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Simulating the Architectural Design Process through Matrix-Based Method

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Abstract. Architectural design is perceived to be a complex process for architects and building design teams to deal with due to the ill-structured characteristics of design problem solving. However, it is important to establish the nature of this complexity in order to gain a better conception of the overall design process. To facilitate this, the design team must be able to decompose given tasks and activities into manageable phases of design process. It also means that interfaces between the activity phases of the design process could be explored, planned and coordinated more effectively and accurately. Modeling the design process is crucial in providing a greater understanding of the complexity of the design process thereby gaining insight into more practical methods and tools to manage it. The modeling approach must also best reflect interactions that transpire between the activities and processes of design. The current study provided this by using the DSM (Design Structure Matrix), which is a graphical model for representing information workflow and exchange of sketching activities as performed by two final year architectural students. This matrix-based method enabled us to simulate the process based on the informational relationships between activities of design as revealed by the participants' sketching actions. The study further suggests that working with the notion of informational dependency can provide an appropriate and critical basis for representing iterative behaviors in design.

Keywords: Complex Process, Design Process Management, Design Process Simulating, Informational Interactions, Iterative Behavior, Sequencing.

1. Introduction

Iteration is an inherent feature of complex activities like architectural design. This salient feature affects the flow of design process and also design's outcomes in terms of quality, cost, and time. Conversely, iteration is influenced by information exchange and interaction in design activities. Its cyclic nature gives rise to iterative behavior in designing [1] . One of the factors that impacts this iterative behavior is the sequence of activities during the flow of design information. Understanding informational relationships between these activities is vital for the effective representation, modeling and simulation of design activities and processes. Traditional representation methods like CPM, Gant Chart, PERT, Petri Net, IDEF3, and WBS (Work Breakdown Schedules) are prevalent in the process management domain. However, they are poor in simulating design processes in a way that could illustrate the effects of design cycles [2] . This is due to the fact that such methods are based entirely on workflow concepts instead of information flow. Furthermore, these methods are often used to represent sequential relationships, whereas iteration loops emanate from coupled interactions. However, more recent methods in representing processes and activities are increasingly reliant on information-based models. Potentially, they provide designers and project managers with a simple but powerful way to model complex processes in design. One of the methods discussed in this paper is the Design Structure Matrix (DSM). It is the powerful tool developed by Steward and extended by Eppinger [3,4]. DSM enables the formation of a binary matrix to represent the interaction between any two activities and reveals to its user the direction of information flow within the overall timeline of project implementation. This simplifies the representation of the relationships among activities undertaken in a project. It enables design managers to speed up the evaluation and selection of the best sequence of operation and activities, thereby allowing them to control the iterative behavior peculiar to a project [1] . This is performed by minimizing the numbers of iteration loops or the number of activities involved in an iteration loop.

2. Main Factors of Complexity the Architectural Design Processes

Using the best method in representing a complex process is considered an essential component of managing a design process. Lack of understanding about informational dependency could be one of the key factors in increasing the complexity of building design projects. Designers require a suitable method to decompose the complexity of building design process in the transparent and simple way [5].

Generally, there are three major factors that influence design process management:

- Design iterations (Design cycles)
- The sequence of activities being performed
- Informational interactions between process activities

Accordingly, the lack of understanding and consideration of the factors outlined above potentially leads to perceived ambiguity and unpredictability surrounding the architectural design process. This paper presents an in-depth study of design iteration and information interaction by exploring the impact of designers' sketching activities. The aim here is to investigate the complex nature of iterative processes, particularly in the way it influences the effective management of the design process.

3. Method and Results

For the purpose of the study, observations were conducted on architectural students performing a speculative design of an internet café at a proposed site in Universiti Teknologi Malaysia. Basic information about the project is outlined in the design brief, which includes the site plan and user requirements. The sketching process was recorded audio-visually and an interview was conducted with the designers to validate and complete the data required for this research. Finally, the data gathered from direct observation and interview methods are analyzed based on the three factors influencing design process management issues as stipulated above.

The results of the analysis as shown in the following tables illustrate various sequences in performing the design process activities. Where, you can see the designers followed different procedures in contrast to the same process of design problem solving. Nevertheless, the directions of information flows that are identified by the following table indicate that the designers' manners based on the point of view of the information dependencies are also different. Therefore, predicting the fixed arrangement for executing the process' activities in such complex processes will be nearly impossible for designers at the prior stages of the process.

