

APPLYING GENERATIVE MODELING PROCEDURE TO EXPLORE ARCHITECTURAL FORMS

ZAKI MALLASI

Perkins + Will, Atlanta, USA

zaki.mallasi@perkinswill.com

Abstract. Computer generated 3D forms using generative procedures have matured in the last decade and now considered as a tangible approach for realizing architectural design ideas. As fascinating as the approach might be, it is still lacking actual application in the early architectural design process. There are many reasons for this, among them: it has many implications over the architectural design process mainly the practicality of design during the conceptual design stage; it is cumbersome to develop construction drawings for complex architectural forms; and the necessity for producing conceptual designs quickly in less time as design requirements and decisions are constantly being changed.

This paper initially reports on a practical development of a computer program which generates architectural massing designs based on integrating forms generation technique in a design scheme. The influence for this development was inspired by Spirolaterals technique used in generating complex 3D architectural forms that are based on parametric shape configuration. The development has three goals: to review the principles for constructing generative forms in the conceptual design stage using simple CAD tools, to assist in the production of design schemes based on a few basic shapes and rules, and to explore 3D forms finding and generation without the need to write a complicated computer program that are difficult to produce by hand. The development resulted in generating an interesting number of 3D compositions. The author applied this technique to experiment during the production of a design scheme.

The paper hence describes the current development of ArchiGen tool to produce generative 3D forms utilizing ArchiCAD © GDL programming language. The tool is embedded within ArchiCAD for generating 3D shapes. One of the main features of this implementation is that users are able to sketch 2D shapes and the tool will deform its three dimensional generation. Moreover, the user being able to abstract the architectural character from the resulting complex 3D shapes. This development extends current related work by allowing

the designer to load shapes into ArchiGen which acts as vocabulary of shapes for a design scheme constraints. It is intended from this work to inspire future work focusing on using generative tools in the early conceptual design stages.

1. Introduction

The source of design inspiration and ideas for producing architectural forms is paradoxical. Designers have interpretative powers for different combination of 2D/3D shapes when considering schematic hand drawings. McFadzean (2000) confirmed that hand-drawn sketches are an important part of the whole design processes and that it involves the application of past experiences or ideas. The author reports that this process acts as a trigger mechanism for recalling previous thoughts and design marks. This 'marks retrieving' activity can be related to the designer's style and possibly identifies key elements of the design information. In this scenario, the proposition in this paper recognizes that digital design technologies using computers can permit designers to think with shapes and forms as marks to be part of the conceptual design process. Above all, there are many possibilities of finding new forms (combination of shapes) with the support of complex computational program which offers more than when working by pencil and paper.

From this stand point, a key consideration here is to exercise the exploration of architectural forms generation during the schematic design phase using shape grammar and computation. Architects among them Peter Eisenman is famous of utilizing design process (Barry, 1996) that disrupts the conventional relationships between form, function, and meaning. This process is notable in the Aronoff Center whereby the unexpected site/topological qualities are traced and transformed in a generative process (see Figure 1 below). As Zaera-Polo (1996) states, this generative process constitutes 'selections of a number of shapes from the site, transformations such as displacements and reorientation is applied, tilting of shapes, and a torquing operation is used to distort spaces'.



Figure 1. Top view of the Aronoff Center 3D model showing the result of manipulating shapes in a repetitive manner (source: Zaera-Polo, 1996)

Barrionuevo et. al. (2004) associates such ability to utilize complex mathematical algorithms resulting in several shape configurations as ‘creative triggers to empower inventiveness’. The mechanism for triggering creativity inspires the design process and can be anything: an object, geometrical combinations, spatial relationship, aesthetic, etc. Other pioneers like Lionel March confirmed that mathematical grammar and rules in shapes computation prompts surprise and serendipity (Earl, 2000). As John Frazer (1995) explained in his metaphor to describe evolutionary architecture, this complex and imaginative form finding process means:

“Using the computer - like genii in the bottle – to compress evolutionary space and time so that complexity and emergent architectural forms are able to develop. The computer of our imagination are also a source of inspiration – an electronic muse”.

