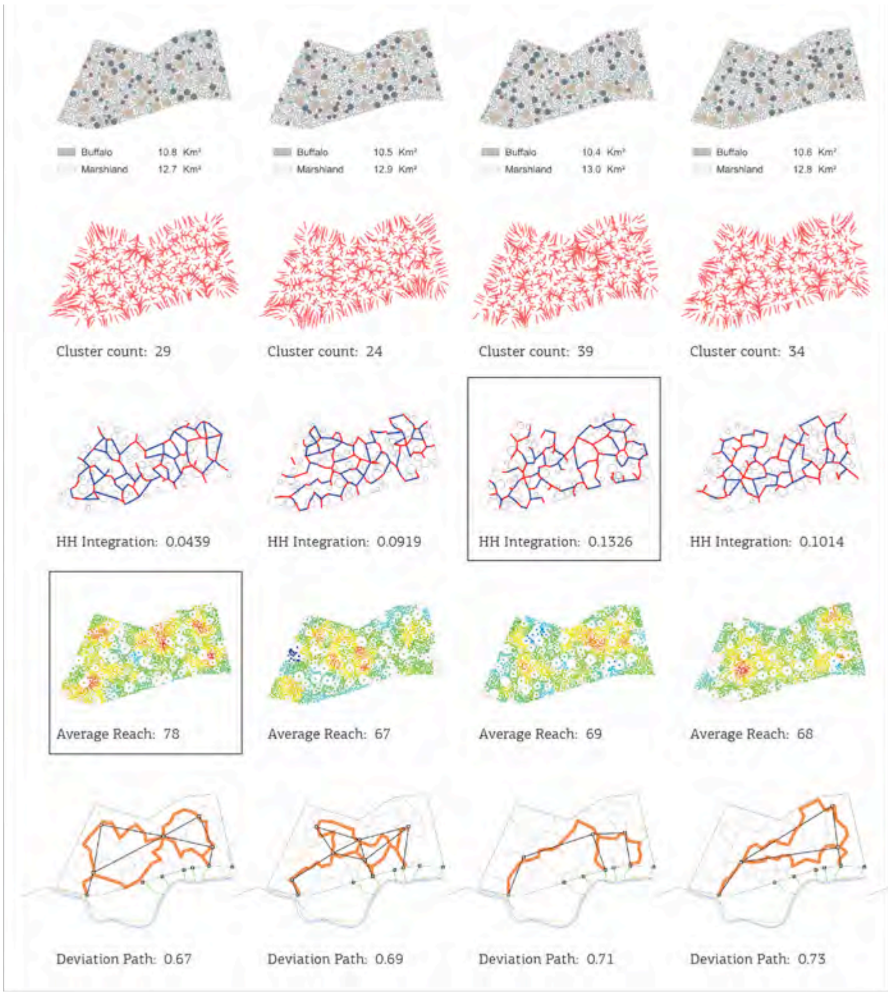

Figure 8. Network generation

4. Conclusions

The scope of research of this work aimed at interrogating the urban question and presenting a more comprehensive view on urbanisation. Urbanisation is understood as a totalising condition that has taken over the entire surface of the earth. The goal of the project was to address the transformations that are occurring in the countryside as a result of urbanisation. This work also aimed to touch upon a number of issues that are being discussed in current debates of architectural and urban design. The increasing interest in landscape urbanism, resource management, sustainability, the expansion of cities and the role of infrastructure and the countryside in supporting human societies.

The custom circle packing algorithm developed in this project was successful in offering a technique for semi-random distribution. Contrary to other computation methods for random distribution such as Cellular Automata, where patterns simply evolve from initial seeds without any desired goal, the custom circle packing algorithm used in this project allows users to gain a higher level of control over areas by granting the user the opportunity to input specific numeric values (weights) for the radius of the circles. Because of this the search algorithm (Genetic Algorithm) was able to optimise target areas and distribute them in accordance to desired adjacencies across the site while keeping the total areas close to the target.

The use of the magnetic field algorithm was successful in offering a solution for clustering a random distribution of elements based on basic rules of distance, direction and avoidance. Magnetic fields allow the designer to assign charges (weights) and cluster elements in relation to a force of attraction and repulsion. They generate convergence points that cannot be anticipated and can only be generated by the computer. This method proved efficient to establish some degree of order and structure to what otherwise is a random distribution of elements. The magnetic charge introduces a force, or intensive difference, that prompts the elements to self-organise into clusters. The algorithm provides a lot of flexibility as values can be updated and re-instantiated in relation to changes in the productive areas.

The marshes offered a unique environment for testing Agent Based Simulation. Unlike cities where infrastructure is costly, fixed and highly engineered, the infrastructure of the marshes is “soft”; movement happens through shallow canals created by boat and animal movement. As in any other aquatic environment movement is not prescribed. In this context, the use of Agent Based Simulations provides a more accurate picture of the movement that would occur in reality. The experiments were successful in generating multiple possible scenarios for network configurations with more or less similar results.

One major limitation for evaluating the work was the difficulty to assign numeric values to the interaction between products and simulate the complex behaviour that occurs in natural environments. Using ecological processes as design drivers is an area that deserves further exploration. However, in many cases, this knowledge lies outside the scope of the designer. Research in this area requires the participation of multiple disciplines with experts in various fields. Another limitation was posed by the scale of intervention of the project. Most of the efforts went into establishing a clear strategy at the macro-scale, which outlined the basis for developing specific areas of the project at the scale of architecture.

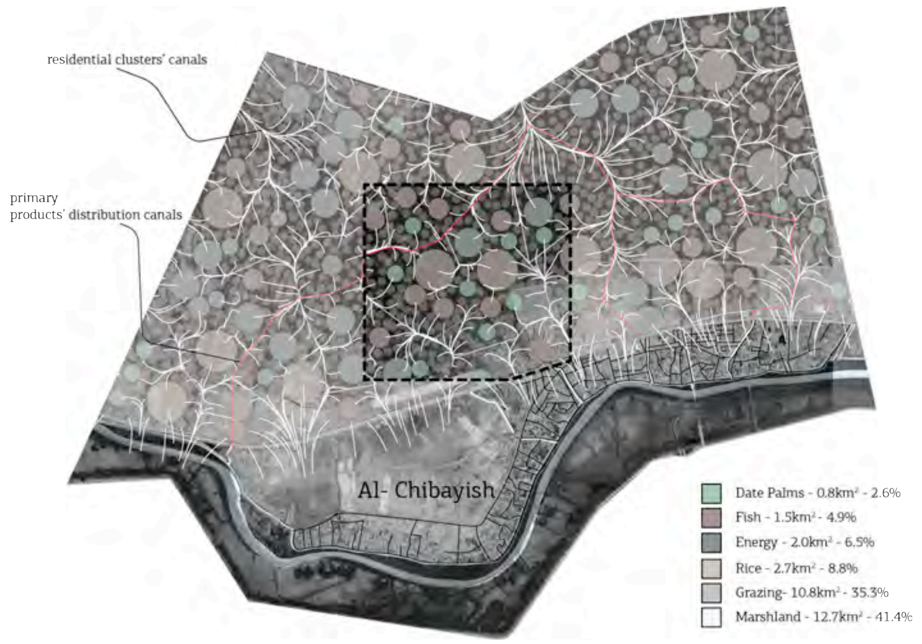

Figure 9. Function distribution and residential clusters

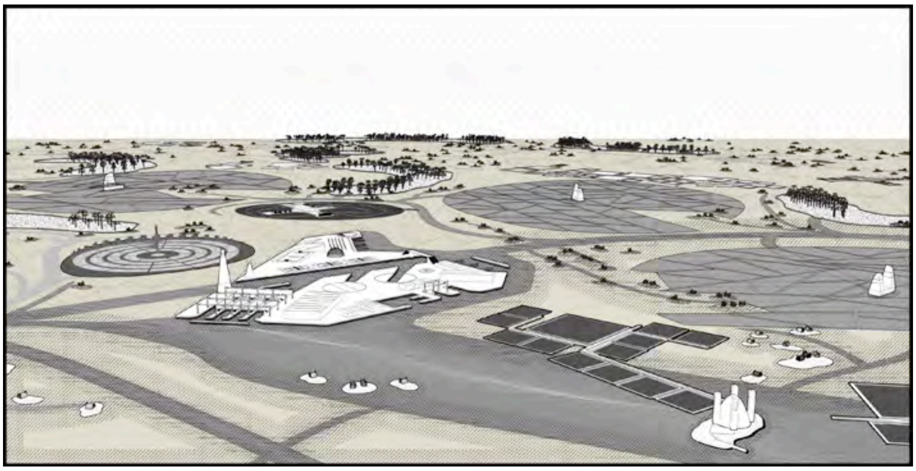

Figure 10. Perspective Drawing of Proposed Project.

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VIRTUAL LANDSCAPE ASSESSMENT AND ROBOTIC ALLOCATION WITHIN EXTREME ENVIRONMENTS

MOHAMMED KHSROH
Columbia University, New York, USA
mk3819@columbia.edu

Abstract. The paper describes an iterated system, which explores the concept of a surveying, deploying, self-assembling robotic swarm system within an extreme environment, in a virtual robotics platform named VREP. The pure geometries that are the basis of this species, through study of locomotion in Fauna and energy transformations, produce several iterations of the proposed robot. The created species are used to generate a process in which the robotic swarms are able to make initial scans of landscapes using a series of visual and proximity sensors attached to each exposed face, in order to determine proper deployment zones for the making of a research facility. The explorations in locomotion and transfer of potential to kinetic energy would allow the geometrically pure robot to hop, flap, walk, flip or turn in order to move to achieve the desired location.

The intent of such swarming nature of the robots is to create a cohesive unit of operation that is able to overcome the journey of deployment and remove the need for site surveyors and construction workers in order to initiate and construct a research facility. In this manner, the robots then would become the very building blocks that constructs these research facilities and are able to be repurposed to meet certain environmental concerns such as a light construction footprint, reusability and the provision of certain amenities.

With SDA (Survey, Deployment and Assembling) robots, the paper explores the steps needed in order to attain a functioning process from landing and deployment, to surveying and construction; with consideration of the difficulties and potential opportunities of this proposal.

1. Introduction

Having a surveying and deploying robot allows us to venture to many frontiers that are yet to be fully researched and explored either due to the harshness of the environment or the difficulty of setting up in order to conduct the research. Environments such as the Arctic, speak volumes when pitted against projects such as AECOM's Hayley VI. The extreme winters and unpredictable change in weather allowed the constructions workers to operate during summer months only until the project completed (Broughton et al., 2005). The advanced nature of the construction and maintenance required to keep operation of the mobile, modular research facility proved difficult and costly especially in times of crisis (Sawer, 2015).

With the SDA (Survey, Deployment and Assembling) robots approach, we might finally have an opportunity to mass manufacture smart building units that bring about the age of exploration, into areas like the deep ocean trenches which have only been 0.05% explored (Copley, 2014); or extreme deserts, where finding an appropriate area to study then settle into is difficult. This might aid us in the understanding of our planet, especially in the wake of climate change. Perhaps we could even send these robots to the stars; to new planets or moons to survey and construct facilities which astronauts could visit and inhabit upon arrival without the need for construction nor surveying. The mass manufactured nature of these robots would allow a lower cost of manufacturing, while providing a lower risk factor in its line of operation, and unlike very expensive tech like the NASA rovers, these robots are easily replaceable, re-used and relocated and repurposed.

Focusing on desert climates: the research engages a test following a methodology that is taken from a simple idea, yet complexly executed approach. As seen in nature, bees or ants usually send a scout to determine the best locations to find resources for the hive and are possible locations for migration and settlement. In this manner, a scout robot would be sent out to survey the land to find an appropriate landing zone for the swarm of SDA robots. Through teamwork, landscape surveying and assessment, these robots would then be able to determine a flat zone for building a research facility near potential analysis and potent resource zones prior to human inhabitation.

2. Methodology

Methodologically, two approaches to tackle the question of exploration arise; one is to use existing technology as a means to investigate a solution to the proposed problem. The other is to explore a new form of robot that is able to operate in a swarm configuration in order to coordinate and move through obstacles in order to survey and reach a proper operation site for erecting a research facility.

In both approaches, there are two criteria to achieve in order to be successful in the operation:

1. Surveying and measuring the degree of appropriateness of site selection for construction and settlement.
2. Registration of nearby robots in order to assess proper teamwork, overcoming obstacles and laying foundation for construction.

2.1. EXISTING TECHNOLOGY AND SENSORY ENDEAVOURS

Experimenting with rough desert terrain, a Quadricopter is used to test sensor types appropriate for surveying and landscape measurement. Firstly, we attach a ray type, proximity sensor to the belly of the Quadricopter, using a simple mathematical script. The return data of ray casting is in the form of angle degree sets that are used to roughly determine the relative percentage of flatness of the landscape. Using a triangulation method, returning a degree percentage of 0 or 180 equals a relatively flat surface. Though accurate in perceiving flatness, the surge of data input on miniscule changes causes long processing buffer times.

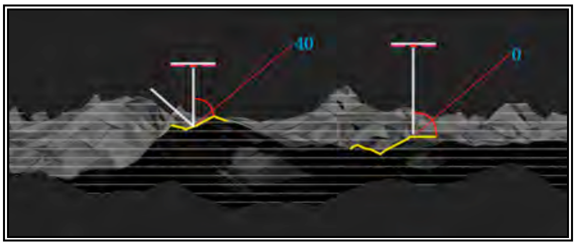

Figure 1. Ray casting and angle measurements.

An alternative method and the focus of this study is to project a 16 x 16-slot grid using a vision sensor located beneath the drone. The projected grid will act as a coordinate pixel plane. Each pixel will have a specific sequence and coordinate, i.e. pixel [1]'s coordinate is equal to (1, 1) on the grid and pixel [2] equals (2, 1), etc. These pixels will act as registration rebound points: when four or more points register as a flat plane, it will trigger a beacon release to mark the zone valid for deployment and construction.

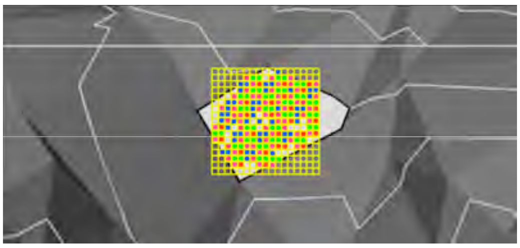

Figure 2. Vision grid casting & registration of positive points.

In the Virtual Robotics Experimentation Platform (VREP), using a virtual landscape and programmable assets, the validity of the proposal is trialed. The Quadricopter's vision sensor is linked to a graph sensor that registers depth by calculating the depth difference between a fixed ray projection from a ray type proximity sensor and the cutoff point. The ray proximity sensor aids to correct several irregularities produced by the current script and its function is to allow the drone to autonomously and randomly scan the landscape for possible valid locations. The main irregularity it tackles is the frequent incorrect hover height when pausing in between movements to scan and survey, thus the addition of the ray proximity sensor helps to recalibrate the *Z*-axis while the drone moves in the *X*- and *Y*-axes. Furthermore, the capping of pixilation counts aids to emit anomalies on the landscape from incorrectly registering as a valid zone for deployment. In Figure 5, the graphs illustrate correct and incorrect registers of planes, while the spike in the graph is a bug that occurs when the proximity sensor intersects the three-dimensional terrain model.

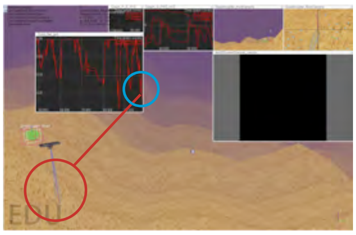

Figure 3. Malfunction of the vision sensor as it fails to gain proper height, causing the laser to intersect heavily with the ground.

Figures 4 & 5. Correct ground registration vie ray and vision sensors.

2.2 SCANNING, DEPLOYMENT AND EXPANSIVE ATTACHMENT

Within any environment, there exists a set of challenges that might create difficulty for proper equipment or construction elements to reach the site; either due to extreme terrain or weather or simply because of resources and expense. The exploration in mind is to be able to overcome all of those possibilities by providing a system in which smart building blocks are set in motion at locations at which it is easier to drop off. This becomes important in scenarios where the drone itself cannot really do much other than the surveying of land. The robots then are delivered to a designated area and would guide themselves to the beacons or designated areas tagged by the survey drone.

Figure 6. The robot in the spawn matrix.

Using a three-dimensional (3 x 3 x 3) matrix projected using a series of vision and proximity sensors, the surrounding of the robot is registered and processed to a receptor that by script is able to register solid from void, neighboring robot or a landscape element. Following the precedent of army ants and weaver ants, the robot relies on collective behavior in order to overcome obstacles and build structures. While currently at a preliminary phase of development, the scheme relies on finding void area within its matrix, that when responding to the call of a beacon would continue fill with other robots as it creates unique structurally stable schemes, which aids it to continue its journey until it reaches the construction site.

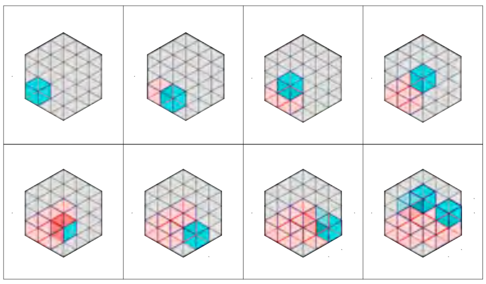

Figure 7. Example process of filling the deployment matrix.

Upon simulation, we created a spawn point at the origin point (0, 0, 0) in VREP, and a script for status display to document the matrix spawn sequences to be called back whenever needed. The sequences (Figure 9), work as a labelling system for each robot, in case one needs to be reproduced for maintenance and/or repurposing to accomplish specific tasks.

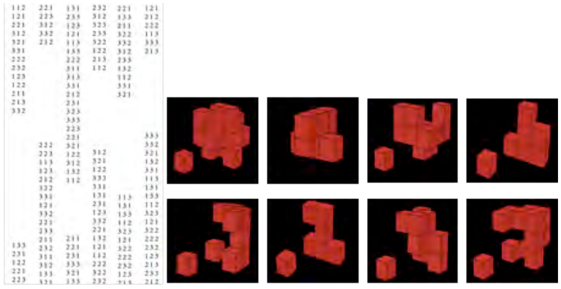

Figure 8. Sequence charting and several iterations of matrix spawning using VREP

Furthermore, the coordinate system within the robot when analyzing the voids, calls upon these iterations in order to decide the best structurally stable scheme to proceed with and eliminate all other options. Once a suitable answer arrives, the script stops further analysis, even if there are other possibilities available.

It is worth noting that if anything challenging occurs as the research develops, the robot's ability to interpret elements of the landscape within the matrix as structural elements, could aid overcoming obstacles and provide foundation support for facilities.

2.3 PROPOSED TECH AND OPERATIONAL LOGIC

Looking at the possibility that these robots would be applied to multiple setting including interstellar exploration, drone usage would not always be viable in many situations; the proposed pure shaped robot would have to accommodate the sensing, surveying and construction as a single holistic approach. Using the several iterations that the project evolved from, the robot could then be registered as a combined approach. Being highly influenced by the intelligence made possible by having overcome the aforementioned obstacles. In the spirit of continuing with using pure shapes as catalysts to the design, the idea calls for two cube shapes that have latches, one positive and the other negative. These cubes are able to topple, toggle and flip in order to move and arrive towards a certain goal, attach and construct.

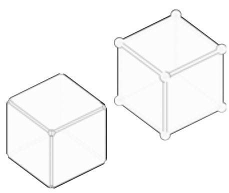

Figure 9. Negative and position set

Actuators attached to the cube allow it to be able to conduct its motion but what is more important is the sensors that would able to register viable ground rather than the having a secondary system like a drone do the scouting. In essence, all the robots have to do then is be delivered to a location on site, or nearby if conditions do not permit.

