

# **UNIVERSITI PUTRA MALAYSIA**

EFFECTIVENESS OF UTILIZING AUTOMATIC RESIDENTIAL SPATIAL DIAGRAMMING BY SENIOR ARCHITECTURAL STUDENTS

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FRSB 2012 3

### EFFECTIVENESS OF UTILIZING AUTOMATIC RESIDENTIAL SPATIAL DIAGRAMMING BY SENIOR ARCHITECTURAL STUDENTS



By

**ALI GHAFFARIAN HOSEINI** 

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

September 2012

### DEDICATIONS

"It is my honor to dedicate the ultimate result of a consequential twenty five years study progress as a Doctor of Philosophy degree dissertation to my parents

### MOHAMMAD GHAFFARIAN HOSEINI & BEHJAT ANSARI

Whom without their support, I wouldn't be standing here"

# ALI GHAFFARIAN HOSEINI

2012

Abstract of thesis presented to the Senate of Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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September 2012

Chair: Prof. Rahinah Ibrahim, PhD

**Faculty: Design and Architecture** 

This research is categorized under design computing and cognition while focusing on the way architects think and perform throughout the architectural residential spatial diagramming practices. This research tries to move forward design computing fundamental process through comprehending the design cognition procedure during the spatial planning practices. Architectural spatial planning practices are usually illdefined and over-constrained causing the architectural spatial layout planning as one of the most complicated and challenging stages of the design process. Additionally, CAD development process has majorly focused on preparation of detailed, wellrendered and high end visualization outputs rather than measurement based evaluation outcomes. Therefore, architects have difficulty automatically evaluating the functional efficiency of architectural spatial diagrams during the conceptual design stage. Correspondingly, this research utilizes organizational simulation/evaluation theory to mitigate the aforementioned obstacle. In addition,

this study examines the effectiveness of utilizing such systems in order to step forward towards automation of the architectural spatial diagramming.

This research highlights the design computing and cognition in terms of assessing the development of an innovative approach for performing the architectural spatial diagramming compared to the conventional method. This research followed a quantitative computational experiment thus; a respective computational prototype has been developed to assist during the automatic visualization and evaluation of architectural spatial diagrams. The research verifies the effectiveness of the innovatively developed process based on implementation of a comparison between the conventional and the proposed process.

This research supports March and Simon's theory while extending VDT's organizational design simulation/evaluation theory hence formalizing graph theoretical evaluation principles to be applied for architectural residential spatial diagramming purposes. Consequently, this research claims the effectiveness of utilizing the developed system compared to the conventional progress.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

### KEBERKESANAN MENGGUNAKAN TEKNIK SPATIAL KEDIAMAN AUTOMATED OLEH PELAJAR SENIOR JURUSAN SENI BINA/ARKITEKTUR

Oleh

### **ALI GHAFFARIAN HOSEINI**

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Kajian ini tergolong dalam kategori reka bentuk pengkomputeran dan kognisi di samping memberi penekanan ke atas cara para arkitek berfikir dan amalan menggunakan reka bentuk seni bina gambarajah keluasan kawasan/spatial kediaman. Kajian ini cuba melangkah setapak dengan menggunakan reka bentuk asas proses pengkomputeran dengan memahami prosedur reka bentuk kognisi semasa proses reka bentuk perancangan spatial/ kawasan sedang dijalankan. Amalan perancangan reka bentuk arkitektur spatial/kawasan adalah yang paling payah dan penuh pengekangan, menyebabkan perancangan reka bentuk arkitektur kawasan/spatial menjadi proses yang paling rumit dan di tahap yang mencabar di dalam sesuatu proses reka bentuk/design. Tambahan pula, proses pembentukan CAD telah banyak tertumpu kepada proses penyediaan perincian, output akhir yang mempunyai visualisasi yang tinggi dan bukannya ukuran berdasarkan hasil penilaian. Oleh itu, para arkitek menghadapi kerumitan secara automatik di dalam menilai kebenaran fungsi gamba rajah arkitektur reka bentuk kawasan/spatial di peringkat reka bentuk konsep.