Table1. Activities' Interactions (Designer 1)

	SHEET NAME													
Sheet in-hand	A	E	D	F	D	F	E	F	G	H	I	J	H	K
Resource Sheet		A,D,B,C		E(Abstract of sheet A,B,C,D)		E		E	F	F,G,D,E	H,G,B	E,D,H,I	J	H,I,J
Activities' Interactions	AC1→AC4,AC1→AC5,AC1→AC7,AC1→AC8,AC1→AC9,AC1→AC10,AC1→AC11,AC2→AC4,AC2→AC5,AC2→AC7,AC2→AC8,AC2→AC9,AC2→AC10,AC2→AC11,AC3→AC4, AC3→AC5,AC3→AC11,AC4↔AC7,AC4→AC8 ,AC5↔AC7, AC5→AC9,AC7→AC11,AC9↔AC4,AC10→AC11,AC10↔AC9,AC11↔AC4,AC11↔AC5,AC11→AC7,AC11↔AC9													

Table2. Activities' Interactions (Designer 2)

	SHEET NAME																
Sheet in-hand	B	C	D	E	F	G	H	I	J	I	J	K	J	K	J	K	L
Resource Sheet				A,D,B,C	B,C,D	D,B,C	F,G,D	G,H	I,H,D	G,H,J	I,H,D	J,D	K	J	K	J	J,K,H,I

Activities' Interactions	AC1→AC3,AC1→AC4,AC1→AC6,AC1→AC7,AC1→AC8,AC1→AC10,AC1→AC11,AC2→AC3,AC2→AC4,AC2→AC5,AC2↔AC6,AC2↔ AC7,AC3→AC4,AC3→AC5,AC3↔ AC6,AC3↔ AC7,AC3↔AC8,AC3↔AC9,AC4→AC5, AC4 ↔AC6,AC4↔ AC7,AC5↔AC7, AC7→AC9,AC7→AC10,AC9↔AC10,AC9↔AC11, AC10↔AC11

Table3. The Sequence of the Execution of Activities (Designer 1, Designer2)

	Designer 2	Designer 3
The Sequence of activities' performing	1-(1,2,3)-1-(4,3,6)-(1,2,3,5,7)-(2,3,4,5,7,8,9,11)-(4,7,9,10,11)-(4,8,9,10,11)-11-11-11	1-1-1-(1,8,10)-(1,2,3)-(2,3,4,5,6,7)-(2,3,4,6,7)-(4,5,7)-(9,10,11)-(9,10,11)-(10,11)-(10,11)

Managing complexity by modeling the process is the most important step of this study and will discussed in the next section. In fact, we intend to show you how a designer can simulate the process toward investigating the effect of these major factors on each other, and also on the whole process. In this way, we present the procedure of simulating our practical processes based on the DSM in the following.

4. Simulating the Architectural Design Process by DSM

4.1 Constructing the Matrix of DSM

To build the matrix, at first, we identify task interactions by focusing on the information flows between them. After that, we can start drawing the DSM's process.

The activities of the process are the components of the DSM's matrix. They are put in the same order at the head of DSM's columns, and also on the left side of the matrix as the title of DSM's rows. It is notable that DSM's matrix is square, meaning that there are an equal number of rows and columns.

In the next step of building the DSM, we start to fill the matrix with X-marks, which is done based on the direction of information exchange among activities. By looking down each column, an X-mark will put in the intersection of the row if the activity corresponding to that row is supplied with information gained by performing the activity corresponding to that column. On the other side, looking across each row represents receiving outputs. The element on the diagonal must be left, meaning that each activity does not require information from itself.

After completing the matrix, and because of complexity and iterative behavior that are common in the design processes, you will see some marks above the diagonal. These upper diagonal marks address feedback which corresponds to the required inputs that were not available at the right time of performing the activity. In this situation, dependent activity is executed based on assumptions regarding the status of the input activities. After completing the subsequent activity, if the process does not confirm to those assumptions based on new information acquired in the later phases of the process, the dependent task will need to be re-done.

4.2 Identifying the Main Reasons of Complexity through DSM

In fact, by making the DSM's matrixes for two sketching processes, the processes would be decomposed into smaller chunks that allow us to explore the informational exchange among the process' activities (as the components of the matrix). In other words, matrix simulation eases the way to find the iteration loops, feedback, and the total interactions among the process' activities for a design manager. A design manager can be able to identify the kind of activities' interactions (sequential, parallel, and coupled) as the starting point in managing the complex process. Several examples of these interactions are shown in the following matrixes.