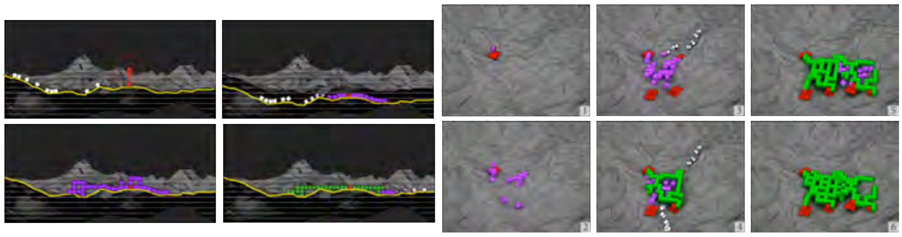

Figure 10. Process of arrival to beacon location to platform completion

3. Possible Applications

The main intent of the project is that rather than using robots as a means to build – a tool rather than the building block – we start to use robots as the builders, the building tools and building material. The approach allows these building block robots to establish research facilities or spaces of occupation in remote and extreme areas. Inspired by the reinvigorated age of exploration on both Earth and the big upcoming Mars mission, this project imagines the settings where the act of construction and of remaining outside is difficult, and surveying land for appropriate locations of settling grueling. With this in mind, instead of approaching the problem by designing deployable structures/architecture, combining the act of research with the act of settlement on the band of mass produced, geometrically simple robots brings much possibilities for automated construction and smart buildings. The modularity of the units allows for the creation of multiple units all with a designated function of operation. An example would be a unit for solar absorption, another for sanitation, air filtering, heating, cooling or insulation, and so on. Specificity perhaps might detract from flexibility of having these units as purely manufactured building blocks (robotic bricks perhaps) but the outcome allows for these robots build a fully functional space geared towards human well-being, especially in extreme environments.

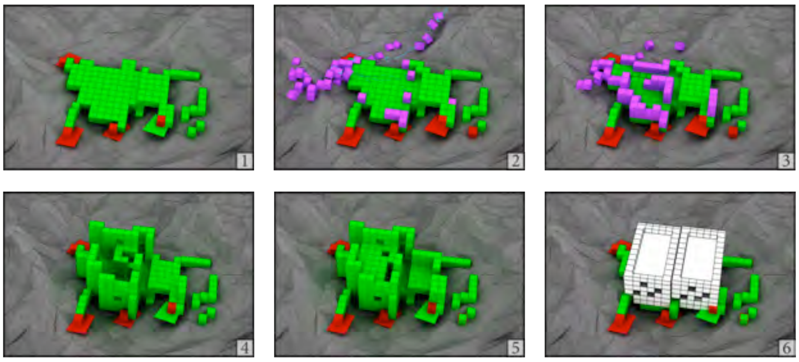

Figure 11. Process of building self-assembly

4. Challenges Ahead

Calibration of the sensors along with the scripting that creates the rules of SDA needs further revision in order for the robots to perform all tasks required of them without relying on satellites or drones. This is nowhere more evident than in the case of the proximity sensors nested in the robot. These sensors attached to each external surface to scan and analyze the landscape face difficulties when the proximity of the sensor to the landscape becomes a stone's throw away. In this situation, the data input might faze up and create confusion on how to proceed and how to register what is nearby.

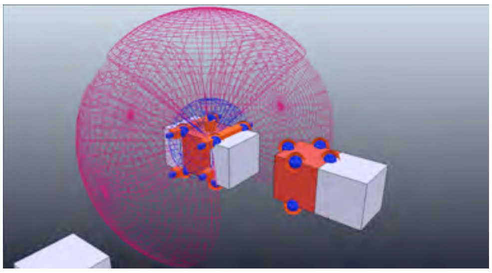

Figure 12. Robot test for proximity sensors and motion through a motor.

The second challenge to solve would be the design of the robot to appropriately accommodate the environment it is deployed to. The use of pure geometric shapes, e.g. a cuboid, hexagon, dodecahedron, etc., in this study was a progressive iterative process, starting with the simplest to manufacture (the cuboid) to the relatively complex (the dodecahedron). The eventual outcome of this search in shapes is to create a series of robots with shapes unique to the environments explored and researched, e.g. a sphere or a tube with half-spherical ends best responds to deep ocean trenches as it withstands the increase in pressure due to increase in ocean depth.

Choosing the triangle (can generate many other shapes, e.g. square, octagon, trapezoid, etc.) as a base shape to generate several species that are able to latch, move, and aid one another to achieve certain tasks, yielded several interesting results. The two most prominent were the hexagon-shaped robot and the dodecahedron robot.

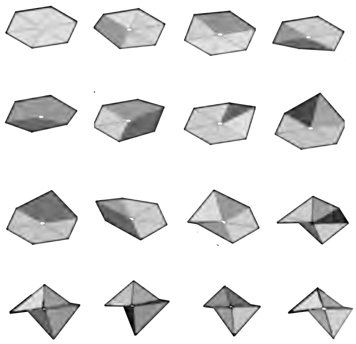

Figure 13. Hexagon robot iteration, studying transformation and locomotion possibilities.

The use of the triangular outlines of the hexagon as joints and their tip points as placements for actuators creates a flexible and malleable robot, capable of moving by flapping, jumping and walking by manipulation of form to determine the best possible method to succeed in its task. The iteration may lead to answering to several needs and services, from transport, to building units and energy harvesters (robot surfaces as solar panels).

Though the dodecahedron offered a multitude of ways to move and navigate through environment, two notable ways is by rotation and the use of angular motion and peristalsis, i.e. a snake-like motion. The ability it has to pull or rely on other dodecahedrons allows it overcome vertical obstacles or even stack up in rows without any extra aid, allowing it to create platforms, walls and even columns.

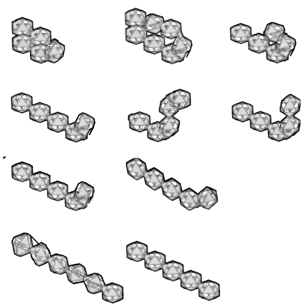

Figure 14. Dodecahedron robot iteration, study in motion, flexibility and assembly.

5. Conclusion

The attempt to allow robots to become buildings blocks offers many opportunities and restrictions to design approach and methodology. The research here limited such approach to architecture of the extreme, in environments where construction would be difficult. In these conditions, the design aesthetic would become less important since this eliminates design restrictions and the need to justify culture type. Instead, it is driven by the need and necessity to achieve a goal and a task. Such design problems allow extreme solutions to occur. The heavy reliance of modular self-assembling robots would allow for ease of manufacturing, processing and even assemblage. In that regard, parts could both remain permanent until in need of replacement due to age or malfunction or be a recyclable element that can be used at other locations when needed. These species then would allow for a future of architecture that is automated and iterative by nature's decree as a robot responds to that environment, bringing us to an age of sensitive design ruled by the troubleshooting brain of an elemental robot.

Acknowledgements

Mark Collins
Toru Hasegawa

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DYNAMIC SIMULATION OF EXTERNAL VISUAL PRIVACY IN ARAB MUSLIM NEIGHBORHOODS

A case study of Emirati neighborhoods in Abu Dhabi, UAE

SNEHA MANDHAN, DAVID BIRGE AND ALAN BERGER
Center for Advanced Urbanism, Cambridge MA, USA
sneham@mit.edu | dpbirge@mit.edu | aberger@mit.edu

Abstract. The countries of the Gulf Cooperation Council have, in recent years, undertaken several initiatives to make sustainability central to their urban agendas. This research aims to operationalize the concept of sustainable development – environmental, economic and socio-cultural – in the region, and develop parameters that define it. Using native neighborhoods in Abu Dhabi as a case study, it focuses on the development process of a computational toolkit which has two major components – a quantitative toolkit which contains modules for simulation of aspects of environmental and economic sustainability, and a spatial toolkit which contains modules for simulation of socio-spatial practices associated with the specific social and cultural context. One of the primary needs of these communities, identified through an extensive review of literature and through conversations with Emiratis, is that of visual and acoustical privacy. Privacy from neighbors and passers-by, externally, and between genders, internally within the house. Using this as a starting point, this paper describes the development process of a module that aims to measure levels of external visual privacy of surfaces at a housing plot level, from neighbors and passers-by. The first section of the paper establishes the context of the research. The second section focuses on describing the process of modeling built form and testing it for visibility and thus, privacy.

1. Introduction

This paper is a part of a research effort aiming to define the parameters of sustainable development in the Gulf Cooperation Council (GCC) region. Using Abu Dhabi as a case study, it focuses on operationalizing these parameters into a digital toolset that will allow urban professionals to dynamically model urban form and design for increased levels of sustainability – environmental, economic and socio-cultural. This paper focuses on the aspect of social sustainability, and discusses an external visual privacy module aimed at the simulation of privacy through a series of visibility analyses.

In recent years there has been a lot of dialogue around the issue of social sustainability in cities. Social sustainability, broadly defined as "the continuing ability of a city to function as a long-term viable setting for human interaction, communication and cultural development." (Yiftachel & Hedgcock, 1993), is more difficult to measure than environmental and economic sustainability. Additionally, "all-purpose indicators of social sustainability are too general to be useful", and thus, indicators specific to local contexts and issues need to be developed (McKenzie, 2004). In order to aid the development of socially sustainable neighborhoods for native communities in the region, this ongoing research aims to establish local parameters and metrics for social sustainability, and develop a digital toolkit consisting of modules that allow for simulation and testing of designs for these parameters.

Cities of GCC states have had a brief history of urban development, spurred by the establishment and growth of the hydro-carbon industry in the region, and sustained by it. The sudden inflow of wealth from and labor for the oil industry triggered a need for urgent urban development. Since local communities were small, foreign labor was invited to drive this growth (Hamouche, 2004). This resulted in the importation of Western urban planning and design ideas – gridded street layouts, super blocks, and villa typologies (Eben Saleh, 1997). Villa housing projects developed by the oil companies for their employees, came to be seen by governments and the local population as 'modern' and soon became the primary model for residential development, one that local communities aspired to (Bahammam, 1998). The villa typology, criticized by many as being environmentally and socially unsustainable, has now become embedded in the urban diction of the region through building regulations and standards (Bahammam, 1998). This has accelerated the transformation of local communities, resulting in the distinctive national identity being threatened by an emerging global and international identity (Mahgoub, 2004).

The lifestyles of local communities, primarily Muslim, are guided by the rules and principles laid down by Shari'a law. This set of Islamic regulations establishes several principles and cultural needs guiding socio-spatial practices, which shape neighborhood and urban form (Al-Hathloul, 1996; Alshuwaikhat, 1999; Bianca, 2000; Eben Saleh, 1997). One of these needs is that of visual privacy in residential neighborhoods, addressing the risk of strangers looking into the domestic domain which is regarded as a female space (Bianca, 2000; Othman *et al*., 2015). Traditionally, this was controlled through various built elements, such as the placement of doors and windows, the heights of adjacent buildings, and the incorporation of internal courtyards and gendered spaces within the houses (Abu-Lughod, 1987; Othman *et al*., 2015). Additionally, traditional neighborhoods “revealed a hierarchy of domains beginning with private spaces contiguous to the dwelling unit, semi-private spaces under the control of immediate neighbors, and public spaces and circulation routes” (Eben Saleh, 1997). However, contemporary neighborhoods have often been criticized for not attributing the same amount of importance to this need (Al□Kodmany, 1999; Bahammam, 1998).

This paper addresses this need by illustrating the development and outlining the potential application of a module aimed at measuring and designing for external visual privacy. This module is a part of a larger toolset that spatializes and digitally simulates for the various social and cultural needs of native communities in the region.

2. Case Study

Abu Dhabi is the capital and largest of the seven emirates that form the UAE, having an area of 67 340 sq km, and population of 2.65 million, 19% of whom are native Emiratis (Abu Dhabi e-Government, 2016). Despite forming such a small proportion of the total population, Emirati neighborhoods dominate the urban landscape (approximately 55% as per initial GIS spatial data calculations), as shown in Figure 1. Neighborhoods are constructed and villas allocated to Emirati families at no or minimal cost through a welfare program facilitated by the Abu Dhabi Housing Authority (ADHA). The widespread default to the villa typology, as well as the top-down planning and construction process pose a significant opportunity to rethink housing in the GCC region and drive new residential development towards social sustainability. This research focuses on Emirati neighborhoods in Abu Dhabi as a basis for testing and designing for local parameters of social sustainability.

Figure 1. Low-rise neighborhoods in Abu Dhabi city.

3. Digital Toolset for Social Sustainability Design

Academic and professional discourse outlines social sustainability as one of the three pillars of sustainable development (Murphy, 2012). In recent years, several local and global agencies have developed a series of social sustainability indicators attempting to measure equity, access to services, and social connectivity, among others (Axelsson *et al*., 2013). However, the general quality of these indicators, and the disconnect between these indicators and their physical implications, restrict the use of these to purely theoretical conversations.

This research aims to spatialize the social and cultural complexities and needs of Emirati communities in Abu Dhabi, and attempts to develop a toolkit that allows for digital simulation to dynamically model for these needs. Through an extensive review of literature and conversations with stakeholders, the research team identified social and cultural needs that Emiratis prioritize for their neighborhoods. This includes needs such as privacy, flexibility, hospitality, neighborly cooperation and personalization (Al-Kodmany, 1999; Bianca, 2000; Saleh, 2004; Tomah *et al*., 2016). Each of these needs has physical and spatial implications – elements of urban form that can provide for these needs. This ongoing research aims to analyze the spatial dimensions of each of these needs and convert them into parameters that can be digitally modeled and simulated.

4. Spatializing Privacy

One of the primary sociocultural needs of the Emiratis is that of privacy – both internally within the home, and externally from passers-by and neighbors. This need relates to the segregation of genders within households and neighborhoods stemming from religious beliefs (Abu-Lughod, 1987). It also emphasizes the need for the separation of private, semi-private, semi-public and public spaces within the Emirati neighborhood (Al-Kodmany, 1999; Othman *et al*., 2015; Saleh, 2004; Tomah *et al*., 2016).

Being an aspect that is typically measured qualitatively, this research proposes a novel method of spatializing privacy and simulating it digitally, thus allowing designers and planners to experiment with urban form and develop solutions that address this need. It borrows from established concepts of isovists and isovist fields (Benedikt, 1979) to perform a series of visibility analyses to determine the levels of visibility, and thus levels of privacy for surfaces within plots in a neighborhood. Since this research focuses on sustainability at a neighborhood scale, this module focuses on the simulation of external visual privacy only. However, the same concepts of visibility analysis can be used to simulate privacy within houses to guide internal space configuration.

4.1 EXTERNAL PRIVACY: ALGORITHM

The tool yields privacy levels for grid cells measured for horizontal and vertical surfaces at a house/plot level within neighborhood settings, thus evaluating privacy from passers-by on adjacent streets and open spaces, and neighbors. Simply, it measures the level of visibility of any point on a target plot from vantage points on adjacent plots and external spaces. The methodology for the analysis and measurement is described below and illustrated in Figure 2.

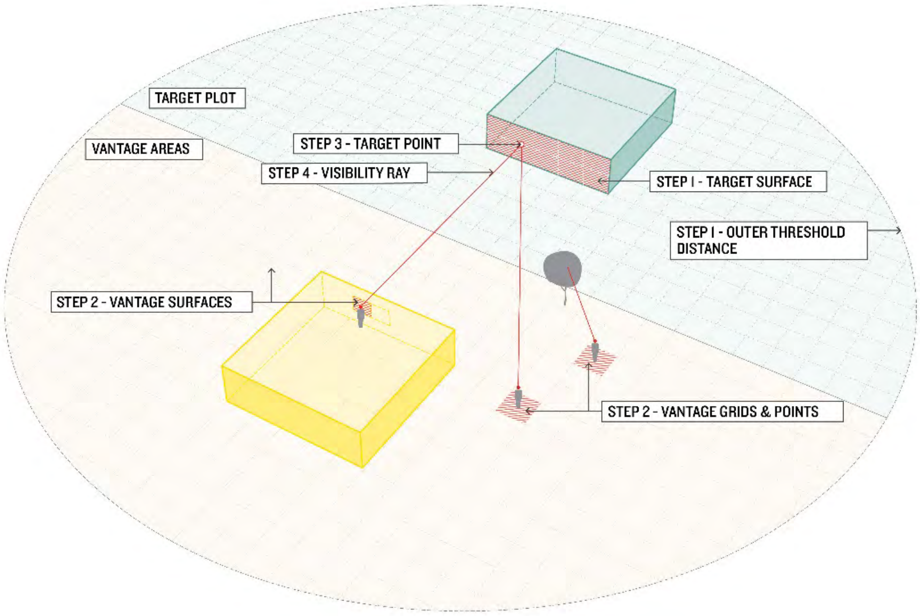

Figure 2. A simple case illustrating the external privacy algorithm.

Step 1 – Set up base parameters
The first step in the process includes setting up the base for the analysis including the target plot for which privacy needs to be measured, and the outer threshold distance beyond which visibility is assumed to be null. Once a complete neighborhood model is built, allowing this distance to be parametric permits flexibility of increasing or decreasing the maximum visible area within the neighborhood.

Step 2 – Select vantage surfaces
Identifying all vertical and horizontal surfaces (typically windows, ground planes, roof tops etc.) which allow for vantage points to the target plot.

Step 3 – Generate vantage and target points
In order to establish vantage and target points from and to which visibility is to be measured, surfaces need to be divided into grids. The number of grid units should be parametric to allow for increasing accuracy as per available computation capacity. For horizontal surfaces, the grid centroids are calculated, and points projected vertically to viewing or target levels (based on whether the surface being analyzed is a vantage surface or a target surface). For vertical surfaces, points are to be established within the grid cells at viewing or target levels. For viewing levels, standing and seating eye

levels of 165 cm and 75 cm respectively are set as defaults, but can be changed parametrically as needed. Likewise, for target cells, default point heights are set at eye level of 160 cm and torso level of 95 cm, to account for the visibility of faces and bodies within the house. Once this is done, points that are within window boundaries become active while those outside windows remain dormant. This allows for consideration only of points that allow for visibility in and out of the building, while still calculating points on blank walls to allow rapid, parametric reconfiguration and sizing of windows.

Step 4 – Measure visibility/privacy
Once the vantage and target points have been established, visibility rays are drawn from all vantage points to all target points to measure for levels of visibility to any specific target point. Lines that form an angle with the surface that is above either the threshold for reflectance, in the case of windows, or the maximum viewing angle of 90 degrees, as well as those that intersect with solid obstacles in their paths, are deleted. These variables are made parametric to allow for manipulation of window surface treatments. After this process, an index of visibility per grid unit is calculated based on the number of visibility rays incident on it as shown in Figure 3.

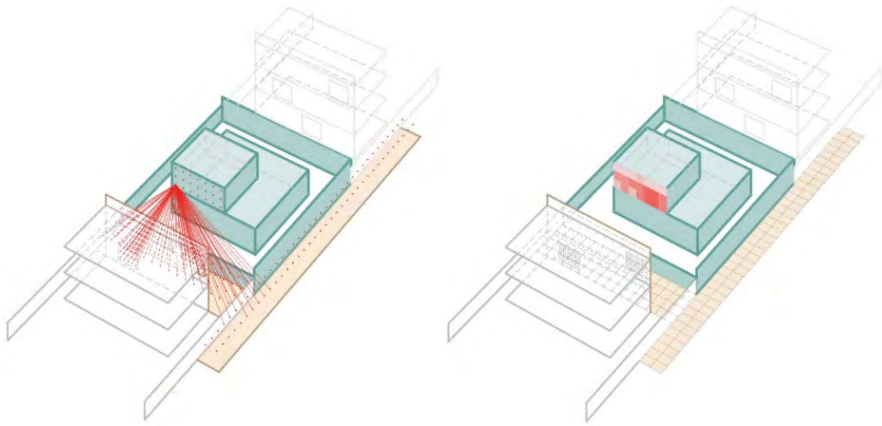

Figure 3. Generation of visibility rays to measure index of visibility for target surface grid.

