GENERATING A DESIGN AUTOMATION FOR FUNCTIONAL RELATIONSHIP IN RESIDENTIAL BUILDING: DEVELOPING PLUG IN

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GENERATING A DESIGN AUTOMATION FOR FUNCTIONAL RELATIONSHIP IN RESIDENTIAL BUILDING: DEVELOPING PLUG IN

Abstract
Designers, architects, and students face many problems in finding the optimum zoning or exploring different alternatives during early design stages, which consumes time and energy. To solve this problem, a computer editing tool will be an added value that helps users at this stage. The optimization of functional relationship is very important as many factors should be considered such as orientation; vertical and horizontal relationship; areas, view, building regulations, opening to wall ratio, form-to-form relationship, spaces proportions, circulation, and other related issues. In computer generative design, recent research has reached a goal to generate functional relationship in residential buildings and others, by using spatial relationship plug in, such as ‘SYNTCATIC v-2.7’ used in grasshopper software. This plug-in considers many of the mentioned factors, however it neglects other needed factors, such as vertical circulation and corridors. This paper aims to develop and optimize functional relationships in residential buildings, through developing an existing plug in and considering some neglected factors, especially the horizontal circulation. The existing grasshopper plug in “SYNTCATIC v-2.7” will be developed, after analyzing its missing and ignored factors, to be able to help architects to take decisions for zoning in early design stages. Then this developed plug in will be tested and applied in a case study for verification. As an outcome the developed plug in will be able to facilitate architects' work, since it allows them to test various alternatives easily at the beginning of the design, to be able to select the optimum one. This enhanced plug in will consider especially horizontal circulation in residential buildings, which was neglected in the existing plug in.

Keywords
Space Syntax, Optimization, Architectural Creativity, Generative Design, Circulation

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1. INTRODUCTION

Nowadays, there is a transition from traditional tools to digital one especially in architectural field. Digital technology becomes more integrated in the lifestyle and used as supplementary tools (Manzoor et al., 2021). For example, plans and 3Ds were all drawn manually by architects at the mid of the 20th century, but recently to facilitate their works, they use digital visualization technique on computers like 3ds Max, Revit and sketchup (Zambrano Guerrero, 2020). In the future, it is expected that all design process from schematic phase till the production phase will be achieved by using digital tools, causing shorter time compared to traditional methods (Yildirim, & Yavuz, 2012), also by using this tool, users can easily interact, share and connect the data to the internet.

Currently zoning and schematic design could be done in a digital way by using many toolkits such as “SpiderWeb” (Schaffranek and Vasku, 2013), and “SYNTACTIC-v.2.7” (Syntactic, 2022) both of them are used in Grasshopper software (Associates, 2023). These toolkits need more enhancement, since some factors are neglected (Yildirim, & Yavuz, 2012). In this paper, this enhancement is explored. One of the essential architectural aspects that affects social performance of building is the spatial arrangement and analysis that should be considered during architectural design process. Both of them integrate Space Syntax theory in their methodology (Yamu et al., 2021). Space syntax is a theory, which analyses the spatial formations in numerous forms, such as buildings, towns, landscaping and architecture (Hillier and Hanson, 1984). The organization of a space differs from society to another, since each society has its own characteristics; also, spatial configuration is related to social and cultural variables. Space syntax evaluates and understands architectural zones, it is a link between research and design, also it allows architects and designers to investigate their ideas, to estimate the results of each suggested idea and how it will work (Dursun, 2007). By using this theory, architects can test their designs not just physically but also as living organism which interacts with habitants and users. This theory is applicable for urban and architectural scale.

2. METHODOLOGY

The followed methodology in this paper will start with literature review on space syntax theory, on its application and on some plug in such as “SYNTACTIC v-2.7” and “Spider Web” to understand how they work, and then collecting data to identify plug ins parameters and problems. Doing a comparison between these two plug ins to select one of them to work on its development. Then finding missing parameters in the existing plug in will be the next step, to suggest some inputs parameters, and to write script for developing existing plug in. The latest step of the methodology is testing this script and applying it on a real case study to check results.