Sehubungan dengan itu, kajian ini menggunakan organisasi simulasi / penilaian teori untuk mengurangkan halangan yang disebutkan di atas. Tambahan pula, kajian ini mengkaji keberkesanan menggunakan sistem tersebut untuk melangkah setapak ke arah automasi reka bentuk gamba rajah seni bina ruang/spatial.

Kalau hendak di bandingkan dengan kaedah konvensional, kajian ini memberi penekanan reka bentuk pengkomputeran dan kognisi di dalam segi penilaian pembangunan pendekatan inovatif untuk melaksanakan gamba rajah seni bina ruang. Kajian ini diikuti satu eksperimen pengiraan kuantitatif dan akhirnya disusuli dengan penghasilan prototaip pengiraan untuk membantu proses visualisasi automatik dan penilaian reka bentuk gamba rajah seni bina ruang/spatial. Penyelidikan mengesahkan keberkesanan proses pembangunan inovatif berdasarkan perbandingan yang dilakukan di antara proses konvensional dan proses yang dicadangkan.

Kajian ini menyokong teori Mac dan Simon sementara memperluaskan reka bentuk teori simulasi organisasi Vdt / tepri penilaian seterusnya memformalkan graf teoritikal penilaian prinsip-prinsip yang akan digunakan untuk tujuan gamba rajah reka bentuk seni bina ruang kediaman.. Oleh itu, kajian ini terbukti mendakwa keberkesanan menggunakan pengembangan sistem baru ini berbanding dengan penggunaan sistem konvensional.

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### **ACKNOWLEDGEMENTS**

# As a student, I would like to present my most sincere gratitude to my supervisor;

### PROF. DR. RAHINAH IBRAHIM

# and the respectable supervisory committee members;

ASSOC. PROF. DR. RUSLI ABDULLAH

ASSOC. PROF. AR. MEOR MOHD FARED

I certify that a Thesis Examination Committee has met on 07<sup>th</sup> September 2012, to conduct the final examination of Ali GhaffarianHoseini on his thesis entitled " **EFFECTIVENESS OF UTILIZING AUTOMATIC RESIDENTIAL SPATIAL DIAGRAMMING BY SENIOR ARCHITECTURAL STUDENTS**" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy degree).

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### DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



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# LIST OF ABBREVIATIONS

1D-2D-3D- nD	One Dimensional- Two Dimensional- Three Dimensional- n Dimensional
ADT	Abstract Data Type
AIS	Artificial Intelligence Systems
BIM	Building Information Modeling (Computational Structural Engineering Software)
BMDP	Bio-Medical Data Processing
C4ISR	Command, Control, Communications, Computers and Intelligence, Surveillance, and Reconnaissance
CAD	Computer Aided Design
DIMACS	Center for Discrete Mathematics and Theoretical Computer Science
Dynagraph	Dynamic Graphs
Dynet	Dynamic Network
GRADAP	Graph Definition And Analysis Package
Graphisoft	Graphic Software
GraphML	Graph Markup Language
IT/ICT	Information Technology/Information and Communication Technology
KBS	Knowledge Based Systems
Matlab	Matrix Laboratory
MLE	Maximum Likelihood Estimation
NEOGOPY	Negative Entropy
NetDraw	Network Draw

NetMiner	Network Miner
NTDS	New Technology Design Systems
NURBS	Non-Uniform Rational B-Splines
SAS	Statistical Analysis Software
SEED	Software Environment to support the Early phases in building Design
SNA	Social Network Analysis
SPSS	Statistical Product and Service Solutions (formerly Statistical Package for the Social Sciences)
SYSTAT	The system for statistics
TCADS	Traditional Computer Aided in Design Systems
VDT	Virtual Design Team
VR	Virtual Reality
VRS	Virtual Reality Systems