4.2 EXTERNAL PRIVACY: APPLICATION

The index of visibility helps designers to measure visibility, and thus privacy, of existing houses, and guide design for privacy of new houses. The parametric variables allow for dynamic modeling by providing feedback about levels of privacy. The toolset allows designers to plan and design neighborhoods by enabling the location of private, semi-private, semi-public and public areas within plots as they relate to their surrounding plots, and designing for fenestrations within the building envelope. It, therefore, provides a novel way of objectively designing for privacy by using quantitative and measurable units where designs can be tested for privacy in real time. Once combined with other sustainability modules, the toolset allows for analysis of trade-offs between various strategies for addressing the need for privacy and other social sustainability parameters.

4.3 LIMITATIONS AND NEXT STEPS

The tool is in its initial stage of development and will address several of the following limitations through its progress. Including them here outlines not only the limitations of the tool as it currently stands, but also establishes next steps for its development.

Allowing for maximum flexibility of the tool in terms of changeable parameters such as viewing levels and the number of grids surfaces are divided into, will allow for the tool to be applicable for a broader scope of services in various contexts.

Additionally, for windows, there is a vision zone where visibility changes as per the location of an individual relative to the location of the window within the house. Accounting for this specificity will increase the accuracy of the visibility measurement.

Clarity of vision reduces with distance, in most cases. Thus, weighting visibility rays based on their lengths (distances between vantage and target points) would enable a more accurate measurement of privacy.

5. Conclusion

Social sustainability, due to its inherent unquantifiable nature, is often considered secondary to environmental and economic sustainability. In order to achieve holistic sustainability, local social and cultural needs of communities need to be an integral part of the sustainability dialogue. However, the vague and qualitative nature of social and cultural parameters makes it difficult for urban professionals to effectively measure and design for these. This research hopes to set an example for these professionals by exhibiting the practical translation of these qualitative needs into spatial and measurable features that can be digitally modeled and simulated.

Using a series of parametric variables, the toolset allows for flexibility, making it widely replicable. Slight modifications to the tool can also yield new tools that measure other aspects of privacy such as internal privacy, based on the same concepts of visibility analysis. Thus, even though this toolkit is being designed specifically for native neighborhoods in Abu Dhabi, the authors see it as being widely applicable for the region due to the inherent parametric nature of the modules, and the expandability of the toolkit by addition of topical and regionally appropriate modules as needed.

This paper presents a module that is a piece of a larger toolset that aims to spatialize and simulate several other social and cultural parameters prioritized by native communities in the GCC region. These modules can be used individually by designers when focusing on specific aspects of house designs, as well as in pairs or groups to prioritize certain aspects over others. Trade-offs between various parameters can be measured and strategies for addressing those trade-offs tested dynamically. The social sustainability toolset is also seen as a part of a larger holistic sustainability toolkit that includes modules for environmental and economic sustainability. Through this, this research aims to address the existing practice of approaching specific parameters of sustainability independently, thus looking at sustainable development as a holistic concept.

Acknowledgements

This work was funded by the Cooperative Agreement between the Masdar Institute of Science and Technology (Masdar Institute), Abu Dhabi, UAE and the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA – Reference 02/MI/MIT/CP/11/07633/GEN/G/00. We would also like to thank the team at MI – Dr.K.Alawadi, M.Mirkovic, M.Almheiri, L.Abu Ashour, and A.Almulla – for thoughtful conversation and useful insights about Emirati communities, and for their work on urban morphology in Abu Dhabi.

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MODELING DECORATIVE FORMS AND DESIGN KNOWLEDGE

RACHED BARBOUCHE
National School of Architecture and Urbanism, Carthage University, Tunisia
rachedbarbouche@yahoo.fr

Abstract. Form analysis in architecture is a method to increase knowledge of human made objects, by observation and description. Modeling attempts to identify characteristics carried by these objects and the rules of their production. Two approaches are relevant here. The first concerns the analysis and modeling of an object corpus (decors worn by windows), belonging to colonial architecture of Tunis from the late 19^{th} to early 20^{th} century and the second deals from a GIS, storing and mapping the forms variation, taken on the analyzed objects. The set allows developing tools for decision support, used not only in the description of a corpus, but also ultimately to lead to the architectural and stylistic classification of the city buildings.

1. Introduction

The review of architectural decor of urban buildings of Tunis from the late 19^{th} to early 20^{th} century shows a remarkable organizational unity and a wide form variety: cornices, friezes, frames, balconies and consoles, are all significant elements that hold meaning and value and act in harmony with the ornamentation of facades. These objects, bear similarities corresponding to conceptual designs, which are terminologically classified in scientist directory based on a conceptualization phenomenon (Pérouse de Monclos, 2004).

Many brief studies focused on decoration as the main compositional element of the architectural facade expresses design knowledge and which reflects the technical know-how of its time; but few of them have addressed the issue from a *morpho-quantitative* stand-point, that considers this device as an identification and measurement tool of architectural and stylistic characteristics of the observed forms.

2. Problem and Analysis Methodology

This paper aims to state the main methodological tools used to analyze and model an unpublished corpus of objects-decor and to understand the rules employed by European architects of the time in designing the buildings decor of Tunis. The question is to know how the organization of this decor appears and to determine to what extent the analysis allows to account for morphological and stylistic properties. These decorative organizations are they specific at the time, at the city or at the authors? The answers can lead to a very broad historical, spatial and stylistic knowledge (Barbouche, 2012).

2.1. METHODOLOGICAL PRINCIPLE

The fundamental postulate of the study stipulates that forms of these cultural objects are artificial human productions. They thereby constitute a clear interest to produce knowledge on their production and their producers. Their architecture would be an appropriate indicator for identification of a certain architectural culture. These objects have an organization accessible to knowledge which justifies the existence of the paradigm of their modeling.

2.2. PROTOCOL ANALYSIS

The study of a set objects-decor worn by the window openings aims to give an objective and controllable content at which appears to constitute the morphological identity of these objects. It adopts an empirical method for *characterization* / *identification* based on explicit operations of descriptive and comparative analysis. The analyzed objects are considered here both in that each of them having a form and that this form can be correlated with that of others to determine what characterizes them.

The method is to decompose systematically the objects into elementary entities and to specify the form of each of them, to account for their structural and plastic organization. It seeks to specify these elements into distinct homology classes and to register, following a proper codification (Gardin, 1978) which is translated in tables called “attributes-objects”, the morphological properties of each object for each class of similar elements. For this purpose, a homology relationship is founded between the elements by observing, with systematic comparison, regularities and variations of their disposition. The assembly provides structural modeling of analyzed objects, corresponding to a double morphological identity and distinguishing structural identity and plastic identity of elements of that structure; then these are taken in specific operations of quantification and measurement.

The results interpretation of the analysis is based on a set of data processing instruments whose forms are to be analyzed in turn, but which are designed for it. These instruments allow one hand a scientific treatment of the studied forms identification and develop specific formal models. On the other hand, they enable to validate or refute modeling performed on logical and objective criteria. They constitute adequate tools of objectification and aid in the construction of model objects (Duprat, 1995).

3. Modeling of Decor

The arrangement of the decor is considered here as a system that governs produced forms. It controls and measures them following organizational laws that modeling allows to highlight and to explain. The modeling of the objects organization is necessary to understand the issues. Its objective is to define elements of each specimen and to study relations of the parts of a same specimen and those of homologous parts from one specimen to another. This is to build a structural model of the objects; that is to say a systematic representation of a stable and efficient modeling process, applicable to all occurrences encountered (*Figure 1*). Modeling offers thus the advantage of recurrence and the ability to compare all specimens with each other.

The study conducted using this analytical framework aims to describe properly all the cases present in the corpus, raising the difficulties and impossibilities due to complex entities that appear in the operations of decomposition of studied objects.

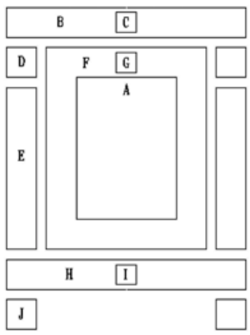

Figure 1. Structural model of the decor : (A) Lintel; (B) Coronation; (C) Central decor of coronation; (D) Lateral decor of coronation; (E) Jamb; (F) Frame; (G) Frame decor; (H) Support; (I) Central decor of support; (J) Lateral decor of support

The structural model thus defined is subject to catalogs of elementary forms; one catalog by class of homologous elements where are recorded, at various levels of decomposition, structural and plastic properties. These significant *morpho-structural* informations, suitably transposed into a coding system in the form of tables “attributes-objects”, are subject to statistical calculations, logical seriations and mapping tools (Deloche, 1985).

The matrix method or the seriation method by “scalogram of Guttman”, applied to table “attributes-objects” can handle a lot of informations as the case here. According to this method, sets x and y (structures and elements) are reordered by permutation of rows and columns depending on the information quantity they respectively carry, which modifies the initial image of the table without loss of information or alteration of basic data. The measurement of this information quantity is represented by a matrix diagram called “scalogram” (Bertin, 1977). The method revealed in the order of the diagonal, significant clusters of structures documented and described as homogeneous classes, resulting from strict partitions of the studied set, based themselves on important variations of the information quantity associated. Each structure can be stored in one and only one of these different classes, not only by the number of elements this structure involves, but also by the types of elements belonging to that structure.

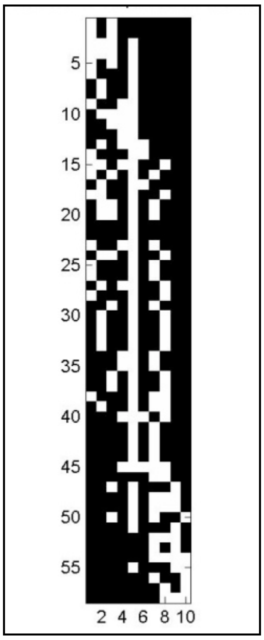

Figure 2. Scalogram of decor structures according on their elements

If calculations show no significant classification of structures and/or elements, they however allow seeing opposition series (*Figure 2*): the column at the center of the graph represents the dominant element (support) that is commonly shared by most structures; the rarest elements which oppose the structures of the top and the bottom of the graph are located on either side of the central column.

4. GIS and Morphological Data

In order to store in an organized and structured way the informations obtained from the morphological analysis and to manage the identified forms of the corpus, a Geographic Information System (GIS) was constructed in wide plot of city buildings. The objective is to develop a knowledge tool, based on the identification of morphological characteristics of windows decor from field investigations, to lead finally to stylistic classifications. This operation also allows testing the application of such tool in the treatment of morphological data with spatial dimension and particularly the inclusion of dynamic mutations of architectural and decorative typologies in the time. The development of the GIS results certainly of a choice dictated by explanatory hypotheses of recorded informations. Search for example to group some forms into coherent classes or study the localization of certain characteristics give an explanatory and interpretative scope, or at least cognitive; in this sense that the review and registration of attested traits or even comprehension of their combinations provide an "*objective knowledge*" (Popper, 1991) of observed phenomena.

4.1. DATA STRUCTURE

The corpus of the study contains 1600 buildings corresponding to about 3550 specimens of window. It is almost exhaustive and enough to define the architectural characteristics of buildings to highlight. The tables of the GIS database were built according to two levels of questions. A first level involves simple queries about buildings on which specimens have been identified, such as dating, height, facade width, designer, builder and building transformation. A second level is to use morphological analysis results by processing information relating to forms variation of the analyzed specimens. These coded informations are integrated into the GIS in tables "attributes-objects" that records modalities of morphological variables representing forms taken by the various specimens for a trait or a given descriptor.

4.2. ANALYSIS, VISUALIZATION AND CARTOGRAPHY

Once recorded, the morphological informations are easily accessible from the database of the GIS. Several operations can be performed such as:

– Select buildings with decors of same forms or find co-occurrent forms on a specific building.
– Seek and locate buildings with specimens that satisfy a given condition on structural or plastic attributes.
– Organize specimens of buildings designed by a particular designer, on a specific date or in given area.

The informations analysis from the database of the GIS is subject to graphics maps showing their spatial distribution in the city, to try explaining them. The objects of the map, which are polygons representing plots of buildings, can be discerned by the values of informations associated with the graphic map (Gauthiez, 1993). Reading the spatial distribution of decor structure elements through city areas shows that some of them are more dominant than others (*Figure 3*). These elements are significant as to the chronology of urban area development. Therefore, there are remarkable correlations between the number of elements that structures employ and city areas. More this number is high more the wealth of decor is accentuated.

Figure 3. Spatial distribution of the *"jamb"* in two areas of the city

The cartography of attested structures (*Figure 4*) shows that they are grouped in each area according to relations which read through their constitutive parts. That reflects the modes of organization adopted by designers of the time: homogeneous groups in wealthy areas, opposed organizations in modest areas where designers incorporate different elements of all kinds to link them to multiple generic models, often hypothetical.


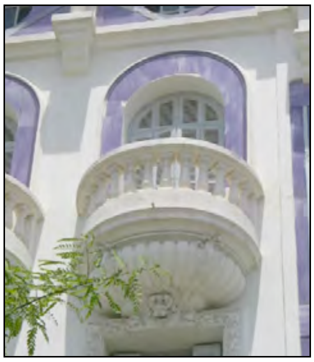

Figure 4. Spatial distribution of the structure composed by *"frame, support and its central and lateral decor"* and specimen with that structure

On their side, motifs of decor are quite diverse, coinciding remarkably, they-also with significant cartography. This is explained by the fact that city areas were built at different times and that each time the designers take different organizations; which results in a particular spatial distribution of decorative motifs from one area to another.


Figure 5. Spatial distribution of windows provided with an *"ornate grate"* and specimen of that category

The review of the motifs cartography (*Figure 5*) shows that some of them are elements of stylistic differentiation. But besides the fact that they are difficult to read directly on the buildings facades, these decorative units are interspersed between areas. However, the variety registered in the motifs spatial distribution reflects the stylistic compositions modes adopted by designers of the time, using each time a different type of organization. That is more urbanization spreads through the city more designers are changing decorative motifs in their works. They employ a variety of decorative motifs that characterize their approach, their style, in an *"ornamental dialectic"*

(Baltrusaïtis, 1986). The character of each area is actually a direct result of movements and stylistic trends that occur over time and not the selection or adaptation of designers to use such a decorative motif exclusively for such an area (*Figure 6*).

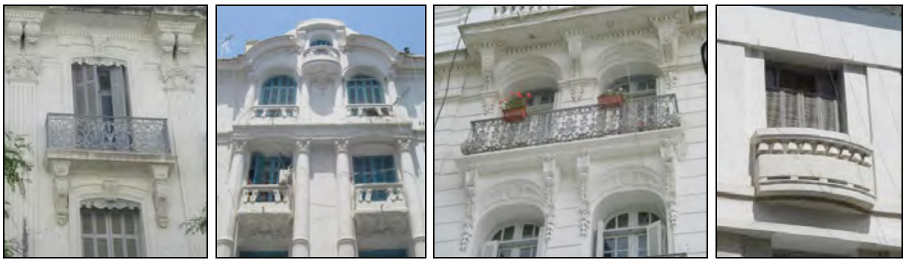

Figure 6. Archetypes of major stylistic trends in the treatment of windows decor in Tunis; (*from the left to the right*) 1895, 1906, 1910 and 1934

The study of the decor tries also to match decorative motifs classes to differentiated designers groups, maintaining them within these groups multiple special relationship, be it academic training received or comparable professional situations. The stylistic results are observed under that angle. Since this is to characterize architectural objects built at a given time, over a defined area, in a stylistic research purposes, relied on morphological characterizations of these objects. These are the analysis results and the treatment of its morphological informations that we try to use here; and looking particularly from the angle where they reveal the structure of the production field for the time, being through the homology of relations between respectively producers and products.

5. Discussion

The reconciliation of obtained morphological informations to dates, areas and architects allows giving them a stylistic scope and contributes to recognition of the composition rules of each era and in each city area. It is useful to know how a decor form participates in a stylistic classification. It can characterize a particular class, differentiate a specimen of a class or be common to all classes. Certainly, the study of the weight of each form in a stylistic classification is complex and lengthy, but calculations extracted from the database of the GIS can give significant indications.

Assuredly also, it must not ignore *"the difficulty of classifying"* (Parrochia, 1991) but it must admit that well-built classifications are likely to bring new knowledge of the studied objects and men who designed them and the conditions or the circumstances of their design. Direct examination of empirical data not allows certainly neither to observe properties of studied objects nor to predict the result of the formal calculations which are essential to the understanding of observed phenomena.

The study of decorative forms allows using different methods, to model the phenomenon, analyze the data and formalize the results. These mediation means that fall mainly to mathematical formalisms and computer algorithms aided to objectify the taken steps and they proved as effective instruments for analysis and knowledge. While these methods are still laborious, if not repulsive, but it must not to lose sight of the content of their results, by confining these classification techniques to a simple role for instrumental mediation that reorganize the morphological informations and represents them under a new face. However, decor variations are all choices made by the designers, their motivations are multiple and often subjective, thus evading a reconstruction quantified of works. The richest results accordingly concern the historic character and the degree of correlation between the structure composition and the choice of decorative motifs.

6. Conclusion

The method adopted in the analysis of decorative forms requires many operations in which the work of the operator is important for formulating hypotheses segmentation and description, arising from his own observation and perception (Piaget, 1975). Modeling of decor forms aims to understand the need to consider a fairly coherent theoretical framework itself and enough strong to confront the proposed empirical facts.

The construction of the GIS allowed to store and map informations on observed decorative arrangements and to seek explaining them. This contributed to the development of a rational tool of knowledge and stylistic classification of a reference corpus of Tunis architecture from the late 19th to early 20th century and cognitive aid to its organized development and management. This updatable and interactive tool is an appropriate means of informations analysis and decision support. It could be an unifying instrument to others researches on the built environment and enable professionals and policy makers to have a state documented easily accessible for city buildings and their components.

Acknowledgements

The author would like to thank the Carthage University (Tunisia) and the Analysis Laboratory of Forms at National Graduate School of Architecture of Lyon (France) for their contribution to the development of this research.

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GEOSPATIAL TOOL EVALUATING JOB LOCATION MISMATCH, BASED ON AVAILABLE WORKFORCE AND TRANSIT OPTIONS

Evaluating property location in a city using large-scale datasets.

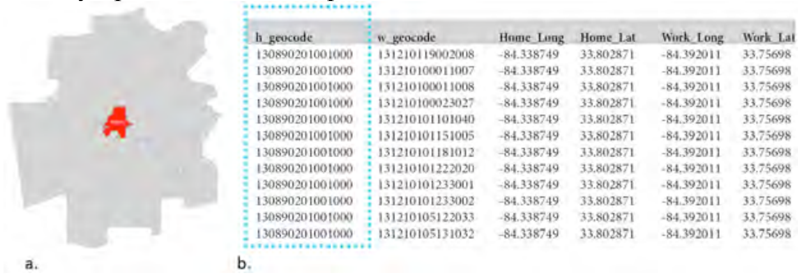
FLORINA DUTT AND SUBHAJIT DAS
Georgia Institute of Technology, Atlanta, USA
Email address: florina.design@gatech.edu, das@gatech.edu

Abstract. The paper addresses the issue of spatial mismatch of jobs and the accessibility to job locations based on different age, income and industry group. Taking Atlanta as a case study, we developed a geospatial analysis tool enabling developers, the city planning bureau and the residents to identify potential sites of redevelopment with better economic development opportunities. It also aids to find potential location to live with respect to user's choices for transit options, walkability, job location and proximity to chosen land use. We built our model on a block level in the city, imparting them a score, visualizing the data as a heat map. The metrics to compute the score included proximity to job, proximity to worker's residence, transit availability, walkability and number of landmark elements near the site. We worked with Longitudinal Employer-Household Dynamics (LEHD) Data along with residence area characteristics (RAC) and work place area characteristic (WAC) data sets, where the total number of data-points was over 3 million. It was challenging for us to optimize computation such that the prototype performs statistical analysis and updates visualization in real time. The research further is prototyped as a web application leveraging Leaflet's Open Street Maps API and D3 visualization plugin. The research showed that there is a high degree of spatial mismatch between home and job locations with very few jobs with driving distance within 5 -10 miles with limited transit options in Atlanta. Further, it showed that low-earning workers need to travel significantly larger distance for work compared to higher class.