The development in this paper seeks three important goals: (a) to explore and review the principles for constructing generative forms as means to fuel the designer’s creativity, (b) to provide designers with simple tool that create shapes computationally based on shape grammar and rules and (c) to explore design ideas in a creative process without the need to write complex computer program. ArchiGen is a generative application that enables designers to control the shape configuration process. In order to be able to describe this development, we first briefly discuss motivation and work related to ArchGen development. Then we will describe the basic features and structure of Spirolateral shapes used in the generative process. The next section describes the computer program development and user interface of ArchiGen. Moreover, we will present a number of example 3D forms generated using ArchiGen. The following section explores the use of ArchiGen in case study project to produce a design scheme. We include in the final part of this paper some ideas that will be subject to future development and observations about ArchiGen. In the design process, this framework presented here will take an advantage of integrating the tool within a Building Information Modeling (BIM) environment like

ArchiCAD. This framework overcomes the traditional methods that conceptual design tools are disintegrated with CAD tools for design development.

2. Motivation and Related Work

A key motivation in this investigation is to explore 3D forms generation as the result of combining basic shapes computationally and CAD programming to produce creative design ideas. At the same time, Generative Art (GA) seems as a coherent and much desirable among other approaches to produce complex 3D systems in the domain of architecture. As a result, GA and specifically 'Spirolateral' shapes creation approaches were of strong influence and are the foundation for this work. And as such, the previous work by Professor Robert Krawczyk in this area was certainly compelling to our work and it has been disseminated and implemented here. The start of this work and exploration was two years ago while working with Bond Bryan Architects in a design scheme. I had the opportunity to develop parametric 3D objects using ArchiCAD Geometrical Description Language (GDL). In the same time GDL script and user interface seems to be a suitable environment for developing a small generative program to express 3D design ideas through computer visualization.

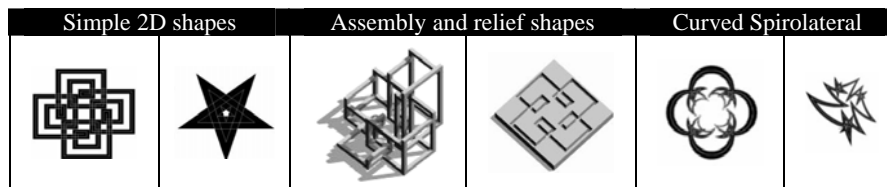


Figure 2. A variety of Spirolateral types developed by Krawczyk (2002)

As Krawczyk (2002) explained, Spirolateral geometries were first studied by Frank Odds in 1973 as a shape configuration approach to produce a variety of architectural layouts. The resulting Spirolateral shape is created by drawing a line or 2D shape such as a rectangle, this 2D shape is then duplicated and rotated a number of times with certain angles as well as gradually increasing in sizes. Previous attempts and research by added a number of mathematical sets which enriched the creation of Spirolateral shapes such as closing a Spirolateral or reversing its closure (Figure 2). In addition he added segmentation of lines, included 'turn reversal' technique and used curves to generate unique patterns. A noted set of variation was later added such as varying randomly the shape height increasing or decreasing of the Spirolateral pattern within each turn. Indeed, the user can

embed any mathematical set to alter the shape of the Spirolateral. The important observation found in his research is that GA provides designers with a process to define the raw data shapes for exploring variety of design patterns.

A very related paper in ASCAAD 2004 conference by Barrionuevo et. al. (2004) attempted to form Spirospace as extension to Spirolateral shapes. The authors developed a unique method to produce Spirospace in a computer program that draws closed or open Spirolaterals in 3-dimensional space. The method mainly transforms the rotation of Spirolateral in 3D and generates complex shape configurations. A Spirolateral shape has both mathematical and character features. The mathematical feature comprises the geometrical properties of the Spirolateral shape such as: the initial 2D shape (e.g. a rectangle), length, width, fixed or random heights, and turning directions. Then the Spirolateral shape inherits character based on the combination of patterns and repetitions made.

