DECISION SUPPORT SYSTEM FOR BUILDING INFORMATION MODELING (BIM) SOFTWARE SELECTION: A CASE STUDY IN CONSTRUCTION FEASIBILITY STAGE

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Abstrak

Penerimaan perisian Permodelan Maklumat Pembinaan (BIM) telah terbukti bermanfaat kepada industri pembinaan bagi meningkatkan rekabentuk, analisis, pembinaan, operasi dan pengurusan data. Disebabkan pelbagai jenis perisian BIM di pasaran, proses pemilihan perisian BIM yang memenuhi keperluan projek dianggap rumit. Kajian terdahulu telah mendedahkan bahawa kebanyakan pemilihan perisian adalah berdasarkan populariti dan cadangan daripada syarikat lain. Justeru, pemilihan yang tidak tepat boleh mengakibatkan penggunaan perisian BIM yang tidak sepenuhya dan memberi kesan negatif ke atas pelaburan perisian BIM. Berdasarkan tinjauan literatur terdapat kekurangan pendekatan yang sistematik dalam pemilihan perisian BIM bagi memenuhi keperluan projek tertentu. Ini menekankan keperluan untuk alat pembuatan keputusan bagi memilih perisian BIM yang bersesuaian. Penyelidikan ini bertujuan untuk membangunkan Sistem Sokongan Pemutusan (DSS) yang dinamakan topsis4BIM yang mengintegrasikan antaramuka pengguna, pangkalan data bercirikan BIM, Fuzzy TOPSIS dan alatan Web 2.0. Projek pembinaan sebenar telah digunakan sebagai kajian kes untuk demonstrasi dan pengesahan rangka kerja DSS. Hasil kajian menunjukan penggunaan topsis4BIM dapat memperbaiki proses pemilihan perisian BIM berbanding amalan sedia ada. Selain itu, ianya juga telah menghasilkan satu rangka kerja baharu untuk pembinaan DSS masa hadapan dengan mengunakan alatan Web 2.0. Kajian ini memperkenalkan satu pendekatan pembuatan keputusan yang inovatif dan ekonomikal yang boleh menjadi garis panduan untuk meningkatkan penggunaan BIM dalam kalangan pengamal pembinaan

Kata Kunci: Permodelan maklumat pembinaan, Sistem sokongan keputusan, Pembuatan keputusan pelbagai kriteria, alatan Web 2.0

Abstract

The adoption of Building Information Modelling (BIM) software has proven to be beneficial to the construction industry to improve the design, analysis, construction, operation and data management. Due to the variety of BIM software on the market, choosing the right BIM software in construction projects is deemed to be a complicated decision making process. Previous studies revealed that software selection is mainly made based on popularity and recommendation from other companies. Consequently, inaccurate selection would lead to the underutilised features and negative effect the investment on the BIM software. Based on literature, there is a lack of systematic approach to select the right BIM software for specific project requirements. This highlights the needs for decision making tools to select the appropriate BIM software. This research aims to develop a Decision Support System (DSS) named topsis4BIM which integrates graphical user interfaces, BIM features database, Fuzzy TOPSIS and Web 2.0 tools. A real construction project was used as a case study for demonstrating and validating the DSS framework. The findings indicate that the use of topsis4BIM improves the BIM software selection process compared to the current practice. In addition, it also produce a new framework for the next generation DSS using Web 2.0 tools. The study introduces an innovative and economical decision making approach that can guide construction practitioners towards the betterment of BIM adoption.