1. Introduction

There has been rising anxiety in Atlanta related to spatial mismatch of available workforce and job accessibility. Atlanta region's growth is evidently unbalanced, creating a stark divide between the affluent North and disadvantaged South (Policy, 2000). The nature of the problem has either produced a ripple effect of economic growth in certain communities or completely confounded communities with unemployment and degradation. The various studies and empirical inquiry from various sources bolsters the fact that impoverished conditions of the neighborhoods in Atlanta are due to poor job accessibility geographically as well as due to job –education mismatch. Fewer jobs are available within walking distance of public transit stops (Ihlanfeldt, 1993).

The research aims to address the issue of spatial mismatch of jobs and study the accessibility to jobs locations based on different age groups, income group and industry category for any given city. The investigation has two parts. First part accounts for the socio-economic parameters and conditions of available workforce in a specific geographical area (blocks). The second part identifies the degree of current mismatch based on accessibility options to the workplace.



h_geocode	w_geocode	Home_Long	Home_Lat	Work_Long	Work_Lat
130890201001000	131210119002008	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210100011007	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210100011008	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210100023027	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101101040	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101151005	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101181012	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101222020	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101233001	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210101233002	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210105122033	-84.338749	33.802871	-84.392011	33.75698
130890201001000	131210105131032	-84.338749	33.802871	-84.392011	33.75698

Figure 1 a. Red overlay represents the geographical extent of analysis, while the gray overlay represents the whole Atlanta Metropolitan Area. b. Latitude - Longitude table.

2. Geographical Context and Use case

The current exploration is restricted to the home census blocks within the city of Atlanta (6664 blocks under the study). The number of primary jobs in each census block is considered for each home block. Accessibility measures are obtained for home blocks within the city of Atlanta. The destination or work blocks spread across Atlanta MSA (Metropolitan Statistical Area) (See Fig 1a). Subsequently, we evaluated and ranked geographic locations (block groups) based on job suitability, accessibility, and consideration for future redevelopment. Taking the research further, we developed a prototype of a web application leveraging Leaflet's Open Street Maps API (JS, 2011) and D3 visualization plugin (Figure 2a and 2c). We foresee the use of the tool by residents or visitors to a city, trying to evaluate potential location for work, stay or other businesses. The web application has an input panel on the right, which takes user input i.e. the name of the city, user preference or weights on diverse subjective characteristics like, work location distance, transit time to work, driving distance, walking distance, nearby restaurants, hospitals, shopping malls, etc. Based on the user weights and on the computational model as described below the application computes a heat map at block level for the city visualizing it on the left panel. Each block gets a score, which decides the color overlay for it. This gives a quick overview of potential areas or location in the city, which meets the users need.

3. Related Works

Wang et al. researched to calculate job accessibilities by transportation modes using buffering and network analysis operations. One of the drawbacks of their model is that they did not consider disaggregating by job categories or by different social groups like race, income, etc. They also did not consider built environment qualities and land use types in their statistical model (Wang & Chen 2015). Work of Hadas et al. analyzed the performance of public transit networks with respect to coordination and their connectivity on a case study in Auckland, New Zealand. Attributes they considered were passenger transfers, ride, walk and wait times and type of transfers made. They leveraged Google transit data to develop a tool as a GIS package to evaluate pros and cons of defined zones of transit lines by comparing and analyzing transit network alternatives (Hadas & Ranjitkar 2012). Jianquan et al. showed a six step GIS-based methodological framework to measure urban job accessibility, validated via a case study on Amsterdam. Their work depicted a modified measurement to represent, measure and interpret job accessibility with respect to competition, distance decay, and job diversity. One of the limitations of their work is a disregard to segmented job data, travel modes like a car, public transport and cycling (Cheng & Bertolini, 2013). Kim et al. found that same demographic, socioeconomic and spatial conditions had varied effects on workers in complex ways (Kim *et al.*, 2012).

4. Data Sources and Structure

We used data from various sources. First, we used block data from Census and American community survey summary files. Then, we used Longitudinal Employer-Household Dynamics (LEHD) data along with residence area characteristic data (RAC) and workplace area characteristic (WAC) to find the origin-destination data for jobs, jobs in different age group, income category, and industry type(Census). LEHD is public use information which combines federal, state and U.S Census Bureau dada on Employers and Employees data. Primarily origin destination (OD) data has been used from the LEHD data set (http://lehd.ces.census.gov/). OD dataset constitutes jobs totals associated with both home census block and a work census block. Primary jobs data from LEHD has been used to assess distance traveled and travel time to the workplace. Noteworthy to mention here that primary jobs are the job that accounts for the most amount of income of an individual. To maintain consistency with the census block data from various sources, the year 2010's origin-destination data has been used. The distance traveled and travel time estimates are obtained using Bing's route API. This provided a real-time estimate of travel time and travel distance from each home and work geocode. We also tested Google Maps Distance Matrix API, but that only allowed queries of 2500 blocks per day. While Bing's API service allowed as much as 70000 queries a day, with no upper limit on total number of requests. Additionally, the quality of the data needed was same for both services.

5. Methodology

The following are the major steps of the workflow to develop the computational model delivering various heat maps pertaining to specific metrics as described further:

5.1. STEP 1: CLEANING DATA

LEHD data comes as a very large data set with over 3 million data entry for Georgia from which home blocks within Atlanta is selected and associated with their individual work blocks and some jobs in various category of age groups and income. To keep the data set manageable and reasonable for the purpose of analysis the geographical boundary for the workplaces are restricted to the Atlanta MSA. Processing the LEHD data is done in MS Access using inbuilt query design. MS Access proved to be adequately competent with a robust GUI to handle our big data challenges.

5.2. STEP 2: LINKING DATA

The block shapefiles and basic demographic information as obtained from the census is used to extract the latitude-longitude information for each of the census blocks included in the study area (Figure 1b). An optimized script written in Python is used to extract each block group's latitude-longitude information from the large data set as aforementioned. Each home geocode is associated with multiple work geocode forming a one to many relationships in the origin-destination data set. To match the respective home-geocode and work-geocode MS Access query design is used. Each row represented the work census blocks where people go to work from a particular home block. This is represented as a matrix in the Python script where each row represented a home-geocode and every column entry of the row represented work-geocodes.

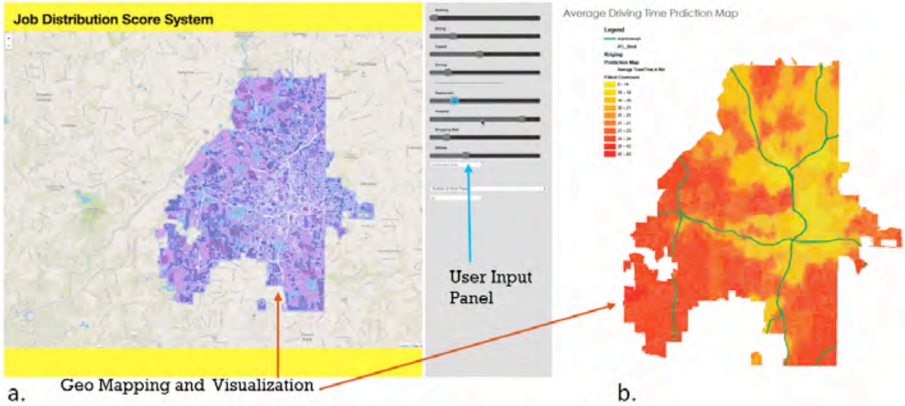


Figure 2. a. Prototype web application showing user input panel and geo mapping panel with visualization of heat maps. b. Visualization: Average driving time prediction map

5.3. STEP 3: WEB DATA MINING

Next, we make periodic queries to Microsoft Bing's Route API service, with source and destination longitude and latitude value as obtained from the matrix so formed. This service was free allowing us to make up to 70000 queries per day. The data returned from Bing's API included Driving distance and time, Walking distance and time, Transit distance and time, from home geocode location to any work geocode location. Likewise, a distance time matrix is computed for each home geocodes (for driving, transit and walking) as shown in Figure 3. We also made queries to Google Places API, for all census blocks, which essentially returned the number of hospitals, restaurants, shopping malls and hotels within a given threshold distance or walking time. Data so obtained was further used to build heat maps for the user, quantifying the suitability of a block for potential stay of the user.

5.4. STEP 4: VISUAL ANALYTICS

Subsequently, the next step was to aggregate the data retrieved and provide useful statistics for each block. The main data components obtained were total vehicle miles, total walking miles; total distance traveled by transit from each census blocks to their job location; total travel time to reach each location from census location. Average miles traveled per job was found by normalizing the number of jobs for the census block. Input threshold distance and threshold times are used to identify how many jobs are above or below certain distance threshold or travel time threshold.

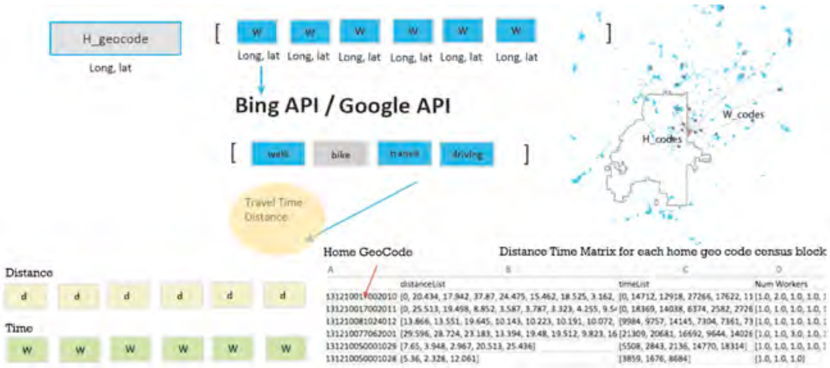


Figure 3. Distance, time, weight (number of jobs for each home –work geocode pair) Matrix

6. Analysis and Results

A wide range of parameters and relationships are studied primarily focusing on two things from the investigation. First, if there is any discernable trend or pattern in the job and home location relationship based on three different travel modes driving, transit and walking. Second, if the mode of travel, let's say driving is the control variable, then is there any difference observed in the travel distance, or travel time among different socio-economic variables i.e. age, income, job sector or industry.

6.1. DIFFERENT TRAVEL MODE

6.1.1. Driving

The result of the analysis (Figure 4a) indicates that the average driving distances are above 16 miles in most blocks in south Atlanta. Additionally, they show high clustering (marked red), positive spatial autocorrelation through hotspot analysis compared to the blocks in the center city. The results of the analysis for people with driving distance above 25 miles (threshold distance as a user input) also corroborates the finding that blocks further south has more number of people with driving distance more than 25 miles, and they show positive spatial autocorrelation. Also, the analysis (Figure 4b.) indicates that the average driving time is above 25 minutes in most blocks in the south. However, the number of census blocks above 25 minutes driving distance are concentrated at the southwest corner and at the northwest corner of the city.

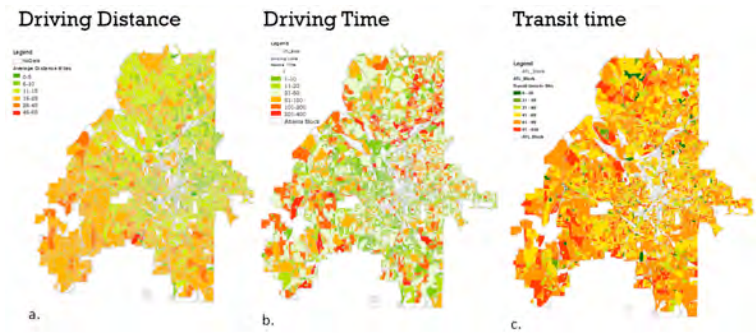


Figure 4. a. Average driving distance from each census blocks b. Average driving time from each census blocks. c. Average commute time for each block using transit.

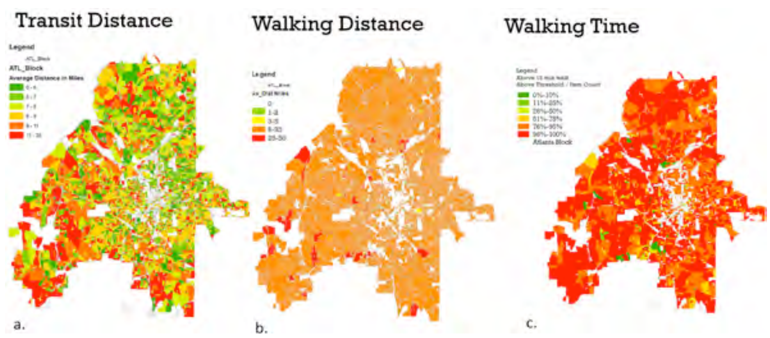


Figure 5. a. Average distance of commute for each block using transit. b. Average walking distance of each block. c. Percentage of people above 15 minutes walking time

6.1.2. Transit

For transit from home to workplace, the results showed the average transit time for the most block in Atlanta is above 40 minutes and those marked in red are above 90 minutes' transit time indicating no transit options to the workplace for the most number of people in that block. Figure 4c and 5a shows a clear trend that most blocks in the southwest and further south have higher transit distance (30 miles).

6.1.3. Walking

The walking distance and time study indicate the blocks that have an average feasible walking distance to jobs are very few blocks where only 0-10 % of the people are above 15 minutes walking time from their workplace. Most block shows almost 90 -100% of the people are located above 15 minutes of walking distance from the job locations. The average walking distance of all blocks is above 6 miles. Only very few blocks have an average walking distance of 2 miles to their workplace. (Figure 5b and 5c)

6.2. DIFFERENT SOCIO-ECONOMIC PARAMETERS

6.2.1. Age

The average driving distance traveled by different age groups are studied creating weight matrix with jobs in different age group categories. The average driving distance for age group below 29years is significantly higher than those in the age group 30 -54 years. This indicates that younger age group people travel significantly more compared to those in higher age group. Greater spatial mismatch is observed for age group 29years and below. (Figure 6a and 6b)

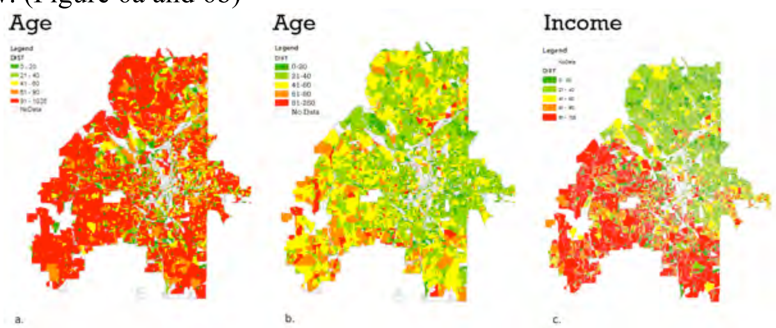


Figure 6. a. Average driving distance for workers 29 years and below. b. Average driving distance for workers age 30 -54 years. c. Average driving distance for workers with earning above $3333 /month.

6.2.2. Income

The average vehicle distance miles for low-income jobs ($1250 –or less/ month) is much higher compared to jobs in higher income bracket (Above $3333/month). Which substantiates that low-income jobs are far away from the city center, and disadvantaged groups need to travel significantly more to their jobs. The northeast side of Atlanta reflects least spatial mismatch of home and job location for high-income workers. (Figure 6c)

6.2.3. Industry Type

The third factor studied is if there is any variation between workers in various industries. The average distance maps show that significantly high average driving distance for workers in Good producing sector, Trade, Transportation, and Utility sector compared to other Services industry sector. The goods-producing industry or trade transportation related business like warehouses etc. substantiates the fact that these industries are located away from city centers increasing vehicle miles, indicating worker's in this industry needs to significantly more to reach their workplace. Workers in services industry are located close to worker's home locations and accounts less travel distance.

7. Conclusion

The use of block level census geography and combining the dynamic data set from Microsoft Bing's API and Google Places API helped to create the possibility of a very high-resolution analysis of socio-economic factors. The results obtained clearly shows that there is a high degree of spatial mismatch between home and job locations. There are very few jobs with driving distance within 5 -10 miles. The transit options from most block groups are inadequate thus driving long distances above 16 – 20miles is the most viable option for travel. There are very few jobs within comfortable walking distance (less than 15 mins.) for low-income workers. Further research is under works to implement the same model in a different city with totally different demographics and socio-economic conditions. Using proximity analysis from real time / dynamic data sources using large scale geocoding and computing can help analyze block and parcel level data using a similar methodology. It can also inform various policy and design decisions, which might be overlooked by over-reliance on Census as the only source of data analysis and decision making.

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SUSTAINABLE BROWNFIELDS REDEVELOPMENT AND TOOLS OF COMPUTER AIDED DESIGN

An inductive inquest on the case of Amman, Jordan.

DEYALA HAMMAD ALTARAWNEH
School of Geography, Earth and Environmental Sciences,
University of Birmingham, UK
deyalatarawneh@gmail.com

Abstract. The task of geography is to establish a critical system which embraces the phenomenology of space in order to grasp all of its meaning in the varied terrestrial scene (Sauer 1925). Brownfields are a global geographic concern that have been considerably researched within the universal discourse. Computer Aided Design (CAD) and its tools have been widely used to enhance and optimize urban plans during both design and implementation phases. Nonetheless, the connection between the two is often broken. While greenfield development enjoys the employment and implementation of a wide array of CAD tools, brownfield redevelopment projects are still struggling with traditional planning and management methods. Looking at the association between sustainable brownfield redevelopment and the optimization of CAD tools and software in the city of Amman, Jordan, the paper attempts to shed light on the unfulfilled potentials of advancement the spatial tools have to offer to the ongoing quest for sustainable urban development on the local scale and the global debate around the urban paradox on the wider scheme. Using empirical data collected and processed in response to the problem posed, the results indicate a CAD-based model could streamline sustainable brownfield development and save substantial time and resources which would otherwise be required using traditional methods. The paper therefore argues that the need for a comprehensive computer aided intervention for the development and management of marginal and overlooked geographies of brownfields in the city of Amman is long overdue.

1. Introduction

The term 'brownfield' has lent itself to the urban planning and the IT industry interchangeably. While understood as any previously developed land or premises currently not in full use, which may be partially occupied, vacant, derelict or contaminated and not necessarily available for immediate use without intervention in the first discipline (Alker *et al.*, 2000), the term is commonly used to describe problem areas in new software systems in need of development in the presence of existing software applications and systems in the second (Hopkins and Jenkins, 2008). The two definitions collide in the sense that brownfield software development occurs within an already complex IT environment of existing applications and systems. On one hand, this suggests any new software architecture must take into consideration and coexist with software currently available on one hand (Baley the Belcham, 2010), while on the other, in the context of contemporary urbanism, brownfield redevelopment stands to introduce change according to the already existing urban fabric (CLARINET, 2002).

Computer Aided Design (CAD), understood as the use of computer systems to aid in the creation, modification, analysis or optimization of a design (Sarcar *et al.*, 2008), is another area where the two disciplines converge. It has been argued that a variety of CAD software has been, and still is, used to increase the productivity and improve the quality of the urban design (Ajene & Sylvester, 2014; Chakrabarty, 2001). However, discussions indicate a considerable lack of their use when it comes to the redevelopment of brownfield sites (Stevens *et al.*, 2007; Carsjens & Ligtenberg, 2007). Brownfield development adds a number of improvements to the conventional urban growth, with the help of CAD throughout design and implementation, brownfield redevelopment can extend its application by insisting the context needs are catered for through recreating spaces and integrating them into the development exercise.

The vast majority of the global construction activity is now focused upon the redevelopment of brownfield sites (David Adams, 2010; Wernstedt *et al.*, 2004; Environment and Economy, 2003; Owusu and Oteng-Ababio, 2015). Such development requires new design to be sympathetic towards existing structures. Unfortunately, the majority of existing brownfield sites pre-date the development of CAD systems and even where such systems have been used, few land databases have been maintained and updated (Turner *et al.*, 2000). This severely restricts the potential application of CAD in the management of the facility and the cost of the provision which is a significant factor during early design stages of any subsequent development.