C

# **GLOSSARY OF TERMS**

AutoCAD Computational Architectural Software	
AutoCAD® Computational Structural Engineering Software BIM®	
AutoCAD® Computational Structural Engineering Software Revit®	
BMDP Statistical Analysis Software	
B-spline In computer graphics, a curve that is generated using a mathem formula that assures continuity with other b-splines	natical
Pajek Computational SNA Tool	
Socio-Gram The visual representation of interaction in a group	
Spline In computer graphics, a smooth curve that runs through a series given points	s of

G

#### **CHAPTER I**

### **INTRODUCTION**

### **1.1 Introduction**

This study attempts to develop a computational prototype for automatically evaluating the functional efficiency of architectural spatial diagrams during the architectural conceptual design stage. Subsequently, the research is progressed to prove the effectiveness of the developed system compared to the conventional method. Respectively, this chapter covers the main introductions encompassing precise indications to the motivational background problem of this research. Afterwards, the main research question is expressed followed by the corresponding sub-research questions. Meanwhile, the main objectives of implementing this research are declared. Afterwards, introductions to the performed literature review; defined research methodology; implemented data collection and analysis and interpretation of final outputs are discussed.

### **1.2 Background Problem**

Architectural spatial planning practices are usually ill-defined and over-constrained. The aforementioned fact causes the architectural spatial layout planning as one of the most complicated and challenging stages of the design process. A problem is considered ill-defined when it is not well defined, where 'the initial constraints on the problem are not fully formulated' (Simon, 1973; Yoon, 1992; Kavakli *et al.*, 2001; Tovey *et al.*, 2003; Lawson, 2005; Menezes *et al.*, 2006). Solving ill-defined

problems consists of searching a procedure and refining a set of design constraints. Over-constrained problems are the sorts of problems that have many alternative possible answers so; architects are consecutively searching for better solutions (Balachandran, *et al.*, 1987; Yoon, 1992; Scott, *et al.*, 2002). On the other hand, architectural design process is initiated with the crucial conceptual design stage and is further developed through adding more details throughout subsequent design stages. (Lawson, 1997; Lawson, 2005; Bilda, *et al.*, 2006).

Moreover, major space arrangements decisions are made through the architect within this phase. Architects generally utilize the traditional method of using pen and paper in order to perform the sketching and spatial diagramming (Pour Rahimian *et al.,* 2011). In this regards, the progress is usually highlighted as complicated while requiring experienced architects for proper performance especially when facing complex projects (Menezes *et al.,* 2006). This research is categorized under design computing and cognition while focusing on the way architects think and perform throughout the architectural residential spatial diagramming practices. This research tries to move forward design computing fundamental process through comprehending the design cognition procedure during the spatial planning practices.

During the architectural design process, architects follow an iterative approach in order to result with an optimum solution for the design problem. In view of that, architects set up the space compositions while arranging the spatial diagramming according to the relationship between the spaces. Architects prepare versatile alternatives in order to discover the appropriate space arrangements (Bouchlaghem, *et al.*, 2005; Udeaja *et al.*, 2008; GhaffarianHoseini *et al.*, 2009). After

implementation of the conceptual design process, architects fine-tune the design ideas while performing the particular design development documentation. Eventually, construction details are produced in order to progress the design process towards construction.

Various CAD applications have been developed in order to create high-end and wellrendered architectural visualizations. Contemporarily, architects utilize CAD software to perform the discussed approaches. Most of these computational programs haven't concerned the crucial initial architectural conceptual design phase, which is mostly based on the ill-defined essence of the space arrangement implementations in this stage. In other words, architectural conceptual design phase has not been a major focus point of different architectural CAD application developers (Michalek, 2001). In other words, the domination of CAD systems has been less focused on the conceptual design stage (Moum, 2006; 2010). Correspondingly, architects have difficulty evaluating functional efficiency of spatial diagrams while not being facilitated with a certain automated evaluation model during the conceptual design stage. Respectively, researchers have tried to facilitate mediums during the design process in order to enable thinking at a higher level (Arvin, et al., 2002; Menezes et al., 2006). In addition, few researches have focused on evaluating the effectiveness of utilizing computational methods for performing the architectural spatial diagramming compared to the conventional manual methodology.