2.1. COMBINED DESIGN LANGUAGE

The 3D Spirolateral generation is defined by a generative design language. The vocabulary for such language combines geometrical shapes, spatial relationships, and art of surprise. The combinations of geometrical shapes are important elements because they are the initial input that leads to unfolding various possibilities of design concepts. Spatial relationships describe the intensity between the basic shapes. It can be described either: visually in terms of the shape patterns resulted or mathematically in its linear displacement, angular and 3D transformation relationship. This generative design approach will result in a voyage of exploration full of surprises – it animates emergent architectural patterns from simple forms.

The basic steps and components used to construct 3D closed Spirolateral shape can be summarized as follows and in conjunction with illustration in Figure 3 below. As a first step, a 2D parametric shape is selected depicting a favorite starting piece for generating the Spirolateral. In the second step, one module is composed of a number of pieces rotated around the center of the Spirolateral. Throughout the whole process the designer can apply either fixed or random height values for the shapes which bring complexity to the shapes. In addition, the goal in this step is to alter proportionally the width and length relationships between one shape and the following one. The third step creates a replica of number of modules and applies a rotation to produce an “element”. Once applied as shown in step 4, it permits the shape to configure rotationally and achieves the beginning of Spiro-cycle. The final two steps comprise the repetition of modules with a specific rotation angle to either create a closed or open Spirolateral.







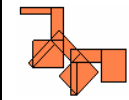


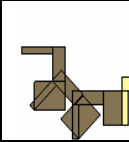
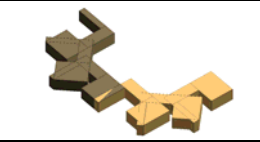

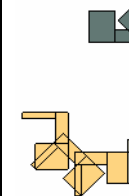

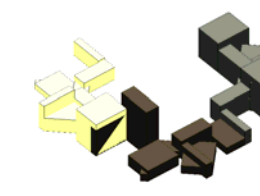
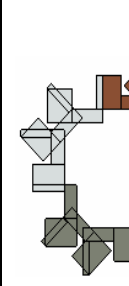

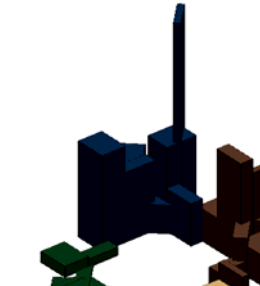
Steps	2D View	3D View (fixed height)	3D View (random heights)
Step (1) Initial Shape or piece			
Step (2) One module			
Step (3) One element (<i>open Spirolateral</i>)			
Step (4) Two elements (<i>open Spirolateral</i>)			
Step (5) Three elements (<i>open Spirolateral</i>)			
Step (6) Four elements (<i>closed Spirolateral</i>)			

Figure 2. Main steps for generating Spirolateral shapes

3. ArchiGen Tool Design

The main issue of the implementation concerns a suitable utilization of CAD modelers available in the market such as ArchiCAD, AutoCAD, Revit, Maya, 3D MAX and others that designers are familiar with and in a relatively easy manner. Gross (2001) clearly mentions that 3D CAD modelers are powerful tools but cannot generate complex and parametric algorithmic 3D forms. In fact, “some forms just can’t be done” as he explains. In addition, Gross distinguishes between two methods to generate 3D forms algorithmically: (1) one that uses scripting languages (internal

programming) within CAD modelers such as VBA, GDL, and MAX Script that are easy to learn, and (2) high-level programming (external) languages such as C and Java but require advanced programming skills to learn.

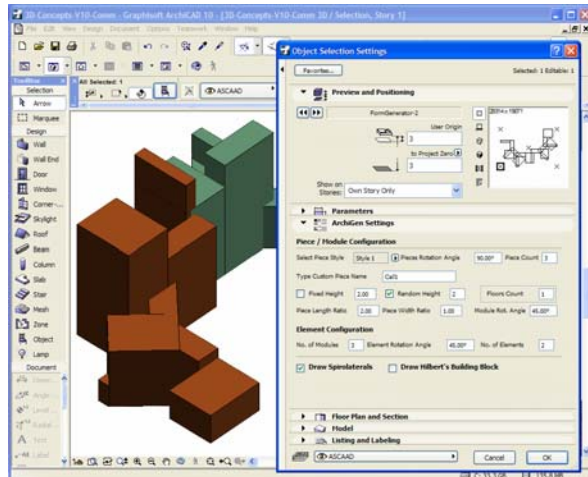


Figure 4. ArchiGen tool developed as one GDL object embedded in ArchiCAD environment