2. Literature Review

In the current high demand for sustainable urbanism, many argue that critical decisions should be made during the design and preconstruction stages (Haas, 2012). CAD enables in-depth sustainability analysis of brownfield typologies, occupancy status, physical conditions, chemical contamination levels, special regulations or required treatment, value/cost and context, amongst others. It allows for multi-disciplinary information to be superimposed within one model, creating an opportunity to conduct these analyses accurately and efficiently when compared to the traditional methods (John, 2013). Recent studies indicate that the demand for sustainable urban development with minimal environmental impact is today higher than ever before (Azhar *et al.*, 2011; Carsjens and Ligtenberg, 2007; Fistola, 2011). Rising energy costs and environmental concerns are the catalyst of such high demand. The environmental and human benefits of sustainable development have been widely recognized. A slight increase in upfront costs can result in a life cycle saving (ibid).

The early design and preconstruction phases of urban development are the most critical to make decisions on sustainability features. Traditional tools lack the capability to perform sustainable analysis in the early stages of design development. Performance analysis is typically measured after the design and construction have already begun. This failure to analyze sustainability continually during the design process results in an insufficient process of retroactive modifications to the design to achieve better performance criteria (Turner *et al.*, 2000; Azhar *et al.*, 2011). However, since CAD allows for multi-disciplinary information to be superimposed within one model, it creates an opportunity for sustainability measures to be incorporated throughout the design process.

A considerable amount of information can be obtained easily and directly from the CAD database to determine many development variables. For example, various design options for sustainability can be studied or tracked using CAD software, and, when choosing redevelopment sites, it allows architects and urban planners to input spatial and geographical data which in return imports information related to climate, resources, eco-system and such. The availability of this information helps designers make better decisions that can reduce environmental impact and determine the most efficient solutions for development in general, brownfield redevelopment included (Stevens *et al.*, 2007; Thomas, 2002).

3. Problem and Methodology

Worldwide, individuals and organizations have responded to the increased demand on sustainable urbanism – included but not limited to, the United Kingdom, United States, and many European countries such as Germany, France and Switzerland – the majority of these ventures are similar in that they utilize CAD tools to provide decision-makers with a concise framework for identifying and implementing practical and measurable construction, operation and maintenance solutions. The examined examples have tracked an overall improvement in brownfield redevelopment projects over the years; however, even today, many projects still fail more often than they succeed. Urban management in such environments has many construction concerns; brownfield sites are often full of hazards, unexpected complexities and tend to be risky and expensive to redevelop. Moreover, the accumulated lack of CAD-based management and development has also made them 'brownfield' sites. Current brownfield and redevelopment projects in Amman, if existing in the first place, use informal tools and traditional methods that often ignore such complexities. Often witnessed in construction, they result in delays, expensive rework and even failed development. A brownfield-oriented approach embraces existing complexities and is used to reliably accelerate the overall development process wherever possible.

The dilemma of brownfields in Amman extends both before and beyond the case set forth in this paper, from the lack of systematic definition of the variety of brownfield typologies materialized, to their conspicuous absence in the national agendas and future urban development action plans in addition to inconsistency, ambiguity, and parochialism which are the bane of brownfield redevelopment. Nonetheless, the sole purpose of this study is to demonstrate ways stakeholders may and wish to use CAD tools and software for various sustainability analyses in pursuit of brownfield redevelopment best practice. The scope of research is limited to brownfield site redevelopment only. Due to the limited time and availability of data, only the case of Amman has been discussed in this research. The final result of the study will be published in the near future.

The paper identifies, as a qualitative case-study, research which allows the exploration of individuals and organizations through interventions, relationships, communities and programs (Yin 2013). For the purpose of the study, a mixed-method approach to acquiring information was adopted. Tools of ethnography, informal chats, semi-structured interviews, in-depth interviews, focus groups and workshops in addition to visual methods were employed to collect data (Atkinson *et al.*, 2007; Banks & Zeitlyn, 2015; Calhoun *et al.*, 2005; de Vaus, 2001). The variety of tools employed allowed for the exploration of the topic of interest from a variety of angles encompassing its versatile aspects.

The paper leans on a larger set of empirical data dedicated for the wider scope of the PhD research. However, by showcasing relevant segments of the data collected, the paper attempts to further investigate the specificities of the problem the paper is addressing.

4. The Investigation

The association between CAD and brownfield site redevelopment was measured on three levels: educational, professional and operational. On the educational level, a total of 62 architecture and urban planning students were surveyed, 28 of whom were later interviewed and 16 of whom that volunteered for a brownfield mapping exercise. A total of eight architecture and urban planning academic staff were also interviewed: four teacher assistants, two assistant professors and two associate professors.

On the professional level, a total of eight architecture and urban planning practitioners were interviewed, while on the operational level, the head of the Geographic Information Systems (GIS) department at the Greater Amman Municipality (GAM) was interviewed in addition to the head of the planning department and head of the development and studies department.

On the three levels, consensus on the significant role CAD plays in brownfield development was established. Students, professionals and officials unanimously highlighted the notable absence of the employment of these tools and the considerable effects it has on urban development in general, and brownfield redevelopment specifically.

Following are selected statement from the three disciplines:

> "… GIS enjoys many spatial analysis tools. We can do selection by attribute, calculate operations… Spatial analysis is basically the connection between data and attributes and their locations on the maps and the patterns that might result from that. Unfortunately, we use none of this."
>
> (Y. Q, Head of the GAM GIS department)

> "… See, I can do a selection by attribute, so for example here I'm doing it on use [clicks on his screen], I click the secondary, unique, now see what it can do? Let's say am looking for residential A land use, it will select the residential A code in all of Amman. Now if I want ownership with this operation and this operation, it would calculate it and give you the areas you are looking for specifically. Tell me you can do this manually."
>
> (A. A, Employee the GAM GIS department)

> "… I mean the manual map of Amman just like everywhere else I believe has a human factor error since the person that is doing the data entry might [make] an unintentional mistake. And that happens. This is an obstacle we can overcome I guess if the mapping used technology and was able to detect the error"
>
> (A. A, Employee the GAM planning department)

> "… There will be a problem however in transferring the data into GIS because the students do the drawings manually or in the best cases they use AutoCAD, in the least professional way that is, and are not really familiar with the GIS as a software… I mean they use AutoCAD yes, but they don't use any of the analysis tools it offers, also AutoCAD doesn't have attributes… True. AutoCAD is a drawing tool, it can do simple calculations but it's not equipped to do any spatial analysis like GIS. This is why GIS would be better for you, the way I see it"
>
> (N. A, Teacher assistant)

> "…There should be collaboration ventures between the different stakeholders, at least between the government and the universities, perhaps GIS employees could teach and train our students and our students can help in the mapping of brownfields in return, we have an army of students and this exercise can teach them a lot about the city… in my opinion, it's a win-win situation, a bit farfetched though, you know how things take forever to get done here."
>
> (A.R, Assistant professor)

> "… It is time to upgrade our education system, the student should learn about the history and development of traditional techniques… otherwise, they should be learning new ones to employ in the market… it all starts here, those students are tomorrow's architects and urban planners, they should be equipped with the right tools."
>
> (S.M, Associate professor)

> "… It takes less than ten minutes to run the complete analysis, CAD proved to be a quick and easy way for a design team to develop an accurate estimate of a proposed development design. It may be used during a project's pre-design as well as design phases."
>
> (S.N, Practising architect)

5. Results and Analysis

Based on the survey analysis, three commonly used CAD-based software were found to be fundamentally utilized in the management, design and implementation of the urban planning and development practice between the educational, professional and operational disciplines in Amman, Autodesk's AutoCAD, BIM's Revit and ESRI's ArcGIS. And while the first and second are most routinely used by students and practitioners, the third is more popular for the spatial mapping and master planning of the city by governmental officials. According to the survey, AutoCAD is most preferred between students for its time-saving drawing tools, Revit is most preferred between practitioners for its building performance such as energy consumption and other analysis tools and ArcGIS is most preferred between officials for its spatial analysis tools.

The analysis indicated the proposal to optimize a CAD-based model in brownfield redevelopment is not only welcomed but encouraged. However, most of the surveyed sample agreed that the problem would be in the implementation due to a number of reasons: the outdated curricula, the traditional methods employed in the organizational level, the needless bureaucracy, and the time, effort and resources the whole transformation process is estimated to consume, to name a few. Furthermore, the examined sample suggested collaboration between the different stakeholders is needed to fast-forward the procedure.

The results of these analyses were also compared to hand-prepared documents. Though most results produced by software were in close agreement, some notable differences were also recorded due to many factors, for example, the digital map of Amman was not updated and was lacking key changes; also, some proposed design features could not be accurately modelled in all CAD software. Therefore, the participants were advised not to rely blindly on software results and always apply manual checks for verification.

The analysis indicates optimizing the use of CAD tools and software can help designers visualize the design at the very early stages prior to construction. Results could not be considered very accurate, but they may be taken as indicators. The indicators eliminate the need to design a space and wait for completion to evaluate it. Using a CAD tool or software, a design team can closely predict outcomes, it allows designers to bypass the onerous and demanding set of calculations required to support sustainable design than when using the traditional tools.

6. Discussion

One of the reasons brownfield development projects often go wrong – not probably as often as discussions claim, but commonplace nonetheless – is because, due to the use of conventional methods in their development and mapping, manually produced maps tends to become brittle when they have been edited by many hands, badly handled or stored, produced with deliberate shortcuts on quality to save time, or been patchily documented, and thus they get harder and harder to change (Turner *et al.*, 2000). Moreover, although most drawings and information sheets can be developed manually and using traditional and conventional techniques, CAD software produces the same information more efficiently as part of their building information model and have the added advantage of parametric change technology which coordinates changes and maintains consistency at all times (John, 2013). Digital map development has also been stubbornly resistant to automation attempts. Thus, small tasks remain expensive and labor intensive and it is seldom cost-effective to convert all the information contained in the manual database into a CAD-based model.

7. Conclusions

In this preliminary research, the paper bid to expand the narration on sustainable brownfield redevelopment and the use of CAD tools and software by looking at case study of Amman. The paper looked at how sustainable brownfield redevelopment can utilize CAD tools and software, and addressed key differences between them and traditional methods in the context of Amman. It looked, crucially, at the current practice and its demand for an upgraded urban management model with an emphasis on the optimization of CAD's role in the process. It finally concludes with advice to urban planners and other stakeholders: to juxtapose CAD with sustainable brownfield redevelopment as reliably reengineering existing environments into the current competitive, integrated commercial city is non-trivial.

The complexity of brownfield redevelopment and CAD has been accumulating almost unchecked for decades, making change now more difficult. As a result, an increasing proportion of the effort involved in developing brownfield sites is spent on the aftercare and maintenance of projects rather than design and preconstruction analysis. The brownfield redevelopment industry as a whole has a poor success rate in delivering noteworthy change to begin with, add that to employing traditional, old-fashioned tools and the prospects further decline.

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Section

X

ARABIC PAPERS

خريطة الرؤية الحاسوبية: مقاربة استشرافية للتخطيط الحضري لمستقبل المدن الجديدة

- دراسة حالة المدينة الجديدة علي منجلي بقسنطينة - الجزائر

عبدالحليم عساسي, جمعة بن مشيرح,
قسم الهندسة المعمارية، جامعة باتنة 1، الجزائر. حي كشيدة، باتنة.
البريد الالكتروني: abdelhalim.assassi@gmail.com
قسم الهندسة المعمارية، جامعة باتنة 1، الجزائر. علي منجلي، قسنطينة.
البريد الالكتروني: boukabousfatima@hotmail.com

و

رشيدة سامعي
مهندسة معمارية معتمدة، باتنة، الجزائر.
البريد الالكتروني: ra3.sa3@gmail.com

ملخص. المجال هو الوحدة التي يمكن من خلالها قراءة الفعل والنشاط اليومي للإنسان، وتفاعلات هذا الأخير مع أفراد مجتمعه ضمن ثقافة توارثها الأجيال وطورتها الإضافات اليومية والاحتياجات المتوالدة. المجال يؤثر على مستخدمه بشكل تفاعلي، يوجه السلوك نحو الاستخدام الوظيفي اليومي، والانتقال بين المجالات يولد تواترات عديدة تعكسه حقول رؤية مختلفة بانفعالات وأحاسيس متعددة. ويمكن وصف المجال محوريا (أين نجد أن الإنسان يتحرك فيه)، أو عن طريق المجال المحدب (أين نجد أنّ كل نقطة يمكن رؤيتها من كل النقاط داخل هذا الشكل المجالي)، كما يمكن وصف المجال بالتفاعل بين النقاط، بحيث أن كل نقطة في المجال يمكن رؤيتها كمتغيرة شكلية، وغالبا ما تكون ضمن حقل رؤية شائكة. وحسب مخبر التركيب المجالي بكلية "بارتلت" Bartlett بالكلية الجامعية بلندن فمبحث التركيب المجالي الحاسوبي يؤدي إلى الفهم الأساسي للعلاقة بين التصميم المجالي واستخدام المجال فضلا عن النتائج الاجتماعية على المدى الطويل، وبناء على ذلك يمكننا استشراف السلوك الاجتماعي والفعل الإنساني في المجال في مشاريع التخطيط الحضري للمدن الجديدة، وبالتالي يمكننا تفادي الاستخدامات السيئة للمجال قبل استخدامه باختيار الحل الأنسب رقميا في مراحل التخطيط ما قبل التنفيذية منها. مدينة علي منجلي كواحدة من أهم المدن الجديدة في الجزائر، وقطب التوسع الأول في عاصمة الشرق الجزائري "قسنطينة"، هذه المدينة عرفت تخطيطات حضرية متتالية ولا تزال، وبعد تنفيذها وإنجاز مشاريع قسم هام منها وشغورها بعد ذلك من طرف السكان عرفت هذه المدينة استخدامات مجالية أسفرت عن خلق مجالات سلبية وبقع سوداء كان يمكن تفاديها لو مرت على المسح البرمجي الحاسوبي الاستشرافي باستخدام خريطة الرؤية. إذن بحثنا هذا يعالج فكرة الكشف عن مواقع الزلل في التخطيط الحضري بتفادي ما يمكن أن يخلقه هذا الأخير من مواقع تساعد في تنامي السلوكات الاجتماعية الخطيرة في المجال الحضري للمدن الجديدة وذلك بناء على مقاربة التركيب المجالي الحاسوبي في شقها البصري (حالة دراستنا تتمثل في مدينة علي منجلي بقسنطينة: ثالث أهم مدينة في الجزائر).

1. مقدمة

عرف العمران البشري تطورا متواترا عبر الزمان والمكان، لعبت الكثير من العوامل دورها باختلاف آثارها وموازينها في رسم صيغ توجهاته وأنواعه وأشكاله، فشكلت مختلف الأنساق العمرانية صغيرة كانت أو كبيرة، متراصة كانت أو مترامية أطراف منفجرة، باقية كانت أو متجددة، ثابتة كانت أو متحركة... فرض الفعل الإنساني منطق فكره فيها وفي المجال الذي يحيط به ويقطنه والذي يعمل فيه، فارتسمت بذلك الصور العمرانية العديدة معبرة عن علاقات اجتماعية أكيدة في إطار زمكاني أكيد. والمشاهد لمختلف النتاجات العمرانية في شتى بقاع العالم يشده بعين المبصر الملاحظ اختلافات بنيوية واختلافات أخرى ضمنية تعكسه سلوكات بشرية وإنسانية بالضرورة -إيجابية كانت أو سلبية- مختلفة من فج إلى آخر ومن قرية إلى أخرى ومن مدينة إلى أخرى تلبي صوريا حاجات الإنسان لكنها ولّدت في معظم الأحيان مشاكل كثيرة. حديثا فكرة التخطيط الحضري كانت تصبو إلى الاستجابة العلمية لحاجات الإنسان في الفضاء والمجال العمراني الذي يتفاعل سلوكه معه فيه. رغم ذلك إلا أنّ العديد من التشكلات العمرانية خلقت انعكاسات خطيرة بل وساهمت في تنامي مشاكل لم يتنبه المخطط وحتى المصمم إليها ولم يتمكنا قبل تنفيذها بالتنبؤ بها، ولعل من أهم تلك المشاكل علاقة الفضاءات الحضرية السلبية الناتجة عن التخطيط الحضري للمدن الجديدة بالسلوكات الإنسانية السلبية مثل الإجرام، وذلك ما تعاني منه المدينة الجديدة علي منجلي المتنفس المفترض للمدينة الأم "قسنطينة"، وباستخدام المقاربة التركيبية المجالية من خلال خريطة الرؤية يتأتى ذلك إذ يمكن استشراف مواقع سوداء تلعب دورا محفزا لممارسة السلوكات الإجرامية مستقبلا.

2. الخلفية التاريخية: "علي منجلي" مدينة جديدة للمدينة الأم "قسنطينة"

تقع ولاية قسنطينة جنوب شرق العاصمة الجزائر وتبعد عنها بقرابة 370 كم، يحدها شمالا ولاية سكيكدة وشرقا ولاية قالمة وجنوبا ولاية أم البواقي وغربا ولاية ميلة (الخريطة 1). تقع المدينة الجديدة جنوب غرب عاصمة ولاية قسنطينة بمسافة تقدّر بـ 15 كم (الخريطة 2).

الخريطة 1. موقع قسنطينة في خريطة الجزائر.
المصدر: http://www.4algeria.com

الخريطة 2. موقع المدينة الجديدة "علي منجلي".
المصدر: http://maps.google.com

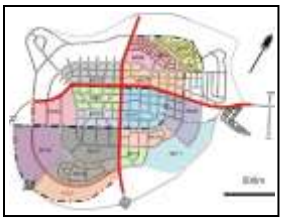
شيدت مدينة قسنطينة على صخرة من الكلس وللعبور بين ضفتي وادي الرمال الذي يقسمها شيدت أكثر من ثمانية جسور فسميت سيرتا مدينة الجسور المعلقة، المدينة الحصينة التي عرفت استقرار البشر بها منذ ثلاثة آلاف سنة قبل الميلاد لتتعاقب عليها بعد ذلك مختلف الحقب التاريخية.

في أواخر القرن العشرين، شهدت عاصمة الشرق الجزائري قسنطينة تطورا عمرانيا سريعا وعلى وجه الخصوص في الفترة الممتدة بين (1987- 2000م)، حيث بلغت المساحة المعمورة 13هكتارا وبكثافة سكانية تقدر بـ 341 نسمة في الهكتار، مقارنة مع سنة 1977م حيث كانت المساحة المعمورة تقدر بـ 2.558 هكتار والكثافة السكانية بـ 135 نسمة في الهكتار (فؤاد, 2001). وتضاعف معدل نمو السكان بعد ذلك وارتفع الطلب على السكن وقدر بـ 32000 مسكن في كل سنة، وظهرت التجمعات السكنية الكبرى والأحياء القصديرية والمباني الفوضوية والبناء الذاتي، وقد أدى انزلاق التربة الذي عرفته المدينة منذ عقود عدة إلى الإضرار بـ 000 100 مسكن من النمط الأوروبي و000 40 مسكن من النمط العثماني في المدينة العتيقة... (Foura, 2005). هذه الأسباب وغيرها دفعت إلى التفكير في بناء مدينة جديدة بدلا من تنفيذ برامج السكنات الكبرى.

حسب "مارك كوت" Marc Cote (2006) فإن إنتاج المدن المعاصرة المحققة وفقا لقرار سياسي يعتمد على أسلوبين: فإمّا نجدها مدنا جديدة تهدف إلى إعادة التهيئة الجهوية وتحقيق توازن الإقليم كبرازيليا وإسلام أباد، أو نجدها مدنا تهدف إلى تخفيف التكدس السكاني للمدينة الحضرية كمدن انكلترا. ويمكن تسجيل المدينة الجديدة "علي منجلي" ضمن الأسلوب الثاني لأنّ ميلادها كان لأجل فك الخناق على المدينة الأم "قسنطينة".