3. EXISTING DIGITAL ANALYTICAL TOOLS

“SpiderWeb” and “SYNTACTIC-v.2.7” are two different toolkits having specific characteristics and capabilities. The first toolkit is used in parametric modeling for urban or architectural scale (Tanzer, 2021),” it depends on some restrictions, which include geometrical and dimensional restrictions. Geometrical restricts are controlling object-to-object relationship, while dimensional restricts are controlling objects distances. The uses of this tool help architect to take decisions in early design stages when the final layout is still unknown (Schaffranek and Vasku, 2013). The “SpiderWeb” works in “Rhino”, which is recently integrated in architecture (Schaffranek and Vasku, 2013). Depending on some inserted inputs, this toolkit analyses and presents many graphs as illustrated in Figure1, such as graph from point, which generates graph based on several points, and graph from data tree that makes graph from special data structure within grasshopper. Also, there is a breadth first search graph that works on a given graph from a starting point illustrated as node, to have accessibility to all nodes from this root node, and shortest path between points, which is related to the shortest path between each pair of specified starting points. In addition to several graph such as dual graph, visual graph grid, and others. In case of several results, all of them are calculated. Also, “SpiderWeb” permits bringing some measurements from “depthmap x” to “Grasshopper 3d” (Mehta, 2022). By mixing space syntax and human behavior in this toolkit, many scenarios could appear and many solutions could be explored, which
will help to choose the optimum one, as illustrated in Figure 2. However, user should know some mathematical theories to have accurate results and alternatives (Schaffranek and Vasku, 2013).

Fig. 1: Shows background Rhino viewport. Graph representation of the neighborhood relations between different rooms (source: Schaffranek and Vasku, 2013)

Fig. 2: shows multiple runs for way finding, from point A to point B (source: Schaffranek and Vasku, 2013)
The second digital toolkit is used also in parametric modeling but just for architectural scale. It is filling the gap between a theory of architecture called space syntax and architectural design practice (Nourian, Rezvani, & Sayirildiz, 2013). This toolkit is exploring automatically many possibilities of zoning referring to the same connectivity represented in a bubble diagram (Nourian, Rezvani, & Sayirildiz, 2013), in which zoning is represented by putting many squares and rectangular shapes next to each other, using different colors and areas to illustrate the horizontal relationship between functions as shown in Figure 3. This plug in uses an ‘interactive bubble diagram’, which is a diagram representing series of bubbles illustrating functional information, to approximately illustrates the horizontal connectivity between different functions using parameters as represented in Figure 4 (Nourian, Rezvani, & Sayirildiz, 2013). In addition, those bubbles differ in size based on the area and importance of each function, to give hierarchy in information (“What is a Bubble Diagram”, 2016). For instance, bubble diagram illustrates which spaces are more integrated or segregated, as shown in Figure 5, and this is a very important step that should be considered in early design stages.

Fig. 3: shows some factors to SYNTACTIC-v2.7 plug in when it is used in grasshopper (source: Nourian, Rezvani, & Sayirildiz, 2013)

Fig. 4: shows bubble diagrams as results of SYNTACTIC-v2.7 plug in. (source: Nourian, Rezvani, & Sayirildiz, 2013)
Fig. 5: shows a few automated justified graphs, illustrating the most integrated and segregated zones (source: Nourian, Rezvani, & Sayirildiz, 2013)

The following paragraph represents inputs that are inserted by user through using the existing plug in “SYNTACTIC –v2.7” and represents outputs of this plug in (Nourian, Rezvani, & Sayirildiz, 2013). Here are several inputs such as putting arbitrary points that represent the center of each functional space, providing for all functions list of names and areas. In addition to drawing lines between points that represent the connectivity between them, providing space syntax components, and choosing the way of visualization of the graph (Nourian, Rezvani, & Sayirildiz, 2013).

While the outputs of this toolkit are, circles around all centers depending on the areas of each space and zoning without suggesting any actual size or dimension. Orientation such as north, south, east and west, as shown in Figure 6 and rainbow colors to differentiate between functions as illustrated in Figure 7 are also other outputs of this toolkit. In addition to a list of depth maps to specify, which spaces are the most integrated and which one are the less integrated (Nourian, Rezvani, & Sayirildiz, 2013).

Fig. 6: shows some inputs illustrated in a list with different colors also it shows the link between components and orientation (source: Nourian, Rezvani, & Sayirildiz, 2013)

By using this toolkit, researcher have succeeded to analyses spatial configuration of spaces, but the phase of “the automated rectangular graph drawing” still in preliminary level as shown in Figure 7, and need more enhancement, as researcher said. In addition, this toolkit is not able to explore all possible solutions (Nourian, Rezvani, & Sayirildiz, 2013).
Fig. 7: shows a triangulation of the augmented connectivity graph, but the proportion and size of cells are not accurate and not related to the actual size. On the right, some rectangles are drawn in relation to the initial suggested bubble diagram (source: Nouri, Rezvani, & Sayirildiz, 2013).

The following table represents a comparison between the two digital toolkits to specify which one is the selected toolkit to be enhanced.