The CAD modeler used in this work is ArchiCAD that includes an interactive GDL scripting environment. The ArchiGen tool considers that basic 3D forms will be generated in BIM environment like ArchiCAD. Hence, it adds an important feature to this work where generative forms are to become integrated and part of the design development stage. There seems to be an exciting opportunity for the constant exchange between complex geometry generated and its development into a real product (i.e. building). GDL scripting allows the design of ArchiGen as one GDL component (or parametric object) with a friendly graphical user interface (GUI) as shown in Figure 4 above. The designer chooses the basic starting 2D shapes and interacts with the Spirolateral parameters to generate shapes for their own purpose and style. Furthermore, the designer is capable of altering these parameters and at the same time will have the capability to view basic architectural drawing information such as: plan, elevations and sections (Figure 5, a) in the standard ArchiCAD viewer. It is important to note that the actual GDL program code is hidden from the designer.

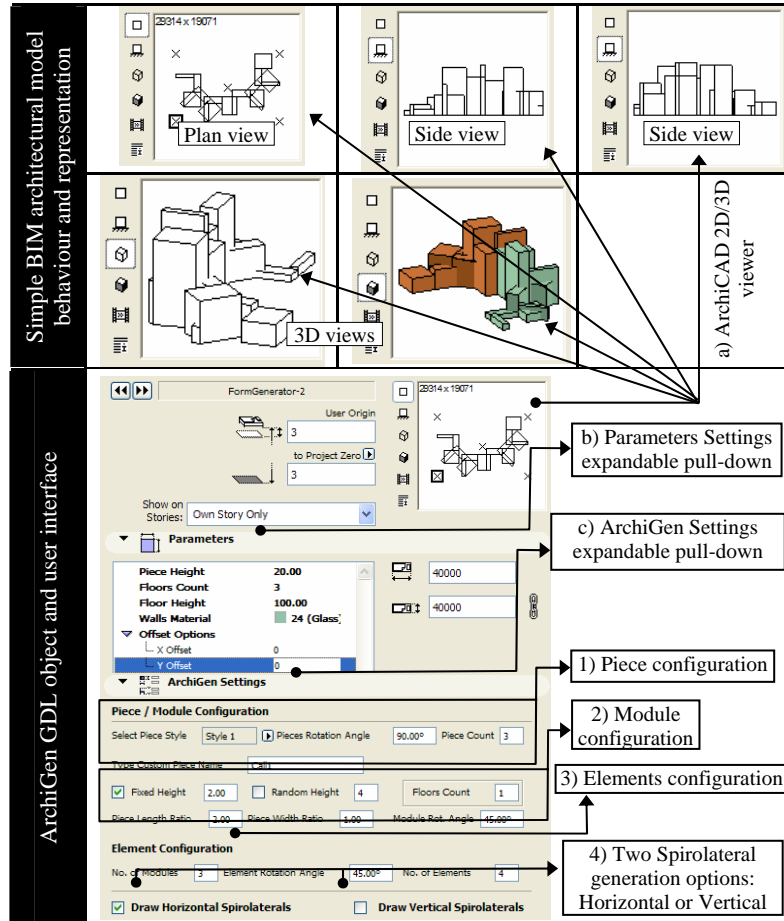


Figure 5. ArchiGen user interface and main components

3.1. USER INTERFACE AND MAIN PARTS

The ArchiGen interface is presented above in Figure 5 showing its three major parts. The interface is designed to allow user interaction with the tool in an easy process. Mainly, these three parts and their sub-user interface elements support a powerful process to generate Spirolateral-like 3D forms. The first upper part of the interface (Figure 5, a) is the standard ArchCAD 2D/3D viewer that permits the user to have a preview of the forms generated.