وقد برمجت المدينة الجديدة "علي منجلي" بالجهة الغربية من هضبة عين الباي، على مساحة بلغت 1500هكتارا، حيث تتوسط مثلثا ديناميكيا للمدن التوابع، قمة هذا المثلث تسمى "ديدوش مراد" وقاعدته مدينتي "الخروب" و"عين السمارة" كما هو موضح في الخريطة 2. تحتل المدينة الجديدة "علي منجلي" الموقع الاستراتيجي بالنسبة لمحاور الطرق الثلاثة: الطريق الولائي (رقم 101)، و الطريق الوطني (رقم 79)، و الطريق السريع شرق – غرب المار بشمالها كما هو موضح في الخريطة 3. كما تتخذ المدينة الجديدة الشكل الشطرنجي من خلال تقاطع و تعامد الطريق الولائي (رقم 101) المتجه من الشرق نحو الغرب مع الطريق الرئيسي المتجه من الشمال نحو الجنوب، و الممتد بدوره ليصل الطريق السريع (شرق-غرب)، ومن هذا التقاطع يتشكل المركز الرئيسي والذي يشمل بدوره المركز الحضري والتي تنتظم حوله الوظائف الحضرية للمدينة الجديدة "علي منجلي"، كما هو موضح في الخريطة 4.

الخريطة 3. علي منجلي والمحاور الولائية.
المصدر: Marc cote, 2006, p58



الخريطة 4. البنية المجالية لعلي منجلي.
المصدر: Said Mazouz, 2013

الصورة 1. نهج لعلي منجلي.
المصدر: الباحثون, 2015

وبالمقارنة مع التجارب العالمية للمدن الجديدة في إنكلترا والسويد وغيرها، اعتمد التخطيط الحضري لمدينة "علي منجلي" على مبدأ التنطيق المرافق للوظيفة السكنية المسطرة لوحدات الجوار المحيطة للأحياء الخمس، حيث قسمت المدينة إلى عشرين وحدة جوار مرقمة بالترتيب من 1 إلى 20 ومتجاورة الواحدة تلو الأخرى والمتباينة بمقاسها وأشكالها (U.R.B.A.C.O, 1994). وطبق مبدأ التسلسل الهرمي لكثافة الأنسجة، إذ نجد كثافة قوية على مستوى المراكز وكثافة متوسطة في المناطق المحيطة بالمراكز وكثافة ضعيفة على المحيط، أما المركز الحضري الممتد خطيا على الطريق الولائي رقم (101) والذي يشمل مختلف الوظائف المتنوعة (سكنية وإدارية واقتصادية واجتماعية ...) فهو يمثل القلب النابض للحياة الحضرية في هذه المدينة الجديدة (Foura, 2005).

3. مشكلة ومقترح الدراسة

يعتبر التخطيط الحضري الخاص بالمدن الجديدة تحديا كبيرا للمخططين والمصممين على حد السواء لما يحمله من مباحث ومطالب عديدة تتعدى البعد الشامل وتتعدى أيضا البعد التفصيلي إلى جدلية المتغيرات السلوكية للإنسان وإسقاطات اختيارات استخدام هذا الأخير للفضاء. مدينة "علي منجلي" كواحدة من المدن الجديدة التي لجأت إليها الجزائر سريعا لفك الخناق عن المدينة الأم "قسنطينة" تعرف الآن رغم عدم انتهاء تنفيذ كل مخططاتها الحضرية عدة مشاكل على صعيد النقل والسكن والتجارة وغير ذلك، ومرد ذلك كان الاستعجال في دفع التخطيط الحضري نحو التنفيذ دون وضع آليات دقيقة لتقييم المنتوج التخطيطي النهائي ما قبل الإنجاز والشغور والاستخدام الانساني، مما انعكس سلبا على الرفاه المنشود من طرف المواطنين، وخلق مشكلا حقيقيا يتمثل في مواقع تستقطب الفعل والسلوكات الإجرامية، كان بالإمكان تفاديه لو تم تحليل المخططات الحضرية باستخدام آلية حاسوبية ناجعة تتمثل في خريطة الرؤية المنبثقة من نظرية التركيب المجالي، فما يمكن اعتبارها قابلة للقراءة هي الثوابت البصرية المشتركة لدى البشر، والتي منها يمكن الانطلاق لتحديد مكامن النقاط الساخنة والنقاط الآمنة في المحيط الحضري للمدينة، ومنها يمكن خلق فضاءات آمنة بل بالأحرى فضاءات قابلة للدفاع.

4. دراسات سابقة

مثلت المدن الجديدة عبر التاريخ في شتى بقاع العالم الشغل الشاغل لسياسات العمران، واكبتها نظريات عديدة وطرق مختلفة لأساليب التخطيط العمراني ما فتئت أن تتجدد كل ما استجدت معطيات الزمان والمكان ومتطلبات واحتياجات الأجيال المتوالية. دراسات عديدة تطرقت لمشاكل تداعيات التخطيط الحضري بعد تنفيذها اخترنا منها تلك التي لها صلة بموضوع دراستنا وهي الآتية:

- دراسة Claudia و Andreas (2011) بعنوان:

"Strategic Planning and Design with Space Syntax"، الدراسة تهدف إلى فتح آفاق التخطيط الاستراتيجي بناء على النمذجة والمحاكاة، وأثبتت أن مقاربة التركيب المجالي أضافت قيمة دقيقة للتخطيط الاستراتيجي والتصميم الحضري تمكّن من الوصول إلى بيئة مستقبلية مستدامة.

- دراسة Kayvan (2012) بعنوان:

"A configurational approach to analytical urban design: ‘Space syntax’ methodology" الدراسة تبين أنّ السياق التصميمي الحضري يمكن تعزيزه بأساليب التحليل بواسطة التركيب المجالي الحاسوبي وذلك في مراحل معينة من عملية التصميم. من شأن ذلك أن يساعد في التقييم الموضوعي الآني لمخرجات التصميم ويساعد أيضا في تطوير حلول التصميم وبالتالي يقلل من خطر الفشل أثناء عملية تصميم أو تنفيذ المشروع.

- دراسة Said (2013) بعنوان:

"Fabrique de la ville en Algérie et pérennisation d’un modèle: Le cas de la nouvelle ville Ali Mendjeli a Constantine" بينت الدراسة بناء على الخريطة المحورية وقيم الإدماج الشامل والوضوحية وتوصل الباحث إلى انتقاد المركزية التي خلقت لاتوازنا حضريا ومناطق منعزلة تحمل صفة الخطورة.

- دراسة Tim (2014) بعنوان:

"Space Syntax a SMART approach to urban planning, design & governance" بينت الدراسة أنه من خلال الاستشعار والاستشراف ورسم الخرائط والتحليل والتفاعل والاختبار يمكن فهم التركيبة الحضرية الواجب تصميمها، وقد ساعد التركيب المجالي الحاسوبي سواء كان في البعد الثاني أو الثالث في الوصول لأرضيات لاتخاذ القرارات التخطيطية.

- دراسة Alford (1996) بعنوان:
"Crime and space in the Inner City"، تعتبر أولى الدراسات التي تعنى بعلاقة الجريمة بالفضاء داخل المدينة وذلك باستخدام مقاربة التركيب المجالي الحاسوبي. قامت الباحثة بدراسة هيئة المجال للمدينة الداخلية وتوزيع الجريمة على شوارعها وعلاقة ذلك بكثافة تدفق المشاة.
- دراسة Oscar (1996) بعنوان:
"Creating defensible space"، وصل الباحث إلى أنه خلال مراحل تصميم فضاء قابل للدفاع من الجرائم لا بد من الأخذ بعين الاعتبار لمكونين أساسيين، أولهما أن يكون هذا الفضاء مرئيا من طرف الناس وأن يكون الناس مرئيين باستمرار، وثانيهما فضاء يسمح ويشجع الناس على التفاعل بالتدخل أو الإبلاغ على الجريمة حال حدوثها.
- دراسة Bowers و Johnson و Pease (2004) بعنوان:
"Prospective Hot-Spotting"، هذه الورقة تهدف إلى تطوير إجراءات التعيين الذي يسعى إلى إنتاج خرائط المناطق الساخنة المحتملة لتحديد المواقع المستقبلية المتوقعة للإجرام.
- دراسة Bill و Ozlem (2008) بعنوان:
"An evidence based approach to crime and urban design"، حسب الباحثين فإن العلاقة بين التصميم الفضائي والأمن مرتبطة بجدلية "السلامة في أرقام" Safety in numbers بتحديد "النقاط الساخنة" Hot spots في الفضاء العمراني وذلك باستخدام التركيب المجالي الحاسوبي (مركزين على علاقة العوامل الاجتماعية بالعوامل الفيزيائية المجالية).
- دراسة Bill و Ozlem (2012) بعنوان:
"Safety in Numbers: High-Resolution Analysis of Crime in Street Networks" في هذه الدراسة قام الباحثين بتحليل شبكة الطرق بلندن باستخدام مقاربة التركيب المجالي الحاسوبي بتحليل الشوارع والطرق المسدودة والفضاءات متعدد الاستخدامات ومؤشري النفاذية والكثافة وذلك للوصول إلى معرفة أنماط الجريمة في الفضاء الحضري.

5. المنهجية العلمية المتبعة

يعرف Bill (1999) التركيب المجالي بأنه أسرة من التقنيات لتمثيل وتحليل كل أنواع التخطيط المجالي، وحسب مخبر التركيب المجالي بكلية "بارتلت" Bartlett بالكلية الجامعية بلندن فإن مبحث التركيب المجالي يؤدي إلى الفهم الأساسي للعلاقة بين التصميم المجالي واستخدام المجال فضلا عن النتائج الاجتماعية على المدى الطويل. وقد تأسست مقاربة التركيب المجالي من فكرة أن المخطط المجالي يؤثر بشكل مباشر على الحركة (سواء كانت حركة ميكانيكية أو حركة مشاة)، ويؤثر على الاستخدام المجالي (فاستخدام الفضاء مرتبط بموقع هذا الأخير)، كما يؤثر على معيار السلامة (بالسماح بالتعريف بالخطر وإمكانية خلق فضاءات آمنة)، ويؤثر على قيمة الأرض (تأثير شبكة المجالات على الملكيات العقارية)، كما أنّ له دور في التقليل أو زيادة الانبعاثات الكربونية (علاقة التخطيط الحضري بالبيئة). ويمكن تقسيم المجالات إلى مجموعة مكونات يمكن تحليلها لكونها عبارة عن شبكات من الاختيارات، وتمثل على شكل خريطة ورسومات بيانية تصنّف قيم الاتصال بين المجالات وقيم إدماج هذه الأخيرة، ويمكن تلخيص المبادئ التصميمية للمجال وفق هذه المقاربة في النقطية (مجموع المساحة أو الحجم الذي يمكن رؤيته من نقطة)، والمجال المحدب (هو حيز مجال أين لا نجد أي خط بين نقطتين منه يخترق محيطه)، والمجال المحوري (هو الخط المحوري المستقيم الذي تتبعه القدمين). وتبعا لهذه المبادئ الثلاث يمكن الحصول على ثلاثة أنواع من الخرائط، أولاها تسمى الخريطة المحدبة (تحتوي على مجموعة من المجالات المحدبة)، وثانيها الخريطة المحورية (تمثل العدد الأدنى للخطوط المحورية التي تحيط بالمجالات المحدبة وروابطها)، وثالثها الخريطة النقطية (حجم المجال المرئي انطلاقا من المجالات المحدبة أو الخطوط المحورية).

باستخدام برنامج خريطة العمق Depthmap (النسخة الأصلية المجانية)، وفي إطار نظام فيديو الانتظام البياني VGA: Video Graphics Array الذي يساعد على تحقيق العلاقات التصويرية داخل المجال انطلاقا من خريطة العمق، يمكننا تحليل مخططات في البعد الثاني تم تحويلها وفق امتداد "دي إكس آف" DXF، بملئ المجالات المفتوحة لهذا المخطط بشبكة من النقاط لإيجاد المواقع المرئية انطلاقا من كل موقع نقطة في المخطط واحدة تلو الأخرى، ويستعمل البرنامج نقطة بسيطة للاختبار بانطلاق أشعة منها للبلوغ نحو الهدف، وكل موقع عبارة عن رأس، فتتشكل مجموعة رؤوس يتم حفظها. القيم اللونية في خريطة العمق المتشكل عبرها الرسم البياني يستعمل فيها مجال طيفي انطلاقا من النيلجي بقيم منخفضة عبر الأزرق والبنفسجي والأخضر والأصفر والبرتقالي والأحمر إلى الأرجواني للقيم المرتفعة. فالقيم المنخفضة تعبر عن سهولة المرور والقيم المرتفعة تعبر عن العكس (Turner and Pinelo, 2010).

لتوصيف وتشخيص حالة دفاعية المجال (قوية أو ضعيفة) من الإجرام في حالة دراستنا أخذنا بعين الاعتبار كل من المؤشرات التالية:

- الاتصالية أو الرابطية Connectivity: لقياس عدد المجالات المرتبطة أو المتصلة مباشرة بالمجال (قياس موضعي ثابت)، فقلة الروابط تدل على تدفق قليل أي مجال قابل لاستقطاب الجريمة.

- معامل التجميع Clustering Coefficient: وهو يعطي قياسا لنسبة الرؤية البينية للمجالات داخل الجوار المرئي لنقطة كيفية. عرّف على أساس أنه نسبة الرؤوس المترابطة فعليا داخل الجوار للرأس الموضعي مقارنة بالعدد الذي يمكن ربطه. فإذا وجدنا قيمة منخفضة له فمعنى ذلك أننا يمكن الوصول إليه. كما نجد بالمقابل قيما عالية لمعامل التجميع في نقاط الانعطاف أي عند الجدران أو عوائق أخرى، على المستخدم هنا تغيير الاتجاه. وهو يحمل الخاصية الموضعية. وإن كان العكس فالوصول إليه غير ممكن مما يجعله مجالا منعزلا قابلا لممارسة السلوكات الإجرامية.

- المراقبة Control: لقياس درجة مراقبة المجال للمجالات المجاورة مع اعتبار الروابط البديلة التي تمتلكها هذه المجالات، ويعتبر قياسا موضعيا غير ثابت بل متحرّك، فإن كانت قيمة المراقبة صغيرة فذلك يدل على أن المجال لا يمكن مراقبته وبالتالي يمكن أن يكون مجالا يحتمل ممارسة الجريمة فيه.

- النقطة المحدّدة للعمق Point depth entropy: تسمح لنا باستكشاف قياسات تردد توزيع الأعماق. حساب النقطة المحدّدة للعمق تؤدي إلى معرفة نفاذية الرؤية من عدمها داخل النظام انطلاقا من موقع معين. النّقطة المحدّدة للعمق هي أقل عدد للحروف والحواف التي نحتاج إليها للمرور عبرها انطلاقا من رأس إلى آخر. وهي تحمل الخاصية الشاملة. فإن كانت قيمة النقطة المحددة للعمق قوية فذلك يدل على أن دفاعية المجال ضعيفة يسمح لممارسة الجريمة فيه.

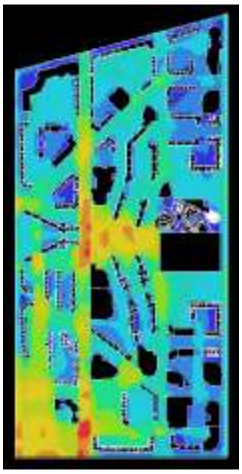
- الإدماج Integration: قياس يصف متوسط عمق المجالات، ويحدد مدى سهولة الوصول إلى جزء مجالي، وهو قياس شامل ثابت، فإن ثبت العكس فالمجال منعزل يساعد في فعل الجريمة.

6. تحليل حالة الدراسة (نموذج تطبيقي)

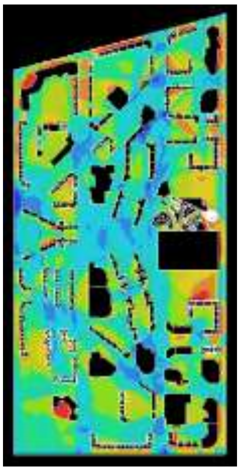
كما أشرنا سابقا، فتعتبر المدينة الجديدة "علي منجلي" تركيبة عمرانية تتكون من عشرين وحدة جوارية (الخريطة 4)، وفي ورقتنا هذه سنقوم بدراسة الوحدة الجوارية رقم 02 لاعتمادنا فرضية إجرائية تقول:

رغم أن الوحدة الجوارية رقم 02 تقع في المركز الحضري لعلي منجلي بتماسها التام مع نقطة تقاطع المحورين الرئيسيين في هذه المدينة إلاّ أنها لا تخلو من المناطق الساخنة. فإن ثبت هذا بواسطة تطبيقات خريطة الرؤية الحاسوبية رغم أن هذه الوحدة الجوارية منطقة مركزية فهذا يجعلنا تأكيد وجود مناطق ساخنة عديدة في الوحدات البعيدة عن المركز الحضري.

في الصفحة القادمة نجد الرسومات البيانية الخاصة بالمؤشرات الخمسة السالفة الذكر مع نتائج تحليلها الرقمية أسفلها:

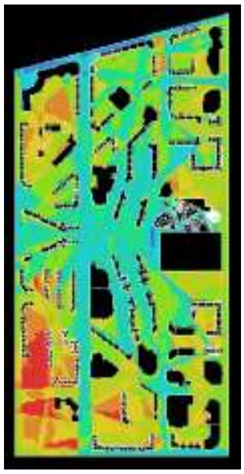


الشكل 1. خريطة الرؤية الخاصة بالاتصالية للوحدة الجوارية رقم 02. المصدر: الباحثون



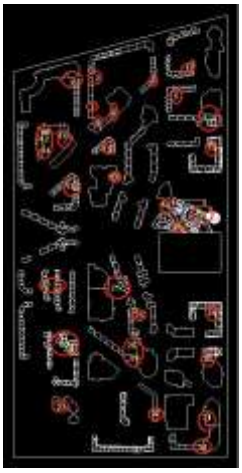
الشكل 2. خريطة الرؤية الخاصة بـ م. ت للوحدة الجوارية رقم 02. المصدر: الباحثون

الشكل 3. خريطة الرؤية الخاصة بالمراقبة للوحدة الجوارية رقم 02. المصدر: الباحثون



الشكل 4. خريطة الرؤية الخاصة بـ ن.م.ع للوحدة الجوارية رقم 02. المصدر: الباحثون

الشكل 5. خريطة الرؤية الخاصة بالإدماج للوحدة الجوارية رقم 02. المصدر: الباحثون



الشكل 6. مخطط توزيع النقاط الساخنة في الوحدة الجوارية رقم 02. المصدر: الباحثون

الجدول 1. النتائج الرقمية لتطبيقات خريطة الرؤية.

