GRAPHICAL VISUALIZATION PRINCIPLES FOR MAINTAINING FUNCTIONAL RELATIVITY OF SPACES DURING ARCHITECTURAL DESIGN

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ABSTRACT

Maintaining the functional relativity of spaces during architectural conceptual design phase is difficult when performed manually specifically while facing a huge amount of complicated relativity of spaces in more complex buildings. This paper presents a proof-of-concept model using an available Social Network Analysis (SNA) tool to facilitate spatial diagramming visualization during conceptual design phase. Utilization of SNA was examined at four incremental levels. The initial level determined the feasibility of our research while the second level focused on prioritizing values for the spaces and the relations between the spaces. The third level examined the classification possibility of architectural spatial relationships in one horizontal plan. The fourth level examined if we could develop multiple layers that are connected by one common connector. We intellectually validated our research by comparing our model with another manual diagram by Nooshin (2001). We expect our study to provide us guidelines in developing prototype for a spatial diagramming tool using SNA, which architects can use to maintain the functional relativity of spaces through a pre-defined matrix.

Keywords: *Social Network Analysis, Architectural Spatial Planning, Architectural Conceptual Design, Maintaining Functional Relativity.*

1. INTRODUCTION

Architectural design process is initiated with the conceptual design phase alternatively called the schematic design progress. Conceptual designing is the phase where designers develop several alternative schemes before proceeding further into design progress. Designers proceed by iteratively changing their spatial layouts to obtain the best result for their conceptual idea (Lawson, 1990; Schon, 1983; Bilda, *et al.*, 2006). Spatial diagramming helps architects to embrace the overall design concept while ensuring the functional arrangements of those spaces are met. However, it is quite a challenge trying not to change any spatial relationships while reworking on a new spatial arrangement. Alternatively, maintaining the functional relativity of spaces based on the architectural rules and the architects' own ideas is the most important aspect of architectural spatial planning. This research believes that successfulness in automation of the architectural spatial planning progress will eventually affect the overall conceptual design stage. Moreover, maintenance of the functional relativity of architectural spaces during the spatial diagramming procedure results in preparation of a much more accurate schematic design process; thus, this research is focused on the architectural conceptual design phase. This study examines whether architects could use the Social Network Analysis (SNA) methodology to facilitate the rapid spatial programming activities during the conceptual design stage. SNA has been used extensively in the communication field as a set of methods for analyzing social structures (Scott, 2000). The methods specifically allow an investigation of the relational aspects (called links) between people (called actors) in the tool (Hoseini, *et al.*, 2008).

SNA is based on an assumption of the importance of relationships among interacting units (Wasserman, *et al.*, 1994). Alternatively, the basic factor that makes a society is the interaction among actors. Therefore, it is possible to swap the role of actors into functional spaces, and societal relationships into spatial relationships (Hoseini and Ibrahim, 2007; Glover and McMillan, 1985). Hence, scholars have posited that we can use SNA as a space planning tool during conceptual building design to maintain the functional relativity of spaces while evaluating various alternatives for spatial layout arrangements. Architectural spatial planning is performed through the representation of spaces and relations between them in the form of a graph.

In mathematics and computer science, graph theory is the study of graphs and mathematical structures (Biggs, *et al.*, 1986). A *graph* is a set of connections between objects. It is a set of objects called points or vertices connected by links called lines or edges, and is represented visually by drawing a dot for every vertex, and drawing an arc between two vertices (Hartmann, *et al.*, 2005). This study is concluded with guidelines on how we can use SNA as a spatial planning tool to maintain the functional relativity of architectural spaces during the architectural conceptual design phase.

2. LITERATURE REVIEW

Selected literature on SNA, architectural design progress, conceptual design process, and spatial planning are presented in this section. Here, we present a summary on how they can guide us in developing our spatial planning tool utilizing SNA. We posit that structural network between SNA nodes could replace the references to functional spaces and the relationships between them. Therefore, we could modify the visual output of structural relationships towards designing an architectural floor plan. So many endeavors have been done to explain or clarify the architectural design process and the genesis of design solutions, commencing from early 1960s (Lundequist 1992). The first generation design methodologists who work on design process as something linear are no longer taken into account (Moum, 2006). Lawson critically emphasizes that there is no obvious difference between problem and solution, analysis, syntheses or assessment in the design process (Lawson, 1997). The design is a concurrent learning process about the nature of the problem and the variety of the achievable solutions (Moum, 2006).