This second middle part (Figure 5, b) of the user interface is the 'Parameters' expandable pull-down page. Typical general parameters are

like the piece height and the Spirolateral material. Typical specific parameters include:

- **Floors count & floor height:** those parameters are used to construct 3D Spirolateral. It is a new feature embedded here to give vertical identity to the forms generated. In many ways, it is similar to establishing a number of levels in the generated form as analogy to building floors. Figure 6 below illustrates a sequence of form variations and different shape configuration of vertical Spirolateral as result of changing the input parameters.

1) 1 No. of floors, 5 units floor height	2) Offset 3 units in -X direction	3) Offset 5 units in Y direction	4) 2 No. of floors, 5 units floor height, 0 offset in X/Y	5) 2 No. of modules at 45° rotation	6) 4 & 3 No. of elements at 90° rotation
a) Rectangular starting shape parameter: 2 pieces at 90° rotation, 1 unit piece height, and 0 No. of floors					
b) Circular starting shape parameter: 2 pieces at 90° rotation, 1 unit piece height, and 0 No. of floors					

Figure 6. Floor count and floor height parameters showing different rotation angles and offsets

- **The X/Y offset options parameters:** facilitates the form creation process with important spatial relationship and in a way to spread the pieces either in X or Y directions. This technique permits horizontal spatial translation which will affect the end shapes.

The final lower part which users will interact with most of the time is the “ArchiGen Settings’ expandable pull-down page that allows the user to configure ArchGen form generation settings (Figure 5, c). The page contains the default spatial relations for defining a Spirolateral shape in four easy sub-sections (Figure 5: 1, 2, 3 & 4): piece configuration, module, configuration, element configuration, and two options for generating Spirolateral-like shapes (either horizontal or vertical). Designers can interactively manipulate the shapes created by altering the settings of values in each sub-section. 3D models are then generated within ArchiCAD tool for visualization.

3.2. PRINCIPLE STRATEGY TO USE THE PROGRAM

Surely, running such a program that embeds parametric design procedures requires a shift in the designer's thinking as this process is 'the means' not the 'outcome'. The designer is supposed to adjust the outcome of this process to enhance and shape the architectural character of his/her heir design. A designer needs to have a clear strategy and deliberately select the initial 2D shape that has potential to achieve new forms. As shown in Figure 7, these shapes (or styles) are classified under three categories that the user selects from the 'Style' selection list: (a) predefined simple shapes such as: rectangle, circle and ellipse; (b) shapes created by the user as GDL object and loaded into the program; (c) irregular shape modeled in ArchiCAD and parametrically morphed (Para-morphed) in ArchiGen. Then the designer interacts with the design process through varying the associative parameters of the initial shape selected – some can be random like height or offsets in 3D. It is not surprising then that this dynamic interaction approach with the program is intentional production of complex 3D geometries.

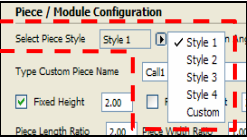




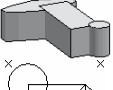





Style Selector Interface	Category (A)			Category (B)	Category (C)
	Style 1	Style 2	Style 3	User Customized	Style 4
	 	 	 	 	 
	Rectangle	Circle	Combined shapes	User created	Para-morph

Figure 7: The three initial pieces and categories in the 'Style' selector

Some examples of generated forms derived from categories 'B' and 'C' are shown in Figure 8, describing the development from an initial piece. Especially the settings generated from category 'B' - it is a new and an important feature that allows designers to load-in or use 2D/3D customized GDL objects pieces that are not included in ArchiGen 'Style' list. Then the Spirolateral mechanism is applied in a similar process using this shape to produce interesting configurations. A powerful representation of this output configuration is best communicated by illustrating the change in its characteristic during progression stages as shown in Figure 8. Forms generated from category "C" is an illustration of the unlimited and varied architectural compositions that can be constructed by assigning random heights to a morphed form. The designer with changing one of the parameters defines an extraordinary new form of sculptures. Not only that,

the process itself reconfigures a new kind of geometries around the object, not just their parametric values.