Table 1: shows comparison between two toolkits SYNTACTIC and SpiderWeb (source: author)

<table>
<thead>
<tr>
<th>TOOLKIT</th>
<th>SYNTACTIC-v2.7</th>
<th>SPIDERWEB</th>
</tr>
</thead>
</table>
| **EXISTING OUTPUT** | • Rainbow colors for functions  
• Circles for each space.  
• Orientations such as north, and south.  
• Bubble diagram  
• Illustrates graphs  
• Depth maps  
• The minimum squared error (SSR).  
• Different zoning  
(for architecture scale) | • Zoning  
• Graph from point  
• Graph from lines  
• Graph from cells  
• Dual graph  
• Visual graph grid  
(for urban and architectural scale) |
| **MISSING OUTPUT**  | • Proportion of spaces  
• Circulation and links between spaces such as corridors | • Proportion of spaces  
• Circulation and links between spaces such as corridors |
The selected tool for enhancement is the “SYNTACTIC-v2.7”, because this toolkit is more developed and related to the architectural scale. This paper will improve this toolkit by adding some important neglected factors such as horizontal circulation as shown in table 1, to generate a better “automated rectangular graph drawing”, the output after enhancement will be similar to a plan composition with corridors. Circulation is an important missed factor in the existing toolkit, since in architecture circulation means “the pathways through a floor plan”, and the successes or failures of a plan is related to the strategy of these pathways (“Circulation”, 2009), also it is defined as movement through spaces (Hamer, 2016). Planning the circulation is very important in each architectural project and should be designed from the beginning, because if the circulation is not well planned, then users feel uncomfortable during the transition from zone to another and through movement. In addition, Space’s circulation in a project is like blood circulation in the body, when the route is clear and unobstructed, circulation works best (Azzahra & Sahriyadi, 2020). Adding that circulation is applied at different scale; it could be inside building as architectural scale or around building as urban scale (Hamer, 2016). In this paper the circulation in architectural scale is the selected one, and more specifically the circulation though residential building. Notice that sometimes the circulation is interrupted by changing levels of putting certain furniture, for architectural reasons like providing a focus point for users or moving them slow down. There are different types of circulation (Hamer, 2016), that should be well understood to be enhanced, such as the following:

- **Direction of movement**: direction could be horizontal or vertical. Horizontal circulation includes paths, entries and exits. Furniture, columns and objects presented in the space, also affect this circulation. For these reasons there is a relation between furniture and the flow of the space (Ministry of Business, 2023). While, vertical circulation includes stairs, lifts, ramps and escalators. It is related to movement up and down of people in the building. This paper will enhance just the part related to the horizontal movement.

- **Type of use**: public or private, front or back of house; public circulation is representing the most easily reached area in a building, such as the accessibility to living room, salon and dining room. While the private circulation is representing the less accessible zone and the more intimate movement within the building, the one that need more privacy, for instance back door in a house (Hamer, 2016). The type of use is an important point in horizontal circulation for improving the plug in, since it is essential to know which functions are the segregated one and which are the integrated one.

- **Frequency of use**: common or emergency.

- **Time of use**: morning, day, evening, or continuous (Hamer, 2016).

In this paper, these circulation types are respected during developing the plug in, to create the ideal horizontal circulation. After doing a comparison between the two existing plug ins, and selecting one of them to work on it, and after specifying the neglected and missing factors in each one. The selected plug in to be developed will be “SYNTACTIC-v2.7”, as mentioned before. Focusing on the vertical circulation as a main factor. Now the coding for enhancing this plug in will start in the following paragraph.

### 4. CODING OF THE SUGGESTED PLUG IN

The suggested plug in is coded by using Visual Basic script known as VBScript, since it is a script language that could be used in Grasshopper, also it is easier and faster than other programing languages. The source of data input varies from 2D zoning in Rhino, and name of zones that helps in identifying each function, as shown in Figure 8, in addition to the width of the corridor, created between these zones, which is related to the type of the tested building such as residential, commercial or any other type. While the outputs of this suggested plug in are: first the corridors, which represent circulation created between inserted functions, second the new zones’ location represented by rectangular surfaces, after their relocation. Third output is arrows illustrating vectors direction of shifted zone, such as x, y or z direction. The fourth output is the areas of each zone, and the finale output is names tag of each function represented with different colors.
Fig. 8: shows a Data Flow Chart representing inputs and outputs of the suggested plug-in (source: author)
4.1. Testing the Suggested Plug in