The design problem is not easy to define or expose. It is multi-aspect and iterative. The designer should understand what really constitutes the problem, to distinguish hierarchical relationships, to join and to combine (Lawson, 1997). Indeed, every designer operates in a virtual world, an imitated simulation of the real world in practice (Schön, 1983). Abstract physical models or the media of communication (e.g. architectural drawings) provide the designer great manipulative and instantaneously analytical autonomy without wasting time or costs. This wasting was inevitable if the ideas had to be tested directly at the building site (Lawson, 1997) thus, this research believes the designer should be facilitated with a suitable tool in order to perform the initial and crucial architectural conceptual design phase easily. However, the conventional design tools are aimed at organizing the design process in a rational and logical way, so saving more time and resources for the intuitive and creative parts of the design process (Lawson, 1997), and somehow still have significance (Moum, 2006).

Although IT/ICT provides some design mediums quite different from which contemporary designers have adopted them, however, its tools seem very close to the aforementioned goals. Moreover, to better fit in globalization tendencies, design process should change its conventional entity. This change is needed because traditional expectations of design teams are no longer in play. Current design projects are too big and too complicated for a single person—or even a small group of designers—to handle them. Moreover, due to globalization today—no matter whether these changes are desired or not—design team members are dispersed in varied locations and most importantly in different time zones. As a result, design researchers nowadays face a new challenge called Collaborative Design Process (Binder, et al., 1998).

Conceptual design phase's history goes back to an earlier stage. Yet, its importance definitely has been magnified after the emergence of current trends toward globalization (Hoseini, *et al.*, 2008). Conceptual design phase is one of the most important aspects of a design procedure. This phase has been widely placed under the distinct attention of designers. Designers interacting with computer programmers have tried to develop various tools to facilitate this phase. Having access to such computational tools will positively affect the final result of the designed project since the designer can visualize the final building before it is built.

Another helpful tool during the architectural conceptual design phase is sketching. Architectural sketching can record the possible solutions which can be the main answer to the whole project's design implementation procedure. The sketches are essential tools for recalling the available conflicts and possibilities. This study tries to focus on the very crucial and essential conceptual design phase, which strongly affects the whole implementation of a construction project. Additionally, external representation has been important to various other fields of problem solution for facilitating cognitive mechanisms (Larkin, *et al.*, 1987; Bauer, *et al.*, 1993; Hegarty, 1992). Through well developed sketching, a design project will progress successfully further onwards (Bilda *et al.*, 2006). On the other hand, spatial diagramming is the initial phase of any architectural design process. It occurs at the early conceptual phase and forms the whole design procedure. This phase is about finding the optimum solution to the design problem based on the project requirements and objectives while objective requirements are mostly impressed through various constraints (Medjdoub *et al.*, 2001). In summary, this stage of design is the most essential phase resulting in the preparation of a better facility plan layout. Therefore, the focus point of this research is on the architectural conceptual design phase. Alternatively, the idea of visualization in architecture should be extended to focus more on the crucial architectural conceptual design phase resulting in enhancement of architectural design process.

Previously, most SNA studies only looked at social structures in a selected community (such as Everett and Borgatti, 1999; Krackhardt, 1988), with more recent studies looking at knowledge transfers throughout group structures such as Levitt (1994) and Ibrahim (2005). Graph theory is strongly integrated with SNA to help its visualization and analysis procedures (Scott, 2000). Schematic architectural conceptual design follows the same rules. Various spaces of a building project and their relations are mostly represented in forms similar to basic graph theory visualizations. SNA is based on an assumption of the importance of relationships among interacting units (Wasserman, et al., 1994). Similarly, the architectural spatial planning is ultimately about spatial configurations, their connections, shapes, and the orientation of physical forms (Gross, et al., 2001). Therefore, the purpose of this study is to determine whether the architectural spatial planning could benefit from further understanding of the SNA foundations.

SNA analyzes and visualizes relations between actors of a certain network, whereas the architectural spatial planning consists of analyzing and visualizing spaces of architectural units and their relations. When swapping the functional spaces with SNA nodes, this study posits that SNA tool can be reconfigured for use as an architectural space-planning tool during conceptual design phase (Hoseini, *et al.*, 2008). SNA has applications in organizational psychology, sociology, military, anthropology, etc. (Dekker, 2002; Widmer, et al., 1999; Ellen, et al., 2001; Mendieta, et al., 1997). Although SNA has been used in a wide range of various fields, it has yet to be used as an architectural design tool. Hence, this study attempts to enhance the computational SNA tool to assist architects during the conceptual design phase for further automation of the architectural layout planning stage.