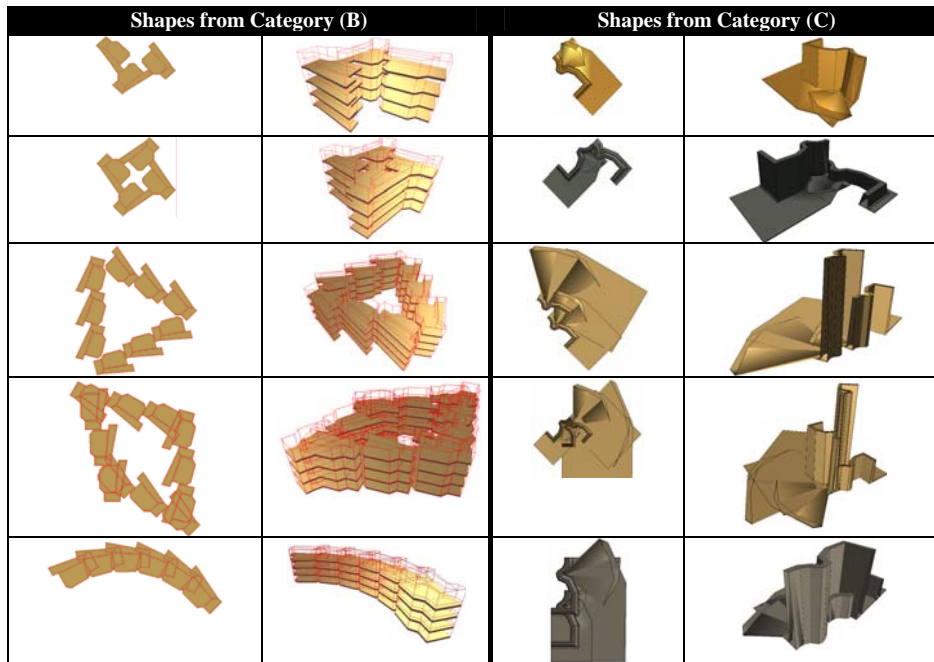


Figure 8: Top and perspective views of the variety of structures created by categories B & C

4. Implementation in Design Scheme

Architectural design is a dynamic process that demands numerous objectives to be considered. There are functional, historical, aesthetics, site constraints, and others to be taken into account before the production of an architectural artifact. Primarily, the focus when applying Spirolateral approach in this proposed design scheme is to create architectural-object recognizing some of these expectations. In addition, the transformation of conceptual forms created into BIM-recognized geometry is crucial as it leverages the integration of such complex design approach into practice.

The proposed design scheme is part of the University of Newcastle and will be integrated with the Campus Master Plan as a new gateway to the University. The site is unique and located at the Kings Walk heritage site of Newcastle (Figure 9). The site is bounded by the existing historical Haymarket area including the old library and cathedral. The design brief seeks to develop the scheme to facilitate public accessibility space through

the proposed building. The building shapes fluid boundaries to become integrated with the heritage character of that area. Among the design parameters is that the form of the building should be read as an independent structure not more than five levels, having the last floor set to the back of the front elevation. The next sections describe the phases for implementing ArchGen tool and the final architectural concept for this design scheme.

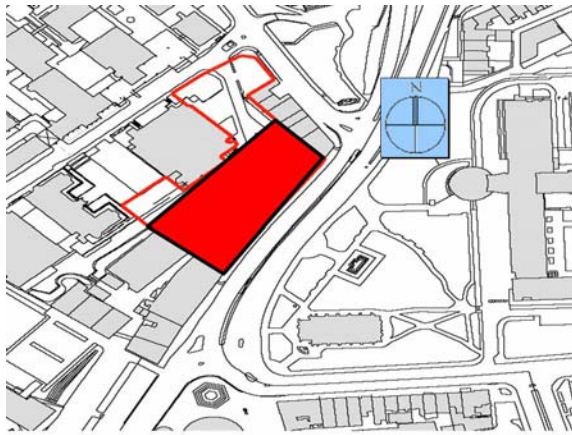


Figure 9. General site and location of the proposed project

4.1. PHASES FROM FORMING TO TRANSFORMING BUILDING FORM

This section illustrates phases for creating the design scheme form and how we transformed it into final architectural design concept. Our aim is to use ArchiGen tool as an interesting medium to inspire the designers when creating architectural forms. The four phases proposed for transforming Spirolateral initial forms are explained below to assist in the demonstrating of how ArchiGen was used to generate 3D forms.