This research posits that facilitating a computational model for automatically evaluating the functional efficiency of architectural spatial diagrams will enable thinking at a higher level. Correspondingly, researchers have stated that architectural design process is moving toward a conversion from the process-based architectural design into performance-based architectural design. Thus, current architectural studies are encouraged to prepare bright insights for shifting the process-based essence of architectural design process into a performance-based concentration (Kalay, 1999). On the other hand, rapid improvement of IT/ICT systems have progressed architecture toward the computerized architectural design process. In that order, architects take advantage of computational tools to enhance the quality of final design outputs while simplifying the architectural design progress simultaneously.

In addition, organizational structure researchers have developed proper performance evaluation methodologies to examine the efficiency of organizations before actually establishing the corresponding organization (KHosraviani, *et al.*, 2004). Furthermore, previous organizational researchers have developed the Virtual Design Team's (VDT) project organization design simulator. This research expects that there are possibilities of utilizing organizational evaluation methodologies for architectural purposes. In other words, architectural databases are expected to be examined in terms of functional efficiency based on organizational evaluation principles. Consequently, this research proposes to develop a computational prototype for automatically evaluating the functional efficiency of architectural spatial diagrams during the conceptual design stage.

Literature sources in accordance with this research are reviewed while critically arguing the potential strengths and weaknesses to be utilized for proper theoretical formation of this research. Correspondingly, the main issue of architectural design process is discussed. As a result, the architectural spatial diagramming is selected as the major focus point of this research during the architectural design process. Respectively, further explanations on the architectural conceptual design stage are given accordingly. Moreover, this research proposes to prepare a computational prototype for automatically evaluating the functional efficiency of architectural spatial diagrams. Consequently, visualization in Architectural, Engineering and Construction (AEC) is respectively discussed and explained.

Computer Aided in Design (CAD) applications in architectural design process is also elucidated correspondingly. This research proposes development of a computational prototype for evaluating architectural spatial plan design during the conceptual design phase. Respectively, the idea of performance-based design utilization as a substitute to the conventional process-based design is expressed. Alternatively, this research takes advantage of organizational design evaluation principle for utilization in architectural purposes. Thus, expressions on organizational design evaluation methodologies are correspondingly clarified. Furthermore, this research attempts to add functional efficiency evaluation criteria to architectural design objectives. Consequently, architectural objectives and space layout planning is discussed. The idea of computerized architectural design is eventually explained in order to clarify future circumstances of the prospect computational prototype which is expected to be developed in this research. Accordingly, the significance of this study is to examine the effectiveness of using an automatic residential spatial diagramming prototype for residential architectural spatial diagrams during the conceptual design stage.

#### **1.3 Introduction to Literature Review (Chapters II & III)**

The literature review of this thesis covers detailed revisions regarding the architectural conceptual design stage, its role within the architectural design process and its corresponding correlation with IT/ICT and CAD techniques. Respectively, IT integration within the architectural conceptual design process is widely expressed to be utilized during the other stages of architectural design process rather than the conceptual design phase. Meanwhile, IT integration within the area of architectural design process is expressed while defining development of high end and well rendered visualizations rather than conceptual and evaluative aspects. As a result, the thesis found that there is a further need to better IT integration with the respective architectural conceptual design process. In view of this, further interpreting and describing architectural design process; architectural conceptual design stage, building design process and spatial diagrams are explained. Since the design process needs to be linked to visualization in AEC; discussions on the CAD systems and their respective development procedure; computerized architecture; and eventually evaluation of architectural floor plans specifically during the architectural conceptual design stage are included.