Liggett reviewed alternative formulations of the problem on how space is represented and methods of evaluating a plan (Liggett, *et al.*, 1981). Haythornwhite (1998) stated that one of the most probable ways to improve the future opportunities of the nodes in a network is to improve the information routes between the nodes. However, in this study, we considered the actors' own special properties as one of the most important factors in the network's future opportunities. The objective of our spatial planning tool is to enable designers to optimize the arrangement of functional spaces, while knowingly being assured that they will never break the preferred priority relationships between the spaces. In summary, we will illustrate the similarities between the SNA process and the architectural conceptual design phase. Respectively, we posit that the use of SNA can be extended to facilitate the design of functional spatial arrangement of a building project. Therefore, this study proposes a reconfiguration of SNA tool for use as an architectural space-planning means during the conceptual design phase.

3. RESEARCH METHODOLOGY

The use of SNA technology for facilitating the architectural bubble diagramming process had been earlier identified since 1985 by Glover and McMillan. Their study proposes that the nodes and structural relationships between the nodes in SNA have similar architectural characteristics and used the SNA centralization principle to develop relational diagramming in the conceptual phase while safely maintaining their spatial relationships to other spaces. Similar to their study, we exchanged the relations of different spaces of a building with nodes and their linkages. We also established various parameters such as the relations between the members and the priority of members' presence in the network and their relation with each other. However, our study further developed multi-layered connections between either horizontal or vertical layers. The research output will be a proof-of-concept model using an available SNA tool to facilitate spatial diagramming visualization during the architectural layout planning stage. We used UCINET version 6.26 (developed by Borgatti, Everet, and Freeman, 2002) in our study. An experimental research methodology was designed in four incremental steps in order to test the hypothetical proposition of "utilizing SNA principles for maintaining the functional relativity of architectural plan layouts during the conceptual spatial diagramming stage". Architectural plan layouts were considered as the main respondents of the study while being tested with the UCINET instrument. Respectively, the independent variable of "Maintenance of functional relativity of architectural spaces during the architectural spatial planning refinement" was tested according to the dependant variable of "Utilization of SNA visualization principles" forming the experimental set up of this research.

This computational methodology encompassing four testing levels—feasibility, prioritization, classification and multi-layering—are examined. Intellective validation approach (Thomsen, 2003) is selected in order to corroborate the legitimacy of test case results. The aforementioned computational emulation validation process is set to be examined at three incremental levels. Since these incremental levels cover the reasoning, representation and usefulness testing in sequential order, this study examines the reasoning of the proposed functional relativity maintenance guideline intellectively. Positive results of the intellective testing procedure can prove the theoretical formation of the proposed hypothesis (Thomsen, 2003).

During the data collection progress, a typical double storey residential unit was selected. Relational characteristics of architectural spaces were collected based on the relations between architectural rooms. These relational characteristics were converted into numerical values. Data was collected based on the architect's ideas, client's requirements and architectural principles. Architect would interview the client in order to discover his/her requirements such as the list of desired spaces and their respective relationships. Subsequently, the collected information is typically refined based on the architect's ideas according to architectural design doctrines. Spaces are abbreviatively represented in single capital letters such as "D" for "Dining Room". We developed a matrix consisting of information about the different nodes as the input. Here, we refer the nodes as representatives for the functional spaces. We set the matrix to *symmetric* mode because all of the relations between the spaces in a building are symmetric (two-way). A network is called symmetric when all members of that network can send and receive data at equal rates (Skiena, 1990). An architectural spatial planning database was developed and used as the input for UCINET. Nevertheless, intellective validation corroborates the legitimacy of any test case if any changes in input parameters will result in occurrence of changes in the resultant graph. Correspondingly, proper visualization and maintenance of relativity between architectural spaces with regards to the modifications made to the input parameters will be considered as a confirmation on the previously mentioned hypothesis.

3.1. Test Case I

Test purpose: To determine whether the relations between various spaces in a normal architectural residential designing project, can be represented and analyzed using UCINET or not.

Implementation: We replaced the different spaces of a normal house as the nodes of the network and documented the relationships between those spaces as the links between the nodes in the graph. We created a matrix of binary amounts. Figure 1 illustrates a step by step progress from initiation of the design process until setting and establishment of the architectural spatial relationships and their priorities. Step 1 is creating a building project while Step 2 creates the necessary floor planes. Steps 3 and 4 establish the functional spaces and the spatial relationships between those functional spaces.