Phase I: Initial Shape Preparation: designers start by utilizing ArchiCAD interface to prepare a base 2D shape to be used. By default, ArchiCAD saves this 2D/3D shape as GDL object and creates a 2D shape (Figure 11, a). This phase is the primary sketch pad that allows the designer to reference abstract shapes (simple or complex) as input to a generative design process. The designer then interacts with ArchiGen in a semi-automated procedure to place the initial shape within the site boundary.

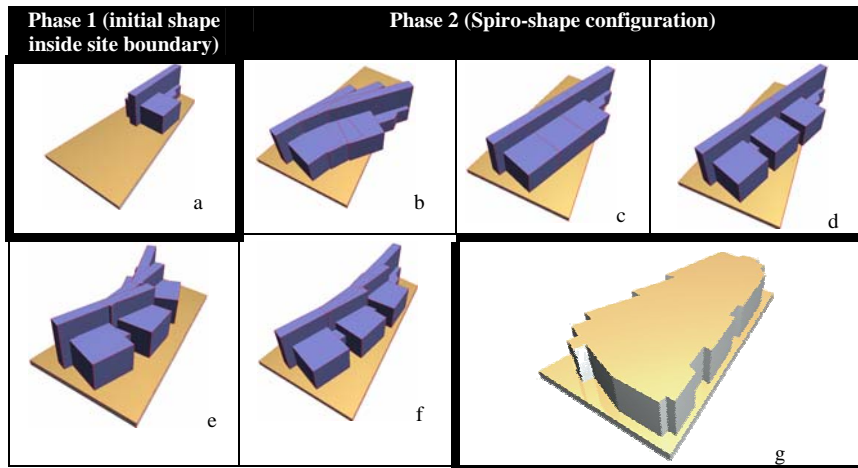


Figure 11: Phases one and two

Phase II: Spiro-Shape Configuration: the designer in this phase is mainly concerned with loading the GDL initial shape into ArchGen interface as custom shape of category ‘C’. Now the designer can start configuring the Spiro-shape by applying ArchGen generative rules such as: number of piece rotation angle, piece count, X or Y offset distances between pieces, and module rotation angle. Figure 11, b-f earlier shows the resulting final 2D shape configuration that will be used in the next transformation phases. The designer produces this final 2D shape by modifying the GDL object in ArchiCAD to utilize the available space on the site boundary.

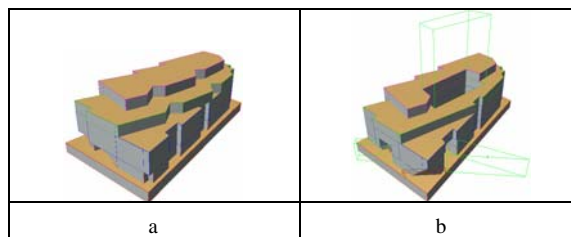


Figure 12: Transforming 3D form in phase three

Phase III: Spiro-Shape Transformation: this phase facilitates designer with an opportunity for shape re-evolution where by the designer redefines the configured shape into interpreted building form (Figure 12, a). It is important to realize that configured shapes from previous phase do not

necessarily lead to a final architectural product. For example, design brief requirement mentioned earlier are difficult to capture in the previous phase. We utilized ArchiCAD 3D modeling methods such as Boolean operations (Figure 12, b) to facilitate horizontal circulation access at the corner part of the form and internal court void in the middle. In addition, we derived level five floor plate to be set at the back from the main front elevation.