The following steps are considered in grasshopper, during scripting the suggested plug in, as shown in Figure 9, which are bringing zones, as rectangles representing different functions, to Rhino, for example the entrance lobby, salon, room1 and room2. Notice that these rectangles could be taken from the output of the existing plug in “SYNTACTIC-v.2.7”, which transforms a given bubble diagram to a rectangular zoning, but unfortunately this plug in is not accessed for certain limitations. The other step is defining these zones as curves in “Grasshopper”, and then inserting VBScript from math legend, in which zones are implanted as rectangle 3d from the type tint. In addition to defining the centers coordinates of certain zones such as salon and entrance lobby, for comparing them to each other. The next step is putting condition between the coordinates of “C” center of salon and “E” center of entrance lobby, for instance if x of C is smaller than x of E then, relocate the salon zone along the X direction, but the positive one. Else, relocate the salon zone along the Y direction, but the negative one, as shown in Figure 9. Based on this condition, zones are relocated in a specific direction and distance to create corridors for circulation between functions, depending on the value inserted in the slider in grasshopper.

Fig.9: A shows the steps followed in Grasshopper. B shows the rectangles drawn in Rhino that illustrate four different functions, which are entrance, salon, room 1 and room2, after their relocation for creating corridors. C shows the commands insert to the VB (source: author)

5. CASE STUDY APPLICATION

The suggested plug in is applied on a residential case study, which is a villa located in AL Kalamoun, Lebanon. Designed by the Lebanese architect Abdel karim Baroudi. This villa is composed of two floors, but the plug in is just tested on the ground floor level of the villa, which includes entrance lobby, salon, stair, lift, office, living room, maid room and kitchen as shown in Figure 10,11.
Fig. 10: shows zoom out the selected part of the villa plan for testing (source: Karim Baroudi, 2023)

Eight rectangles, representing the mentioned functions, were inserted as inputs with their names as shown in Table 2, in addition to the width of the corridor as shown in Figure 12. During the process of the plug in, it is remarkable that the kitchen and the living room are the most segregated parts between the inserted zones, since they do not have any accessibility from the entrance. Consequently, the first output of the plug in was the relocation of the maid room along the Y direction, which is represented by a yellow color, to create a corridor for reaching the kitchen, as shown in Table 2.
Table 2: shows the zones before the movement and the results that was creating corridors after the movement (source: author)

1. Inputs, Before any spaces relocation
2. Relocated the space of maid room along the Y direction (to insert horizontal circulation)
3. Relocated the space of kitchen and living room room along the X direction (to insert horizontal circulation)
4. Creation of new zones to the existing one (for filling the dead ends of corridors)
5. Creation of horizontal circulation (corridors)

The second output was the relocation of both kitchen and living room at the same time in the X direction, for creating a corridor to reach the office, as illustrated with red color in Table2. Adding that arrows were illustrated on the center of each zone’s relocation as shown in table2. In addition, areas appear on each shifted zone, with their names represented with different colors as shown in Figure 13. The results and outputs of the testing applied on this case study, show the success of the proposed plug in, since the solution for creating a corridor by using this plug in, as illustrated in Figure13, is same as the one designed by the architect of the villa without using the plug in. Although it stills need more improvement to be more flexible in use.

Fig.12: shows the grasshopper file of the villa using the suggested plug in (source: author)
6. CONCLUSIONS

The enhancement and development of the plug in, optimizes functional relationships in residential buildings, and improves the 2D zoning in the design process in its initial stage since it considers and respects horizontal circulation, which was a neglected factor in the exiting plug in. Thus, architects can use this developed plug in to create various zoning alternatives in residential buildings and select the optimum one, considering and focusing on the vertical circulation. Also, this enhanced plug in, allows user to create corridors between spaces in residential building without consuming lots of time, which consequently helps architects in accelerating the design process, in solving horizontal circulation problems and in creating plans. Thus, architects could benefit from this digital improvement, since it gives them the opportunity to test multiple zoning and circulation alternatives between functions in their projects, also by relocating some spaces based on a specific condition, they will be able to select the optimum one.

This paper achieved the target of developing the existing plug in “SYNTACTIC-v2.7, and creating zoning in residential building respecting horizontal circulation between different functions, but some limitation was faced such as, this plug in is hardly working on organic shapes, it was just applied on rectangular or squared shapes; this phase stills in preliminary level and needs more development.

In the future, many points could be more investigated in the proposed plug in for having a better one, such as applying this plug in on different building types, and finding a method to specify automatically which zones are the more segregated one and not accessed from any corridor, to create the shortest corridor for reaching them. Also, it will be good to explore a relation between the width of corridors and the type of buildings, since residential buildings have corridor’s width range between 0.9m as minimum and 1.4m as maximum, while other types have different range. In addition to other point like finding a relation between the number of users and the width of the corridor width.
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