Fig.1 Original DSM for Designer 1

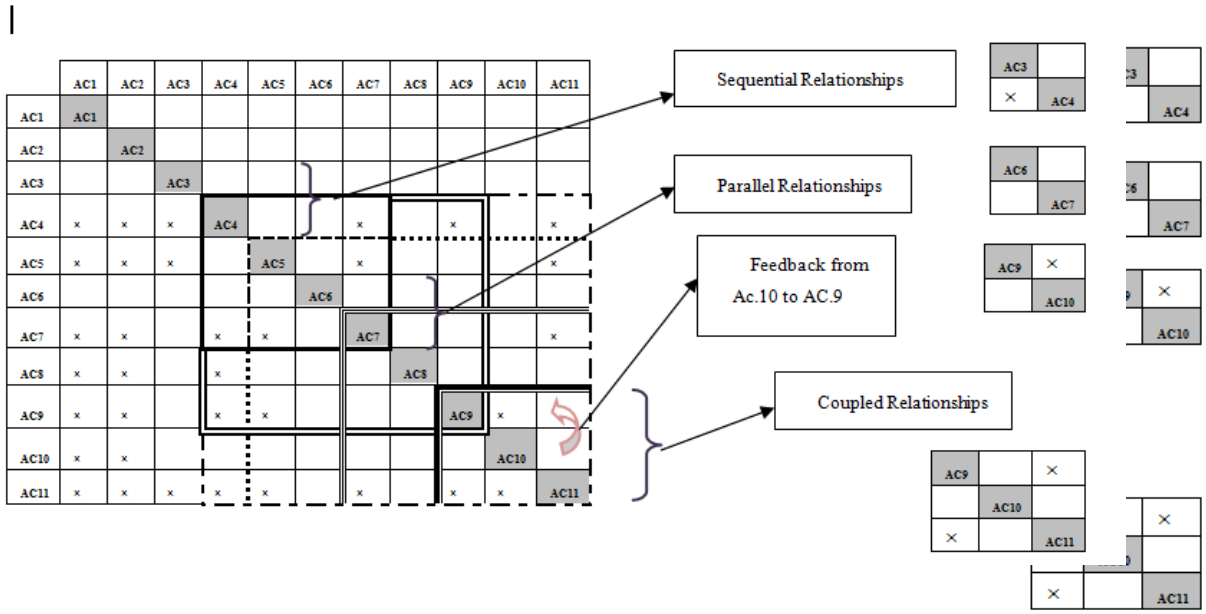
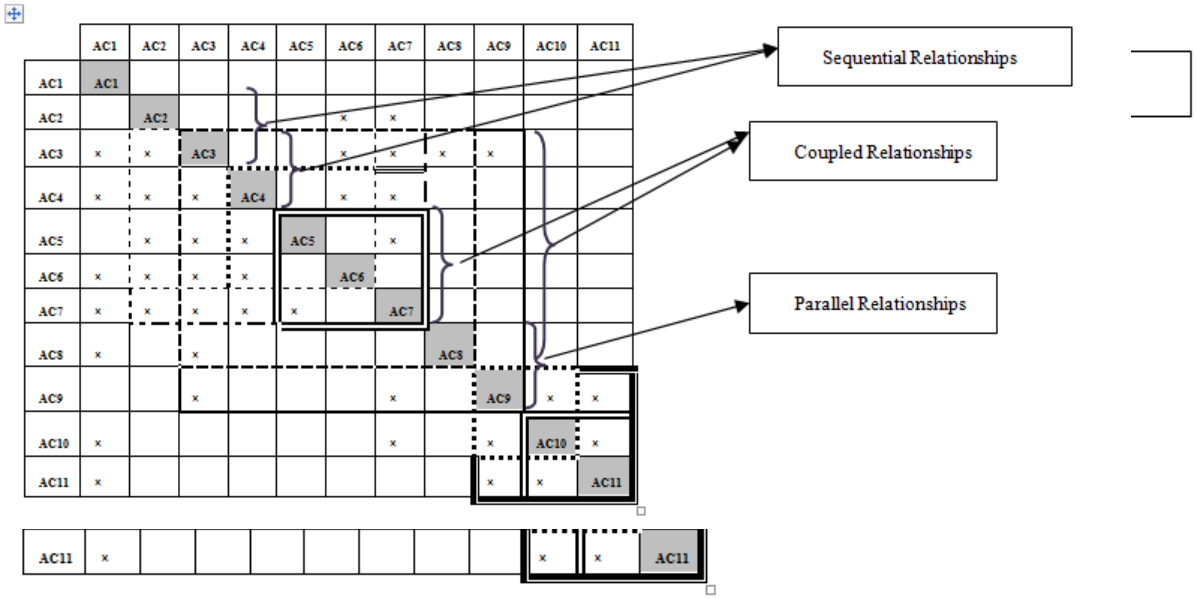


Fig.2 Original DSM for Designer 2

Th



e results of identifying the interactions' dependencies based on the matrixes built for the design processes of this study are shown in the following table which depicts the kind of interactions and the number of iteration loops. The activities that are involved in the iteration loops are shown in this table as well.