	قيم الاتصالية	قيم م.ت	قيم المراقبة	قيم ن. م . ع	قيم الإدماج
القيمة القصوى	2655	1	2,02615	1,8716	0,98835
القيمة المتوسطة	952,945	0,610843	1,00006	1,53218	0,627641
القيمة الدنيا	1	0,284453	0,009846	1,11471	0,222727

يمثل الشكل 1. خريطة الرؤية الخاصة بمؤشر الاتصالية للوحدة الجوارية رقم 02، وهو يبين أنّ المجالات الأكثر اتصالا تتمثل في الساحة المركزية والمحور الطولي الأيسر والساحة الزاوية اليسرى في أسفل الوحدة الجوارية بقيم مرتفعة أقصاها مساوية لـ 2655، وبقدر أقل المحورين المتوسطين الأيمن والأيسر والمحور الطولي الأيمن باللون المختلط بين الأصفر والأخضر بقيم مرتفعة أقصاها تساوي 2100. بينما نلاحظ أنّ هناك العديد من المناطق التي تظهر جليا أنها تحمل قيما منخفضة أدناها تساوي القيمة 1 باللون الأزرق الداكن أو النيليجي، نذكر منها الزوايا الميتة والمجالات بين الواجهات الصماء، والمجالات بشكل مثلث حاد شبه مغلق إضافة إلى المجالات الدّاخلة. أمّا القيمة المتوسطة فهي تخص بقية المجالات التي تحمل اللون الأخضر الغامق (المزرق). ويمثل الشكل 2. خريطة الرؤية الخاصة بمؤشر معامل التجميع للوحدة الجوارية رقم 02، فنلاحظ أنه يبين قيما منخفضة باللون الأزرق في نفس المجالات التي سجلت قيما مرتفعة بالنسبة لمؤشر الاتصالية لكن بقيمة دنيا تساوي 0,284453 وقيما مرتفعة في نفس المجالات التي سجلت قيما منخفضة بالنسبة لمؤشر الاتصالية لكن بقيمة قصوى فتساوي 1، وبقية المجالات فهي معتدلة (نسجل عموما قيما منخفضة في المركز التام للحلقات المبنية، وقيما مرتفعة في زواياها الداخلية التامة). أما الشكل 3. الذي يمثل خريطة الرؤية الخاصة بالمراقبة فهو يبين أن القيم المرتفعة باللون الأحمر والبرتقالي والأصفر نجدها تتموقع في نفس الأماكن التي تتموقع فيها القيم المرتفعة بالنسبة لمؤشر الاتصالية لكن بقيم قصوى تساوي 2,02615، وفي نفس الأماكن التي تتموقع فيها القيم المنخفضة بالنسبة لمؤشر الاتصالية تتموقع القيم المنخفضة لمؤشر المراقبة لكن بقيم دنيا تساوي 0,009846. ويمثل الشكل 4. خريطة الرؤية الخاصة بالنقطة المحددة للعمق التي تبين نفس توزيع القيم المرتفعة والقيم المنخفضة لمؤشر التجميع لكن بقيم قصوى تساوي 1,8716 وقيم دنيا مساوية لـ 1,11471. أما الشكل 5. الذي يمثل خريطة الرؤية الخاصة بالإدماج فهو يحمل نفس منطق توزع القيم بالنسبة لمؤشر الاتصالية لكن بقيم قصوى تساوي 0,98835 وقيم منخفضة أدناها تساوي 0,222727.

7. مناقشة واستنتاجات

المجالات التي قيمها مرتفعة فيما يتعلق بمؤشر الاتصالية تدل على مجالات تكثر فيها الحركة (تنطلق منها وإليها وعبرها الحركة)، وهي مجالات ترتبط بأكبر عدد من المجالات المجاورة، أما المجالات التي تقل روابطها بل تعتبر مناطق عبور قليلة التدفق مرشحة لأن تستقطب السلوكات السيئة مثل الإجرام، والدليل واضح رقميا إذ الفرق كبير بين القيم المنخفضة للمجالات غير الاتصالية والقيم المرتفعة لغير ذلك. وذلك تدعمه أيضا قيم معامل التجميع، إذ يظهر مبدأ التجميع من الفضاءات العامة ثم شبه العامة وشبه الخاصة ثم الخاصة، إلا أن الشكل المعماري للمباني الذي خططه المصمم خلق الكثير من نقاط الانعطاف التي خلقت بدورها مجالات منعزلة يمكن أن تحتضن الفعل الإجرامي في أي لحظة. نقاط المراقبة تظهر بشكل جلي في المجالات التي قيمها مرتفعة خاصة في نقاط التقاطع بين المحورين الطوليين الأيمن والأيسر والقطرين الأيمن والأيسر أين نجد أن الناس يمكن رؤية العديد من الأماكن كما أنّ هؤلاء الناس يمكن مراقبتهم بسهولة، أمّا المجالات التي تحمل اللون الأزرق فهي نقاط ساخنة تقل جدا فيها المراقبة (منها وإليها). ويساند هذا الاستنتاج دفاعية المجالات التي تحمل قيما منخفضة فيما يتعلق بمؤشر النقطة المحددة للعمق وضعف بقية المجالات خاصة تلك المتموقعة في الزوايا الميتة والمجالات بين الواجهات الصماء والمجالات بشكل مثلث حاد شبه مغلق إضافة إلى المجالات الدّاخلة. أمّا قيم مؤشر الإدماج تظهر أنّ الساحة المركزية والمحورين الطولي الأيسر والأيمن والساحة الزاوية اليسرى في أسفل الوحدة الجوارية والمحورين المتوسطين الأيمن والأيسر هي المجالات الأكثر إدماجا في التركيبة المعمارية للوحدة الجوارية رقم 02، والمجال الأقل إدماجا هي المجالات التي تساعد في احتواء السلوكات الإجرامية. وبتموضع خرائط الرؤية للمؤشرات الخمس يمكننا التحصل على المناطق الساخنة كما هو موضح في الشكل 6.

8. خاتمة

أسفرت الدراسة على تحديد أربعا وثلاثين منطقة ساخنة يمكن أن تكون فضاءات ملائمة لممارسة السلوكات الإجرامية، وتأتّى ذلك بمساعدة مقاربة التركيب المجالي من خلال خريطة الرؤية الحاسوبية، وهذا بناء على المؤشرات الخمس التي سجلت توافقا بينها فيما يتعلق بتوزيع تلك المناطق كل على حسب خصائصه التحليلية المجالية. بهذا نكون قد أثبتنا صحة الفرضية الإجرائية في الوحدة الجوارية رقم 02، وهذا يدعونا أيضا بالتوصية بضرورة إكمال دراسة بقية الوحدات الجوارية، مما سيعود على مستقبل المدينة الجديدة "علي منجلي" بالفائدة العظيمة، فتتفادى بذلك مشاكل مجالية قد تستقطب بشكل آلي الفعل الإجرامي، سببها التصميم التقليدي بأخطائه دون تقييم رقمي استشرافي.

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نحو تطوير مناهج برامج نمذجة معلومات البناء لمرحلة التعليم الجامعي بأقسام العمارة بمصر

محمد حسن خليل أحمد
جامعة الأزهر, القاهرة, مصر
archmoh33@gmail.com

ملخص. يهدف التعليم المعماري بشكل اساسي الي اعداد معماريين اكفاء لهم القدرة على ممارسة مهنة تشهد تطورا مستمرا وسريعاً نحو الأفضل، ويستلزم لذلك التطوير المستمر في المناهج والأدوات والتقنيات. وتناقش هذه الورقة البحثية الوضع الراهن لتدريس برامج نمذجة معلومات البناء BIM بمصر في مرحلة التعليم الجامعي مع ربط ذلك بإحتياجات سوق العمل، والذي يشهد تزايد الاعتماد على هذه البرامج والعمل بها في كافة مراحل المشروعات. لذا تبرز المشكلة البحثية في نقتطين: الأولي عدم مواكبة مناهج ومقررات التدريس للتطور الحاصل في سوق العمل على المستوي المحلي والإقليمي والعالمي. والنقطة الثانية: الحاجة الي الأستفادة من امكانيات هذه البرامج في تحليل وتقييم التصميمات في كافة المراحل المختلفة، وبما يساعد على اكساب الخريجين مهارات العمل بها في السنوات الدراسية لما قبل التخرج. وسيتم ذلك عبر المنهج التحليلي المقارن للتجارب العالمية والمحلية في تدريس هذه البرامج مع الاعتماد على تحليل الدراسات السابقة والأستبيانات والمقابلات لرصد الواقع، والذي أظهر الفارق بين التجارب العالمية والمحلية في كون التجارب المحلية تقتصرعلي المقدمات النظرية والأساسيات، بينما التجارب العالمية توجهت نحو تدريس BIM بكافة المهارات وحتى المتقدم منها. والهدف من هذه الورقة البحثية (ايجاد الحلول الناجحة لاستيعاب التطور الحاصل في نوع وكم المعلومات لبرامج BIM وما يتبعه من ضرورة تطوير المناهج التعليمية لمرحلة التدريس الجامعي).

1. المقدمة

تعد برامج التصميم بمساعدة الحاسب من الأدوات الهامة والمؤثرة علي المنتج المعماري بشكل واضح، هذا التأثير بدأ منذ أن تم تطوير هذه الأدوات في منتصف القرن الماضي كفكرة، الي أن انتشر العمل بها في وقتنا الحالي، ثم الي أن تحولت الي أداة لا يمكن الاستغناء عنها في كافة مراحل التصميم، وقد شهدت هذه الأدوات العديد من مراحل التطور بدأت بالبرامج الثنائية والثلاثية الأبعاد والتي تحاكي طرق الرسم التقليدية CAD، الي أن انتقلت الي أدوات مساعدة علي التصميم المعماري CAAD والتي بدء دمجها في مقررات التدريس الجامعي منذ تسعينيات القرن الماضي (Mandhar 2013)، وقد قام مطوروا البرامج المعمارية بتحديد هدف معين لكل نوع من هذه البرامج، فهناك برامج تساعد المصمم في مراحل التصميم الأولي عبر دراسة التكوينات الكتلية والحركة الداخلية وأخري للعناصر الأنشائية، وأخري للمحاكاة والحركة، وأخري تساعد في مراحل تطوير التصميم وتوثيق رسومات التنفيذ، وأخري تساعد في دراسة المبني بيئيا، وأخري تساعد في مراحل التصنيع والتنفيذ (Botchway, Abanyie *et al*. 2015) مما يطرح تساؤلا هاماً: هل يستلزم لذلك أن يكون المصمم ملماً بمميزات وعيوب كل برنامج؟ أم هل الأفضل أن يكون المصمم متخصصاً في برنامج معين مع تكوين فرق للتصميم تشمل أكثر من متخصص في أكثر من برنامج؟

وهو سؤال تحدد اجابته كيفية تعامل مؤسسات التعليم مع هذا التنوع من البرامج وهل تقوم بتدريس مقدمات نظرية لكل برنامج في صورة مادة مجمعة، أم تركز علي نوعية معينة من البرامج، ويبدو أن الأجابة علي هذا السؤال جاءت عبر المنافسة بين منتجي هذه البرامج، والتي تحولت الي انتاج البرنامج الذي يقوم بكافة مراحل التصميم في قالب واحد وهي برامج نمذجة معلومات البناء BIM، وفي ظل هذه المنافسة أصبح لزاما علي القائمين علي التعليم المعماري بأقسام العمارة اعادة النظر في المناهج والتدريس الخاص بكلا من البرامج المساعدة علي التصميم وكافة المواد التي ترتبط بالتصميم المعماري.

2. الدراسات السابقة

لقد قامت العديد من الدراسات الحديثة بدراسة كيفية ادماج BIM في المقررات الدراسية في العديد من الدول بطرق مختلفة منها:

1.2. تجارب الجامعات الأمريكية

تعد الدراسة التي قام بها كلا من Baridon and Santos (2010أ) من الدراسات الهامة عن تطوير مناهج BIM، حيث قاما بمراجعة برامج تدريس BIM لمرحلة التعليم الجامعي في 25 جامعة تقع معظمها في الولايات المتحدة الأمريكية، وقد استخلصا أن 6جامعات تقوم بتدريس BIM في المستوي التمهيدي، و12 جامعة تقوم بتدريس BIM في المستوي المتوسط، و7 جامعات تقوم بتدريس BIM في المستوي المتقدم. وبالنظر لتدريس BIM في المستوي التمهيدي فأشارا الي أنه لا يحتاج الي مهارات سابقة (حتى لبرامج ال CAD) أو مستوي متطور من المعرفة بالكمبيوتر وهو مناسب لطلاب الفرقة الأولي. بينما يستلزم التدريس لمستويات BIM المتوسطة والمتقدم أن يكون الطالب قد الم بالأساسيات الخاصة بطرق النمذجة والربط بين التخصصات وذلك حتي يمكنه الانتقال الي مرحلة التحليلات بأنواعها، وقد اقترح Baridon and Santos (2010ب) أن يتم تدريس BIM عن طريق التعاون مع المؤسسات والشركات التي تستخدم BIM في ربط المشروعات ببعضها البعض عبر قاعدة معلومات BIM وتبادل الخبرات والمعلومات معا، وهي تجربة مشابهة للتجربة التي قام بها Becerik (2012) حيث قام بتدريس BIM لطلاب جامعة فيرجينيا تك عبر عمل مجموعة مكونة من 11 طالب من جامعة فيرجينيا تك، و12 طالب من جامعة كاليفورنيا، وقد قامت هاتان المجموعتين بالعمل علي مشروع موحد مع تقسيم الادوار بين أفراد المجموعتين ونتيجة لذلك فقد اكتسب الطلاب مهارات تطوير المشروع عبر BIM وقد اعتمد الكورس علي مزج مشروع مادة التصميم مع ورش العمل والتدريبات الفردية والجماعية الخاصة بالتدريب علي مهارة استخدام BIM في التصميم معاً، مما ساعد علي اكتساب المهارات المتقدمة والتغلب علي تعقيدات التكوين المعماري عبر امكانيات ال BIM. دراسة حالة أخري قام بها كلا من Karen and Geoffery (2015) من جامعة Southern California بأمريكا، حيث تم تدريس BIM في صورة مادة اختيارية، وقد اعتمد تدريس المادة علي مجموعة من المحاضرين الضيوف من محترفي العمل ب BIM، ومتخصصين برمجيات، وقد اعتمد الكورس علي معرفة مسبقة من الطلاب ببرامج CAD 2d & 3D. وقد تم تقسيم مقرر BIM علي 16 اسبوع دراسي مكون من فصلين، حيث احتوي الفصل الأول (1-10 أسابيع) علي تدريس أساسيات BIM وكيفية نمذجة عناصر المبني مع التركيز علي فكرة عمل BIM في تحقيق التكامل بين التخصصات المختلفة، ثم الأنتقال الي مرحلة النمذجة والرندر والحركة وكيفية اجراء التحليلات البيئية ودراسة الأضاءة الطبيعية، ويتميز الكورس بإهتمامه بكيفية اعداد الأفكار التصميمية في المراحل الأولية Concept، وكيفية تطويرها، كما يهتم الكورس بكيفية اعداد التصميم البارمتري عبر BIM بشكل مكثف وهو ما يختلف عن

العديد من التجارب العالمية. ويهتم الفصل الدراسي الثاني (11-16 أسابيع) بتدريس مهارات متقدمة للبرنامج، حيث يبدأ بكيفية عمل Visual Scripting ثم ينتقل الي عمل Visual Scripting-Solar control ثم ينتقل الكورس الي التدريب على كيفية ربط BIM بصناعة البناء والأكواد، وقد تم تقييم أعمال الطلبة عبر ثلاثة طرق، الأولي: التمارين وتمثل 70% من درجة المادة. الطريقة الثانية: المشروع النهائي ويمثل20% من درجة المادة. الطريقة الثالثة: الحضور ويمثل 10%.

2.2. تجارب الجامعات بالمملكة المتحدة

وبمقارنة تدريس مناهج BIM في المملكة المتحدة بأمريكا الشمالية فإن هناك نقص نسبي للأدبيات ودراسات الحالة حول تطوير المناهج الدراسية والخبرات التعليمية فيما يتعلق ب BIM في مؤسسات التعليم العالي في المملكة المتحدة (Adamu and Thorpe 2015)، ونجد أن الغالب هو تدريس BIM في مرحلة التعليم ما بعد الجامعي في صورة ماجستير ولمدة عام (Mandhar 2013)، ولكن هناك بعض الاستثناءات مثل ما قام به كل من McGough and Ahmed (2013) في جامعة Coventry حيث تم دمج BIM في مرحلة التعليم الجامعي في الهندسة المعمارية والمدنية عبر مرحلتين، حيث تضمنت المرحلة الأولي لطلاب السنة الأولي وتتضمن مقدمة عن كلاً من: مفهوم برامج BIM ، ومهارات النمذجة، ، ثم المرحلة الثانية لطلاب السنة الثانية عبر تدريبهم علي مهارات التصميم والعمل التعاوني، مع تنفيذ مشروع كامل. وتسابق المؤسسات التعليمية بالمملكة المتحدة الزمن من اجل ربط مقررات التعليم المعماري BIM نظرا لأن العام الحالي (2016) هو عام تطبيق BIM Level 2 في صناعة البناء بشكل كامل، وبما يحقق مخرجات التعليم (BIMLOS) بما في ذلك تحقيق الجوانب المعرفية والفكرية والمهارات العلمية وقد وضعت خطة التنفيذ لمدة 3 سنوات بدأت من عام 2014- وحتي الأن (2016) عبر ورش عمل مكثفة وبمشاركة الخبرات العلمية المتخصصة في BIM، والممارسين المحترفين، مع دعم التعليم الذاتي وباستخدام الفيديوهات التعليمية عبر شبكة المعلومات.

3.2. تجارب بإندونيسيا

دراسة أخري قام بها Gregorius (2015م) علي قسم العمارة بكلا من: جامعة اندونيسيا والمعهد التكنولوجي بإندونيسيا، التجربة الأولي من جامعة اندونيسيا: حيث يتم تدريس BIM في صورة مادة اختيارية في السنة الثانية، حيث يهدف الكورس لتعليم الطلاب الفرق بين CAD وBIM حيث يحتوي الكورس على CAD 2D & 3D، وتوثيق الرسومات وطرق حساب الكميات والمحاكاة. ويعتمد التدريس على ورش العمل في معمل الحاسب اسبوعياً، حيث يقوم الطلاب بعمل التمارين في كلا من المعمل والمنزل، ويتم تقسيم ورشة العمل الي 3 فصول، الفصل الأول (1-4 أسابيع) يعتمد على تدريس كيف يقوم الطلاب بعمل الرسومات ثنائية وثلاثية الأبعاد بإستخدام برنامج CAD. أما الفصل الدراسي الثاني (5-7 أسابيع) يتعلم الطلاب النمذجة في برامج BIM، والفصل الثالث (8-14 اسابيع) يتعلم الطلاب كيفية ربط المشاريع مع بعضها مع التجريب على مشروع التصميم الذي قاموا بتصميمه في مادة التصميم المعماري، وهو يعد ربط بين مقررات التصميم المعماري ويساعد على اتقان التعامل مع BIM مع مهارات التصميم المعماري. أما التجربة الثانية من معهد التكنولوجيا بأندونسيا حيث تقوم التجربة على تدريس BIM في صورة مادة الزامية في السنة الثانية ويعتمد التدريس على ورش العمل في معمل الكمبيوتر ويتم تقسيم المقرر الي فصلين كل فصل مقسم الي 8 اسابيع. اما الفصل الأول (1-8 اسابيع) فيركز على تعليم الطلاب الطرق الأساسية للنمذجة، بينما يركز الفصل الثاني (9-14 اسابيع) على كيفية عمل ربط بين التخصصات المختلفة ويقوم الطلبة بتسليم مشروع في نهاية الفصل في صورة مجموعات لمشروع مجمع سكني. ويوضح جدول (1)

مقارنة بين محتوي ومراحل تدريس BIM في العديد من الدول (أمريكا– المملكة المتحدة-استراليا-سنغافورة – اندونيسيا) كتجارب مختلفة الهدف منها الوصول الي أفضل الطرق الصالحة للتطبيق.