This research includes various available architectural CAD applications. This research found that; although different CAD software have been developed in order to provide architects with high end and well rendered visualizations but; due to the intuitive and complex essence of the architectural conceptual design stage; few of them are concerned with the architectural conceptual design stage (Michalek *et al.*, 2002). Hence, this research proposes comparison between the manual and automated

space layout planning. Correspondingly, this research has considered VDT's organizational theory to be utilized for architectural conceptual design purposes. On the other hand, this research applies Social Network Analysis (SNA) principles for the basis of automation process within the architectural spatial diagrams. Alternatively, Graph Theory as the main base of SNA has been covered as the subsequent utilized theory in this research. The final results of the corresponding comparisons are considered as the major principles of this research for development of the computational architectural spatial diagrams evaluation prototype algorithm. Correspondingly, the two aforementioned theories are discussed. This research utilized Social Network Analysis doctrines for the formation of the respective automatic visualization and evaluation prototype. As a result, SNA; centrality degree; SNA data structure and workflow; SNA visualization; SNA software and computational SNA procedure are discussed accordingly. Consequently, similarities between social networks and architectural conceptual design phase are interpreted. Eventually, explanations on merging the identified similarities; architectural conceptual design process and automatic evaluation criteria and techniques are elaborated on.

### 1.4 Introduction to the Research Methodology (Chapter IV)

From the literature survey, prior art study found that, no previous attempts have used SNA for performing architectural spatial planning therefore; this study focuses on automatic evaluation of the architectural spatial planning. This research proposes that; the innovative proposed automatic evaluation prototype is effective compared to the conventional architectural conceptual design process. Hence, a computational experimental research methodology was conducted for this purpose. Moreover, the research methodology chapter elaborates detailed explanations on how the methodology is formed. Correspondingly, dependant and independent variables have been set in order to test the hypothetical propositions of this research. After explanations on the instrumentation procedure on creating the proof-of-concept computational prototype, the thesis explained how it is verified. Moreover, charrette test is applied in order to validate the effectiveness of the proof-of-concept approach.

#### **Research Questions and Objectives**

This research is conducted based on formation of a main research question followed by three sub-research questions to discuss the research implementations. The aforementioned research questions are expressed in correspondence with their respective theoretical construct; definition of components and the particular objectives are based on Ibrahim (2009, 2011)'s Eagle research design framework.

The Eagle research design framework is a table to represent the research question constructs; research questions; research objectives; and the results of study. The main reason of utilizing an Eagle research design framework table is to clearly describe the research components. A research question must at least encompass development of a new workflow from integration of two processes to develop a new knowledge contribution (Ibrahim, 2011). Respectively, the research questions are identified as:

#### Main Research Question

How can we investigate the effectiveness [HOW 1] of using a computational prototype [WHAT] for automatically performing and evaluating the functional efficiency [HOW 2] of residential architectural spatial diagrams? [WHO]

Sub RQ 1

"How can the effectivenss of using an innovative approach for performing the architectural spatial diagramming compared to implementing the same task utilizing the conventional approach be examined ?"

### Sub RQ 2

"How can we develop an automated layout analyzer model to perform and evaluate the functional efficiency of residential architectural spatial diagrams during the conceptual design phase?"

### Sub RQ 3

"What are the criteria for automatically evaluating the functional efficiency of residential architectural spatial diagrams during the conceptual design phase?" Correspondingly, the developed theoretical constructs; research questions; strategies of enquiry and expected outcomes are discussed.

### **Research Design Framework**

After expression of the respective research questions and objectives; the relativity of research questions; theoretical constructs and objectives are defined through development of the eagle view research design framework (Ibrahim, 2011). Correspondingly, the respective eagle view framework for this research is developed as follows (Table 1)



### Main Research Question (RQ)

How can we investigate the effectiveness [HOW 1] of using a computational prototype [WHAT] for automatically performing and evaluating the functional efficiency [HOW 2] of residential architectural spatial diagrams? [WHO]