3.2. Test Case II

Test purpose: To determine whether different values can be set for various nodes and vectors to show linkage and space priorities in the resulting diagram.

Implementation: Using the same matrix for test case I, we now set up a graph consisting of different link priorities and different actor sizes as the input data. In this matrix, the highest value for nodes and lines varies from '3' to '0'. Three means that the node has the highest level of importance or the linkage has the highest priority among others. Referring to Figure 1, we have incorporated the prioritizing function that would allow architects to prioritize the functional spaces and the spatial relationships between those spaces in Steps 3 and 4.

3.3. Test Case III

Test purpose: To determine whether architectural spatial relations can be classified in certain categories with same characteristics.

Implementation: We divided the spaces into certain groups such as 'public' and 'private' areas. Any group that is presented as a single node has a sub-matrix including the group details. We made a *parent* matrix (the first matrix of the hierarchical order of matrixes including the most general data) for the base and two sub-matrixes (private area sub-matrix and public area sub-matrix) for each group. In our example (see Figure 1), the "2-Storey_House" is a parent matrix where "first_floor" and "second_floor" are the two sub-matrixes.

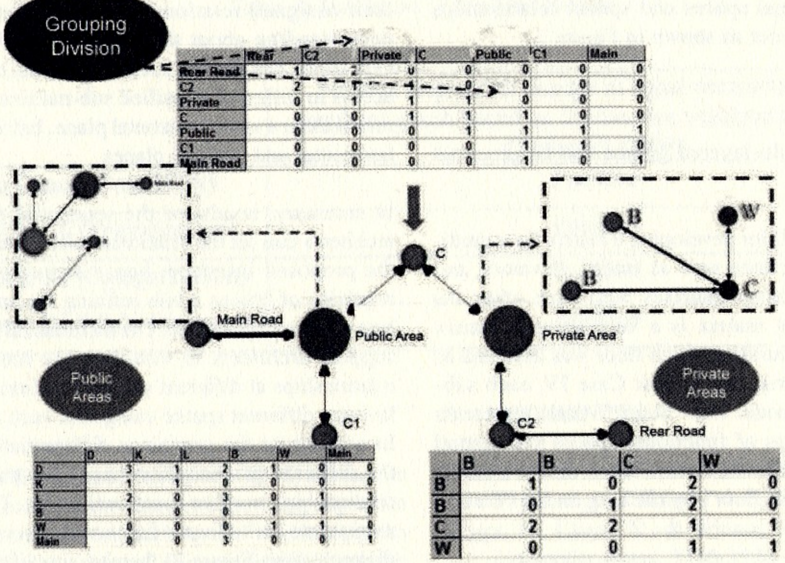

Figure 1: The incremental rapid architectural spatial planning progress.

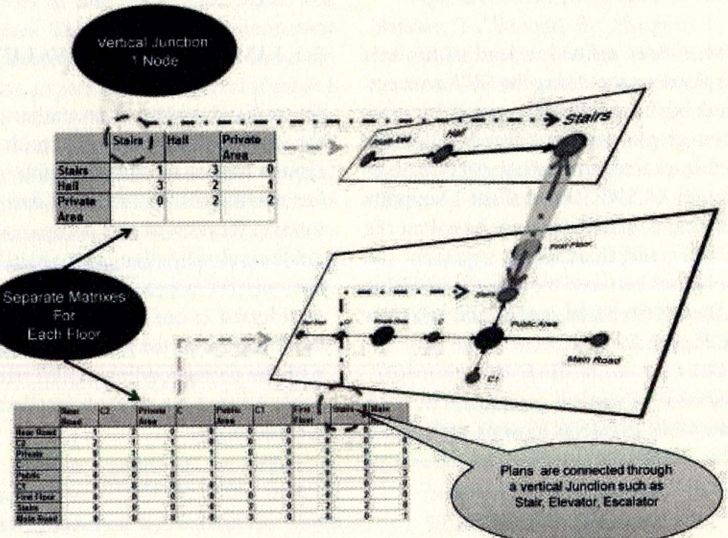

Figure 2: Architectural spatial planning progress and the corresponding graphical representation.

Each "floor" has its own set of functional spaces and spatial relationships assigned to create a different diagram layout as shown in Figure 2.