الجدول 1. محتوي ومراحل ومستوي تدريس BIM في الجامعات *على* المستوي العالمي

اسم المؤسسة التعليمية	مرحلة تدريس المقرر	محتوي/مستوي المقرر	المصدر
الكلية التقنية مدسون (أمريكا)	مرحلة التعليم الجامعي	- مقدمة عن فكرة عمل BIM. - النمذجة والرندر - التكامل مع التخصصات الأخري. - مشروع مصغر	Barison and Santos) (2010 b
جامعة ولاية كاليفورنيا (أمريكا)	مرحلة التعليم الجامعي	-مقدمة عن فكرة عمل .BIM - توثيق الرسومات عبر BIM - المحاكاة والرندر+ الربط مع مشروع مادة التصميم	(Kymmell 2007)
جامعة ولاية بنسلفينيا (أمريكا)	مرحلة التعليم الجامعي	-مقدمة عن فكرة عمل BIM - كيفية عمل تكامل بين التصميم والبيئة المحيطة عبر نماذج BIM.	http://bim.wikispa ces.com/. 25-8-2016
جامعة ولاية كاليفورنيا التطبيقية (أمريكا)	مرحلة التعليم الجامعي وما بعد التخرج	-مقدمة عن فكرة عمل .BIM - النمذجة والمحاكاة والرندر - التحليلات المختلفة للتصميم عبر BIM - ادارة المشروعات عبر BIM - مشروع جماعي	https://www.study blue.com/notes/n ote/n/bim/deck/6 855943 . 25-8-2016
أكاديمية BCA لبيئة البناء (بسنغافورة)	مرحلة التعليم الجامعي وما بعد الجامعي، ويكون في صورة دورة مركزة لمدة 4 أيام	-مقدمة عن فكرة عمل .BIM - مهارات النمذجة المتعددة - التحليلات المختلفة للتصميم عبر BIM - مشروع فردي	www.bca.gov.sg/b im/bimlinks.html 25-8-2016
جامعة سالفورد بمانشستر (المملكة المتحدة)	مرحلة التعليم ما بعد الجامعي (ماجستير) ويكون في صورة مادة لمدة عام	-مقدمة عن فكرة عمل .BIM - أساسيات العمل ب BIM - طرق النمذجة مع ربطها مع تطوير التصميم في المراحل المختلفة. - تحقيق التكامل بين التخصصات المختلفة - الاعتماد في التعليم على مهارات البحث والممارسة مع عمل مشروع فردي وجماعي	www.salford.ac.uk /pgt-courses/bim-and-integrated-design. 25-8-2016
جامعة Glamorgan Morgannwg (المملكة المتحدة)	مرحلة التعليم ما بعد الجامعي (ماجستير) ويكون في صورة مادة لمدة عام	مقدمة عن فكرة عمل .BIM - طرق النمذجة مع ربطها مع تطوير التصميم في المراحل المختلفة. - ويتميز الكورس بتركيزه على تحقيق الاستدامة في التصميم عبر BIM	(Mandhar 2013)
جامعة ليفربول (المملكة المتحدة)	مرحلة التعليم ما بعد الجامعي (ماجستير) ويكون في صورة مادة لمدة عام	- مقدمة عن فكرة عمل .BIM - مهارات تطوير التصميم بواسطة BIM - التحليلات الخاصة بدراسة البيئة والطاقة مع تحقيق الاستدامة. - ادارة المشروعات.	www.bimplus.co.u k/education/educ ationalcoursespos tgraduate-study-bim/ 25-8-2016
جامعة نيو ساوث (ويلز، أستراليا)	مرحلة التعليم الجامعي في صورة مادتين يقسم	- مقدمة عن فكرة عمل .BIM	(Mandhar 2013)

	عليهما مستوي إدراك المادة	- مهارات تطوير التصميم بواسطة BIM - النمذجة والمحاكاة والرندر. - تكامل التخصصات عبر تصميم موحد.	
جامعة اندونيسيا	مرحلة التعليم الجامعي، في صورة مادة اختيارية في السنة الثانية	- مقدمة عن فكرة عمل BIM. والفرق بينها وبين برامج CAD - طرق النمذجة مع ربطها مع تطوير التصميم في المراحل المختلفة. - يتم ربط مشروع مادة التصميم مع كورس BIM	(Gregorius and Tony 2015)

ويتضح من خلال المقارنة السابقة اهتمام العديد من الجامعات الأمريكية بتدريس مادة BIM في مرحلة التعليم الجامعي مع تنوع برامج التدريس ما بين تدريس BIM كمادة منفصلة وبين تدريسها مع ربطها مع مادة التصميم المعماري، وقد اشتملت معظم مناهج التدريس علي كلاً من مقدمة نظرية لفكرة البرنامج وتدريس مهارات النمذجة باعتبارها العمود الفقري لبرامج BIM والتي بناءً عليها يتم اجراء التحليلات، بينما اختلفت المناهج للجامعات الأمريكية في باقي محتويات المقررات ما بين تعليم تكامل التصميم والتخصصات المختلفة وتعليم الاستدامة. بينما تركز جامعات المملكة المتحدة في تدريس BIM على مرحلة التعليم ما بعد الجامعي، وتحديدا برامج الماجستير، مع توجه مستقبلي نحو دمج مقررات تدريس BIM في مرحلة التعليم الجامعي مع الاستفادة من تجارب الجامعات الأمريكية. في الوقت الذي ظهر فيه اهتمام كلا من جامعة ساوث ويلز بأستراليا، وجامعة اندونيسيا بدمج مقرر BIM في مرحلة التعليم الجامعي مع احتواء مقرراتهما علي أهم مهارات BIM خاصة في مرحلة التصميم الاولي والتطبيق على مشروع مادة التصميم.

3. تطبيق BIM في الجامعات المصرية:

1.3. نطاق البحث:

لقد تم تقسيم العينة الدراسية بناءً على دراسة اجراها الباحث والتي تبين من خلالها أن هناك اختلاف بين المقررات في الجامعات الحكومية والخاصة من حيث محتوي ومدة وطريقة تدريس BIM. وتتمثل العينة الدراسية في ثلاثة جامعات حكومية وثلاثة جامعات خاصة (من أقسام العمارة الرائدة في مصر)، وهي كالتالي:

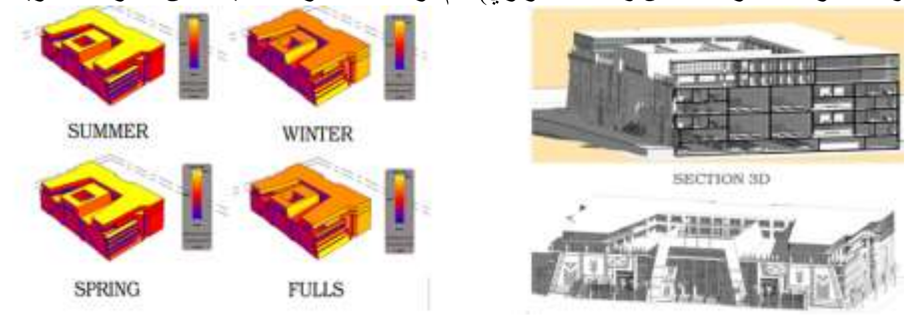
- قسم العمارة – كلية الهندسة – بكل من: جامعة القاهرة، وجامعة عين شمس، وجامعة الأزهر (جامعات حكومية تقع في العاصمة).
- قسم العمارة – كلية الهندسة – بكل من: الجامعة الأمريكية بمصر، الجامعة البريطانية بمصر، والكلية الكندية بمصر (جامعات خاصة تقع في العاصمة).

2.3. طرق تدريس BIM بالعينة الدراسية:

اظهرت الدراسة أن هناك اختلاف ما بين تجارب الجامعات (بنطاق البحث) في تدريس BIM وفقا لخطط التطوير في كل جامعة، فنجد في تجربة جامعة القاهرة أنه نظرا لان قسم العمارة بجامعة القاهرة قد نال اعتماد الاتحاد الدولي للعمارة UIA التابع لمنظمة اليونسكو لمدة 3 سنوات، وهو ما دعي الكلية الي دمج وتطوير العديد من المواد المتوافقة مع تطور منظومة التعليم المعماري عالميا، وكان من ضمن المواد التي ادمج في تدريسها برامج BIM ثلاثة مواد، المادة الأولي هي Knowledge Based Systems ويتم فيها تدريس BIM ومهارات النمذجة والتصميم البارامتري عبر الربط ببرنامج Dynamo. أما المادة الثانية فهي مادة Building Construction 3 and 4

حيث يتعلم الطلاب كيفية حل المشاكل الانشائية بالاستعانة بالمميزات التي تتيحها برامج BIM مع ترك الحرية للطلبة لتسليم مشروعات المادة ب BIM أو بالطرق التقليدية، أما المادة الثالثة فهي Smart Buildings، ويتم فيها تدريس مهارات التكامل بين التخصصات المختلفة وطرق ادارة المنشآت عبر BIM، ويتم فيها التعرف علي البرامج التي تعمل كـ Plugins مع BIM. ويعتمد نظام التدريس في المواد الثلاثة على كل من المحاضرات النظرية مع التطبيق عبر ورش العمل. وأظهرت الدراسة أن 60 % من الطلاب يستخدموا BIM في مشروعاتهم.

بينما نجد في تجربة جامعة عين شمس أن تدريس المادة يعتمد علي دمجها ضمن مقرر مادة تطبيقات الحاسب الالي حيث يتم تناول المادة من الجانب النظري في صورة 4 محاضرات لمدة 4 اسابيع ويأتي تدريسها في السنة الثالثة، الا ان المشكلة التي تواجه تطوير المناهج بها هي اللوائح التي تعتمد علي خطط سابقة خاصة بالجودة، ومع ذلك فهناك خطة لتدريسها في المستقبل كمادة مستقلة بدأ من السنة الثانية مع تطبيق مشروع مصغر، وتصل نسبة تسليم الطلبة لمشروعاتهم بواسطة BIM من 60: 70 %، كما وجد من خلال الاستبيان لجوء الطلاب الي التعليم الذاتي سواء عبر مراكز تدريب متخصصة أو فيديوهات التعليم عبر شبكة المعلومات الدولية. وبالنظر لتجربة جامعة الازهر فنجد ان التدريس الحالي يقتصر على برامج CAD فقط، ولكن هناك خطة مستقبلية لدمج تدريس BIM في كلا من السنة الأولي والسنة الرابعة، أما السنة الأولي فسيتم دمجها مع مادة تطبيقات الحاسب كمقدمة نظرية في صورة 6 محاضرات تحتوي المهارات الأساسية للنمذجة مع تسليم مشروع فيلا سكنية. وأما السنة الرابعة فستكون في صورة مادة اختيارية تحتوي على مهارات التصميم بواسطة BIM، وقد وجد من خلال الاستبيان أن 35% من الطلاب يستخدموا BIM في كلاً من: مادة التصميم المعماري ومادة التنفيذية ومادة الانشاء المعماري، وان هؤلاء الطلاب قد اعتمدوا على التعليم الذاتي عبر مراكز التدريب والفيديوهات عبر شبكة المعلومات الدولية. ويوضح شكل(1) نموذج لمشروع التصميم لطالب في الفرقة الثالثة من جامعة الأزهر حيث قام بدراسة المشروع في كافة المراحل عبر BIM، بدءاً من تصميم الكتلة والمساقط الي أن قام بالدراسات البيئية (دراسة للرياح ودراسة نسبة الفتحات عبر الربط ببرنامج Vasari المتوافق مع BIM، واعداد دراسات حركة الشمس والحمل الحراري)، ثم دراسة العناصر الانشائية لتحقق الفكرة المعمارية.



الشكل (1). يوضح مشروع محكمة قام الطالب بإجراء التحليلات وتصميم المعالجات البيئية عبر BIM

أما تجربة الجامعات الخاصة فنجد أن أبرزها تجربة الجامعة الأمريكية والتي تعتمد علي تعليم الطلاب في مرحلة التعليم الجامعي كافة الأدوات المساعدة علي التصميم (3D Max - BIM – Grasshopper -Rhino-....) مع ربطها بكل من التصميم والتصنيع، وتتيح الجامعة أجهزة التقطيع الرقمية CNC وLaser Cutting للطلاب لتعلم تقنية التصميم والتصنيع الرقمي. ويتم تدريس BIM كجزء من مادتين تبدأ الأولي في السنة الثانية ويتم تدريس مقدمة لفكرة BIM والأساسيات، وتبدء المادة الثانية في السنة الثالثة ويتم تدريس المهارات المتقدمة ل BIM، ويتم تسليم مشروع فيلا سكنية في نهاية المادة. وتتكون المادة الواحدة من 15اسبوع ويعتمد تدريسها على

كلاً من المحاضرات وورش العمل. هذا وتعد تجربة الجامعة البريطانية مشابهة لتجربة الجامعة الأمريكية في الاهتمام بتدريس العديد من البرامج المساعدة على التصميم والتي منها BIM ويتم تدريسها في صورة مادة اختيارية في السنة الرابعة، وهناك خطة لبدء تدريسها من السنة الثانية والثالثة، وتتكون من مقدمة واساسيات النمذجة مع تسليم مشروع مصغر، وتعتمد على كلا من المحاضرات وورش العمل وعلى 12سبوع. بينما تجربة الكلية الكندية تنحصر في كونها خطة مستقبلية لدمج تدريس BIM في السنة الثالثة بدءا من العام الدراسي القادم، وستكون مادة مستقلة من 12اسبوع وستعتمد في تدريسها على مقدمة والأساسيات مع مشروع مصغر. وعلى الرغم من عدم تدريسها كمقرر الا أن نسبة الطلبة الذين يستخدمون BIM في مشروعاتهم قد وصل الي30%. ويوضح جدول(2) محتويات المناهج الدراسية للعينة الدراسية.

جدول 2. محتوي ومراحل ومستوي تدريس BIM في الجامعات المصرية

الجامعات في نطاق البحث	سنة تدريس BIM	نظام تدريس BIM	كيف يتم تدريس المادة للطلاب	مدة تدريس BIM	نسبة الطلاب الذين يستخدمون BIM في مشاريع التصميم
القاهرة	السنة الثالثة وهناك خطة لتدريسها بدءا من السنة الثانية	تدرس في مادة Building Construction، وفي مادة Knowledge based systems مع تدريس التصميم البارامتري عن طريق Dynamo	-محاضرات - ورش عمل لمدة 3 ساعات تطبيقا على المحاضرة + مشروع فردي	12 اسبوع	من 50% الي 60%
عين شمس	السنة الثالثة	تدرس في مادة تطبيقات الحاسب وتحتوي المادة أكثر من برنامج	محاضرات نظرية فقط + لا يوجد مشروع	4 اسابيع لبرامج BIM وذلك لان المادة تشمل أكثر من برنامج	من 60% الي 70%
الأزهر	في خطة التطوير أن تكون في السنة الأولي + مادة اختيارية في السنة الرابعة	في التطوير أن تدرس كجزء من مادة تطبيقات الحاسب	في الخطة أن يكون: محاضرات + ورش عمل + مشروع فردي	في الخطة أن تكون 12 أسبوع	40% ويعتمد الطلاب على التعليم الذاتي
الجامعة الأمريكية	في كلاً من السنة الثانية والثالثة، وهناك خطة لبدء تدريسها من السنة الأولي مع تدريس كافة مستويات اجادتها	مادتين مستقلتين مرتبطين معاً والهدف تعليمها كآداة يمكن استخدامها في التصميم + هناك خطة تدريسها كماجستير في خلال من 2 الي 3 سنوات	- محاضرات - ورش عمل + مشروع يتم فيه التدريب على التصميم والتصنيع الرقمي	15 اسبوع	50 %
الجامعة البريطانية	السنة الرابعة وفي خطة التطوير أن	كمادة اختيارية بهدف الاستفادة منها	-محاضرات - ورش عمل	12 اسبوع	30%

	تكون في السنة الثانية والثالثة	في التصميم			
الكلية الكندية	في خطة التطوير أن تكون في السنة الثالثة	في خطة التطوير أن تكون مادة مستقلة	في الخطة أن تكون: محاضرات + ورش عمل	في الخطة أن تكون 12 اسبوع	20: 25 %

المصدر: الاستقصاء والمقابلة مع المحاضرين والمدربين في الجامعات نطاق البحث

4. النتائج والتوصيات

بتحليل المعلومات السابقة نجد أن هناك فجوة بين التجارب العالمية والتجارب المصرية من حيث اهتمام معظم التجارب العالمية بتدريس BIM على مستويات التعليم المختلفة (مستوي المبتدئين – المستوي المتوسط – المستوي المتقدم) وذلك لأن الأستفادة الحقيقية من برامج BIM تبدأ من المستوي المتوسط، بينما نجد أن جميع التجارب المصرية ارتكزت على تدريس مقدمة لفكرة برامج BIM والفرق بينها وبين برامج CAD التقليدية، ثم تدريس اساسيات النمذجة. وهو ما يمثل مرحلة المبتدئين بينما لم تغطي معظم التجارب المستوي المتوسط والمستوي المتقدم بأستثناء تجربة الجامعة الأمريكية بمصر وجامعة القاهرة، حيث جاءت تجربة الجامعة الأمريكية بمصر متأثرة بالتجارب العالمية من حيث التوسع في تدريس BIM بدأ من السنة الثانية في صورة مقدمة نظرية مع تدريس الأساسيات مع تسليم مشروع مصغر، ثم الأنتقال الي المستوي المتوسط مع تدريس مهارات النمذجة وربطها مع مادة التصميم والتصنيع والتدريب المباشر عبر التصميم والتنفيذ والتصنيع الرقمي، وهو ما يكسب الطلبة المهارات التي يحتاجها سوق العمل، ثم الانتقال الي المستوي المتقدم وكيفية عمل ترابط بين التخصصات المختلفة وكيفية التنسيق بين التخصصات الاخري، وكيفية ادارة المشروعات عبر BIM. بينما جاءت تجربة قسم العمارة بجامعة القاهرة مختلفة من حيث التعامل مع برامج BIM علي انها وسيلة وليست هدف حيث تم دمجها في مناهج ثلاث مواد للاستفادة من امكانياتها في تكامل عناصر المشروع في اطار موحد خاصة في مادة Building Construction، الا انها ليست مدمجة في مادة التصميم علي الرغم من ان نسبة استخدام الطلبة لها قد وصلت الي60%، ولذلك توصي الدراسة بتطوير المناهج الخاصة بتدريس BIM في الجامعات المصرية لتنتقل من مستوي المبتدئين الي المستوي المتوسط والمتقدم، وعبر مواد متخصصة، و يتم ذلك عبر تدريس BIM في صورة مادتين. أما المادة الأولي فتبدء من السنة الأولي وتشمل مقدمة نظرية مع تعليم اساسيات النمذجة بالأضافة لتسليم مشروع مصغر وتتكون المادة الأولي من 12 اسبوع. ويوضح جدول(3) مقترح تطوير تدريس BIM في المناهج الدراسية للجامعات المصرية.

جدول 3. مقترح لتطوير مناهج تدريس BIM للجامعات المصرية

مستوي تدريس BIM	**المبتدئين**	**المتوسط**	**المتقدم**
التخصص المطلوب اتقانه	منمذج	محلل	مدير مشروع
محتوي المادة	مقدمة نظرية+ النمذجة بواسطة BIM + مشروع مصغر	التحليلات الكمية التحليلات النوعية (بما فيها من تحليلات بيئية) بواسطة BIM + مشروع كبير فردي	ادارة المشروعات بواسطة BIM + مهارات التنسيق بين التخصصات المختلفة + مشروع مركب + مع امكانية العمل في صورة مجموعات
المتطلبات الأساسية	ليس بالضرورة ان يكون له خلفية سابقة	ان يكون له خلفية لفكرة BIM وان يكون على معرفة بمواد البناء والتصميم المعماري	الالمام بطرق الانشاء وتكنولوجيا البناء + الالمام ب BIM مع كيفية عمل ربط بين كافة التخصصات

السنة الدراسية المقترحة	السنة الأولي	السنة الثانية	السنة الثانية

المصدر: البحث

أما المادة الثانية فيتم تدريسها في السنة الثانية وتغطي المستوي المتوسط والمتقدم معاً ويتم الأهتمام فيها بكل من مهارات التحليل ومهارات ادارة المشروعات ويتم التطبيق على مشروع كبير فردي كمرحلة أولي ثم التطبيق على مشروع جماعي عبر تقسيم الطلاب الي مجموعات ودراسة كل مجموعة لمنطقة محددة من مشروع مركب، وتتكون المادة من 12 اسبوع ويتم تقسيمها الي 6 اسابيع للمستوي المتوسط و6 اسابيع للمستوي المتقدم. ويتم تقييم مستوي الطلاب بثلاثة طرق: الأولي الواجبات المنزلية في صورة تمارين لمشروع محدد وتمثل 60% من الدرجة، والطريقة الثانية المشروع النهائي ويمثل 30% من الدرجة، والطريقة الثالثة من خلال المشاركة في ورش العمل وتمثل 10% من الدرجة.

الشكر.

يتقدم الباحث بالشكر للقائمين علي تدريس مواد التصميم بمساعدة الحاسب بالجامعات الحكومية والخاصة بنطاق البحث علي حسن تعاونهم ومشاركتهم البناءة في توفير المعلومات الخاصة بالدراسة.

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Imperial House Publishers Ltd

ISBN: 978-0-9955691-0-2