Table4. Iteration Loops Characteristics (Designer 1, Designer2)

	the number of interactions	Activities involved in Iteration Loops											
		Loop1	Loop2	Loop3	Loop4	Loop5	Loop6	Loop7	Loop8	Loop9	Loop10	Loop11	Loop12
designer 1	35	4,5,6,7	5,6,7	4,5,6,7,8,9	4, 5, 6, 7, 8, 9, 10, 11	5, 6, 7, 8, 9, 10, 11	7, 8, 9, 10, 11	9, 10, 11					

designer 2	39	3, 4, 5, 6, 7, 8	3, 4, 5, 6, 7, 8, 9	5, 6, 7	9, 10	9, 10, 11	10, 11	2, 3 , 4, 5, 6	2, 3 , 4, 5, 6, 7	3 , 4, 5, 6	3 , 4, 5, 6, 7	4, 5, 6	4, 5, 6, 7

Consequently, the necessity of representing the process as the foundation of the managing the architectural design process is quite clear for us. Through simulating the process, which is done above, we can determine what the major effective factors are, and how they arise from the sequence of activities. Meanwhile, exploring the effect of the factors can highlight the need of controlling the process to acquire a suitable outcome. Therefore, to emphasize the necessity of managing the design process, the research was conducted to answer the question 'how does the DSM method help a designer manage the process?' The answer will be discussed in detail in the discussion and conclusion of this research.

5. Discussions and Conclusions

Once a designer decomposes and models a process, s/he will be able to identify the reasons for the complexity of the process. The main reason, in terms of the sequence of the execution of activities, will be transparent.

A Matrix-based representation method provides a designer with the simplest and most refined way in this content. When compared to other graphical methods like Spaghetti graphs, it is clearer and comfortable. Identifying the relationships among the activities by looking at the direction of the many arrows within the Spaghetti graph is difficult and confusing for a design manager, while the matrix of the DSM presents the representation in a tidy square with x-marks within. As an example the Spaghetti graph for Designer 1 is presented in the following.

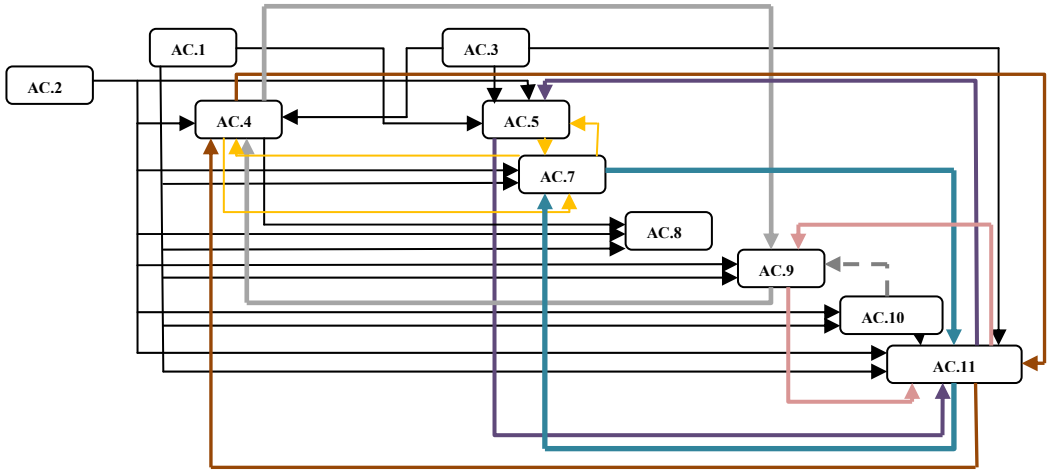


Fig.3 Spaghetti Representational Graph (Designer 1)

Accordingly, the DSM assists a design manager to identify the direction of information flows, which has an effective role in iterative behavior. On the other hand, since iterations have the strong effect on the procedure of the architectural design process, and also on the outcome of the process, it is quite obvious that the matrix-based method is useful to help a manager determine the time, place, and even the causes of the iterations. Therefore, a design manager can find the coupled activities that encompass the iteration loop(s). By exploring the information exchange among this coupled, s/he can be able to identify why the iterative behavior occurred. This iteration loop may arise from the leakage of the information required for the prior activity, or it may happen because of changing information or the revelation of new information received after carrying out the later activity of this coupled.

In summary, we propose that exploring the information flows through this method can guide us to identify suitable sequences. In other words, the DSM provides a manager with special manner in terms of re-sequencing toward minimizing the amount of iteration loops, or the number of activities that are involved within the iteration loop. In this content, there are several methods known as analyzing methods of DSM

such as partitioning, GA, and so on, which can impose the new arrangement into the process (firstly, by focusing on the changing of the arrangement of the activities among the iteration loop) to conduct the process in an optimum way. By doing this, the effective major factors of the complex processes would be controlled, and the process will reach a satisfactory outcome as the final design.

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