Phase IV: Final Form Recognizability: unlike current form generators, the charm of this phase is that the designer is able to use the core BIM object library available in ArchiCAD. For example, the user in this phase replaces the building form with recognized building components such as Curtain Walls in the exterior, Wall elements, Window openings, Floor & Roof slabs, and other building structure components. Figure 13, e is an illustration to explain how the overall Spirolateral form generated and how it was transformed into a recognized architectural product resembling the final design scheme.

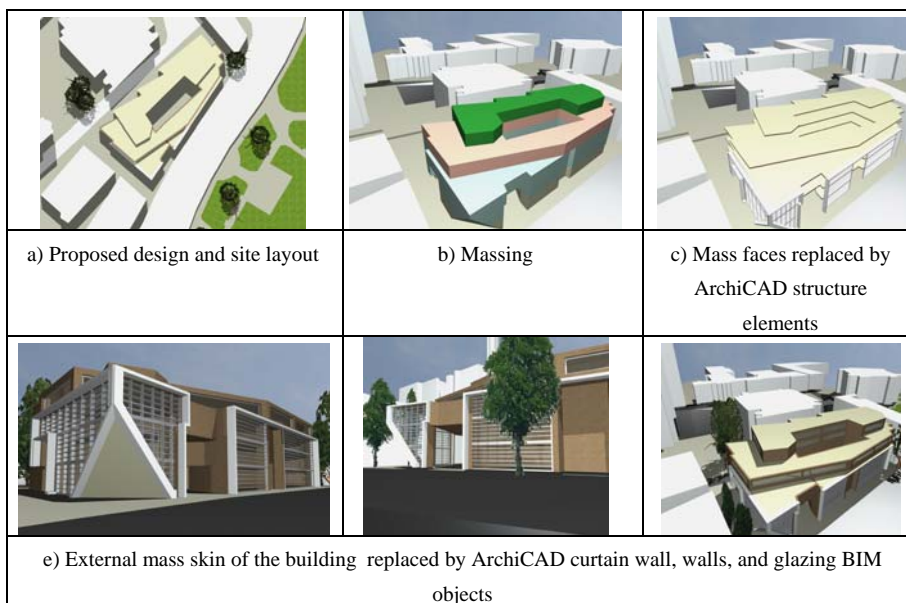


Figure 13: Transforming 3D form in phase three

5. Conclusion - Observation – Summary

Our development described in this paper was concerned with the implementation of a framework for automating the generation of architectural forms. This automation process aimed at exploring architectural

forms with the aid of CAD tool named ArchiGen. The initial 3D forms enriches the design are derived from Spirolateral shape grammar and rules. The tool developed allows the user to change the initial parameters or configurations for Spirolateral shapes to immediately iterate through different forms. The interaction with the program was via a GDL user-friendly program and the exploration of different design ideas was tremendously improved in ArchiCAD visualization.

Different challenges were facing the implementation of approach presented in this paper. The first is the formalization of the design intent using the Spirolateral generative design technique. This was somehow been demonstrated through taking initial Spirolateral shapes through four building form transformation phases. It can be argued that the design character is possibly anticipated at initial shapes(s) phases but the user changes the input parameters to result in multiple designs solutions, rather than a single one. This was one of the main challenges here as in realizing the design identity in a generative design process? The second challenge was the versatility of the computer program that diminishes the user ability for drawing limits between simple and complex designs. Unlike traditional methodologies, the computer implementation in this work is definitely one that generates complex shapes.

In spite of this, the particular usefulness of the development lies in its integrated framework of the ArchiCgen tool with ArchiCAD BIM package. It has unique role in leveraging the delivery approach of initial designs within an architectural context. The goal is on visualizing and analyzing even the 'complex' design concept to produce construction document drawings by utilizing ArchiCAD BIM environment. In other words, the designer benefits from having ArchiGen embedded within ArchiCAD working environment to produce floor plans, elevations, and section cuts through the building information model. One would hence expect an increased interest in utilizing this approach for designing irregular and complicated inspiring forms. What is crucial here for this approach to be utilized in practice is users' willingness to increase their knowledge about the theory underlying this approach. Furthermore, future designers are more becoming acquainted with computer coding that enables them to develop custom-grammar for their design.

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