<b>RQ CONSTRUCT</b>	DESCRIPTION OF SUB RESEARCH QUESTION (SUB RQ)	STRATEGY OF INQUIRY	EXPECTED RESULTS
<b>[HOW 1]</b> Investigating the Effectiveness <b>Theoretical Construct 1</b> Effectiveness of Using the Computational Prototype	Sub RQ 1 "How can the effectivenss of using an innovative approach for performing the architectural spatial diagramming compared to implementing the same task utilizing the conventional approach be examined ?" <u>Research Objective (RO 1)</u> To test the effectiveness of using an architectural spatial diagramming performance and assessment prototype for implementing alternative architectural spatial diagrams	Computational Experiment [Charrette Test Method (Quantitative Pre-Experimental Paired Samples T- Test)]	Identification of the effectiveness of using a computational method for performing the architectural spatial diagramming
[WHAT] Automated Architectural Spatial Diagramming Computational Prototype [HOW 2] Performance and Evaluation of Functional Efficiency of Architectural Spatial Diagramming [WHO] Architectural Spatial Diagramming Theoretical Construct 2 Automatic Space Layout Arrangement Methodology	<u>Sub RQ 2</u> "How can we develop an automated layout analyzer model to perform and evaluate the functional efficiency of residential architectural spatial diagrams during the conceptual design phase?" <u>Research Objective (RO 2)</u> To discover the criteria of developing practical user interfaces for the architectural functional efficiency analyzer prototype	Instrumentation and Computational System Verification	Development of a computational plan layout assessment for evaluating the functionality of architectural spatial diagrams during conceptual design stage hence identifying the criteria for preparation of the automated computational evaluation system
[HOW 2] Performance and Evaluation of Functional Efficiency of Architectural Spatial Diagramming [WHO] Architectural Spatial Diagramming Theoretical Construct 2 Automatic Space Layout Arrangement Methodology	<u>Sub RQ 3</u> "What are the criteria for automatically evaluating the functional efficiency of residential architectural spatial diagrams during the conceptual design phase?" <u>Research Objective (RO 3)</u> To discover the criteria for assessing the residential architectural spatial diagrams in terms of functional efficiency during the conceptual design stage	Computational System Development Validation	Identification of the criteria for automatic evaluation of the architectural spatial diagrams during the conceptual design stage

#### **1.5 Introduction to the Results and Analysis (Chapter V)**

The results and analysis chapter covers detailed explanations regarding the corresponding results and analysis of the performed computational experiment. This study examines the effectiveness of utilizing a computational method for performing the architectural spatial diagramming compared to the conventional manual method.

The study attempts to develop a computational proof of concept prototype for automatically evaluating the functional efficiency of architectural spatial diagrams during the architectural conceptual design stage. Respectively, the computational experiment research methodology was designed accordingly.

This research performed the instrumentation part based on the required software specifications. In this regards, preparation of the computational prototype and the respective verification of the system are further elaborated. Subsequently, expressions on running the effectiveness testing of the aforementioned computational prototype are discussed as the main results for the performed charrette test.

Eventually, limitations of this research are highlighted while principles and implementations of the validation progress based on computational emulation doctrines are mentioned.

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#### **1.6 Introduction to Conclusions (Chapter VI)**

The conclusions chapter covers up the given explanations regarding the final outcomes of this research. Correspondingly, this research has been performed in order to step forward toward promoting insights on automating the architectural spatial diagramming. The research was conducted to provide a proper computational system for better performing the architectural bubble diagramming. Respectively, the final results of this research are expected to propose the development of the aforementioned architectural computational system (Architectural spatial diagramming prototype) for automatic performance and evaluation of the architectural conceptual design stage (spatial diagramming practices) as further expressed.

Alternatively, the literature review chapters have elaborated on the main focus point of the current CAD development process on preparation and implementation of detailed, well-rendered and high end visualization outputs rather than measurement based evaluation outcomes (Michalek *et al.*, 2002). Additionally, major attention on development of CAD systems on 2D-nD progress was discussed while highlighting the lack of attention to the conceptual design stage (Michalek, 2001). This lack of attention is later highlighted to be majorly based on the intuitive and iterative essence of the architectural design process and more specifically the architectural conceptual design stage.

Correspondingly, innovative knowledge contributions of this research on preparing the automated evaluation system for architectural conceptual design stage are further discussed. The benefits for performance of the architectural design process while further respective explanations are elaborated in this section. Correspondingly, the answers to the respective main research question; sub-research questions and objectives are discussed.



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