3.4. Test Case IV

Test purpose: To determine whether multi-layered graphs can be prepared through SNA.

Implementation: We extended Test Case III for developing a matrix for a multi-story building by setting the vertical junctions such as (stairs, elevators, and escalators) as a hub that connects two main matrixes with each other. As mentioned in Test Case III, The parent matrix is a very general matrix representing all functional spaces of the building. Each floor was assumed as a major group and has its own sub-matrix, but in Test Case IV, each sub-matrix group is represented by a single node. The "Stairs*" node represents the vertical connection to the two groups of functional spaces and spatial relationships that we have assigned to different floors. When the architect is on the "second_floor", he can access "first_floor" by clicking on the "Stair*" node (see Figure 2).

4. RESULTS AND ANALYSIS

The experimental protocol at four levels has been refined to lead us towards the development of an architectural layout planning tool using the SNA concept. Results of the experiment are analyzed based on intellective principles (Thomsen, 2003) where positive resultant graphs are considered validation for each Test Case. Test Case I confirms that architectural relational databases could be converted into numerical values in UCINET. Test Case I supports the feasibility of our study with an architectural spatial diagram based on the pre-defined matrix occurred. Different sizes and thicknesses represent the different priorities of the spaces and the relations between them in the resulting diagram for Test Case II. Consequently, these prioritized spaces and relations are visualized as the resultant graph (see Figure 2).

The study successfully illustrates the utilization of vertical connectors in SNA matrix development procedure that would enable architects to work with multi-layer spatial layouts. We believe that this classification of nodes in lieu of their assigned relational characteristics can provide more flexibility and understanding about the whole network of functional spaces to architects. Our study has further created vertical nodes that would allow architects to access to different classified sub-matrixes located not only for groups of sub-matrixes on a same horizontal plane, but also when they are located on different horizontal and vertical planes.

In summary, results of the sequential four test cases have illustrated how architects can set the relational rules based on the project's requirements using the proposed interface; hence ensuring the maintenance of the functional relativity of spaces while refining the space relations in order to achieve the best space compositions. The incremental process in the computational interface support architects to visualize the multiple functional nodes and spatial relationships at different categories (from different floor layouts, within room layouts, different spatial categories such as public versus private spaces, etc.). In addition to the groupings differentiation, architects are also supported by the different prioritization needs for the functional nodes and their spatial relationships to other functional nodes. The interface also allows architects to manipulate and relocate functional spaces to achieve several alternative graph diagrams (see Figure 2) thereby simplifying the architectural bubble-diagram process further.

5. LIMITATION AND VALIDATION

We utilized results of an earlier study by Nooshin (2001) which highlighted the spatial relationships in a residential building with respect to Hijab in tropical terrace houses to compare with our simulated outcomes. We had earlier used her manual results as inputs during the development of the building project's matrix. Results of the comparison validated the results of our experiment. Additional validation is provided by the intellective extent which corroborated not only the proposed theory for SNA utilization but also the success of the developed proof-of-concept in real world. Our study proofed that any modification in the input parameters for each test case had expectedly concur with the corresponding modification to the resultant visualized graph diagram. Table 1 listed the positive intellective validation for each incremental test case for this study.

Table 1: Validation of Analysis Results

	Positive respond to change of input parameters in the resultant graph based on intellective validation of results (Thomsen, 2003)
Test Case I (Feasibility)	**Positive**
Test Case II (Prioritization)	**Positive**
Test Case III (Categorization)	**Positive**
Test Case IV (Multi-Layering)	**Positive**

6. CONCLUSIONS

This paper illustrates the extension of Glover and McMillan's (1985) interactive decision software for enabling architects to make changes by moving any space on different floor plan while safely maintaining their spatial relationships to other spaces. This study claims the creation of connections that enable categorized groupings to be connected between them. The connections are established by specifying spatial connectors at one horizontal plane and especially between at least two vertical planes. The incremental examination of test cases had provided us insights to develop a computational interface and recommends further study for automating an architectural spatial planning procedure for the conceptual design phase in which maintenance of the functional relativity of spaces are critical. The computational interface also allows architects to prioritize the functional spaces and their spatial relationships. In conclusion, positive results enhanced further application of SNA graphical visualization principles for maintaining the functional relativity of spaces during the architectural spatial diagramming refinement procedure specifically allowing categorized spatial groups to be linked successfully between different horizontal planes with vertical connectors.

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