Keywords: Building information modelling, Decision support system, Multi criteria decision making, Web 2.0 tool

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List of Abbreviations

3D	:	Three dimensional medium
AEC	:	Architecture, Engineering and Construction
AHP	:	Analytic Hierarchy Process
BIM	:	Building Information Modeling
CAD	:	Computer Aid-Design
CGI	:	Common Gate-away interface (CGI)
CIDB	:	Construction Industry Development Board
CM@R	:	Construction Management at Risk
CMAA	:	Construction Management of Association America
CPM	:	Critical Part Method
CREAM	:	Construction Research Institute of Malaysia
DB	:	Design Build
DBB	:	Design Bid Build
DSS	:	Decision Support Systems
EIS	:	Executive Information System
ELECTRE	:	ELimination and Choice Expressing Reality
ES	:	Enterprise System
GDP		Gross Domestic Product
HTML	:	HyperText Markup Language
ICT	:	Information Communication and Technology
IPD	:	Integrate Project Delivery
MADM	:	Multi Attribute Decision Making

MCDM	:	Multi Criteria Decision Making
MIS	:	Management Information System
MODM	:	Multi Objective Decision Making
MY SQL	:	Structured Query Language
OLAP	:	Online Analytical Processing
PDM	:	Project Delivery Method
PHP	:	Personal Home Page
PKK		Contractor Service Centre
PMBOK	:	Project Management Book of Knowledge
POM	:	Production and Operational Management
PROMETHEE	:	Preference Ranking Organization Method for Enrichment of Evaluations
PWD		Pubic Work Department
ROC	:	Rank Order Centroid
SAW	:	Simple Average Weight
TOPSIS	:	Order Preference by Similarity to an Ideal Solution
TPS		Transaction Processing System
TQM	:	Total Quality Management
UTHM	:	Universiti Tun Hussein Onn Malaysia
UUM	:	Universiti Utara Malaysia
VIKOR	:	VIseKriterijumska Optimizacija I Kompromisno Resenje

CHAPTER ONE
INTRODUCTION

1.1 Research Background

Construction sector is one of the main contributor in Malaysia's Gross Domestic Product (GDP) within the years of 1991 to 2010 with average of 4.09 % GDP, and 3 % to 5.7 % of national economy (Khan, Liew, & Ghazali, 2014). This is due to the role of construction sector who provide initial infrastructure and building for other sector such as manufacturing, industrial and even tourism sectors (Yong & Mustaffa, 2012). Therefore, the construction sector is significant in social-economy development in Malaysia.

Realising the importance of construction sector, several government agencies have been established such as Construction Industry Development Board (CIDB), Ministry of Work, the Contractor Service Centre (PKK), the Board of Engineer, the Board of Architect and the Board of Surveyors (Kamal, Haron, Ulang, & Baharum, 2012). Numerous efforts have been taken by these agencies in order to enhance the development of construction sector. Since 2007, CIDB has been actively promoting the use of a new technology which is Building Information Modelling (BIM) via seminars, workshops, development of roadmap for BIM adoption in Malaysia, and other promotional programmes. Since the introduction of BIM, it has been recognised in the industry as a significant technology that can enhance construction project management.

This new technology has gained much attention from the construction players around the world. Most of the past studies were focused on the adoption of BIM (Arayici et al., 2011), benefit, risk and challenge (Azhar, Hein, & Sketo, 2011), barriers in BIM (Eastman, Teicholz, Sacks, & Liston, 2011), but there is a limited study on BIM software selection. From the construction literature and industry report, BIM has been proven beneficial in order to enhance construction project management by encouraging communication and collaboration among the project stakeholders, reducing error in design phase, providing important analysis function such as clash detection before the construction process in site, among others (Hergunsel, 2011; Liu, 2010; Rohena, 2011; Sebastian, 2011).

As a result, various BIM software have been developed in order to cater to the demand of BIM from the construction players (Eastman et al., 2011; Ruiz, 2009). This situation has created a decision problem for construction player in choosing the appropriate BIM software that can fulfils the company and project needs (Eastman et al., 2011). Each of the BIM software offers different function, features and cost. Moreover, the adoption of BIM required high involvement not only for the hardware and software, but also include expensive training expenses (Olatunji, 2011). According to Ruiz (2009), the wrong selection of software package can affect company investment and performance. In his study, he mentioned that there is a case where companies in Texas are losing money due software selection without a proper analysis.

Thus, due to these reasons, the decision aid in BIM software selection is significant in order to fulfil the project needs and minimize investment risk in BIM adoption. Literature has proven the ability of Multi Attributes Decision Making MADM Decision Support System (MADMDSS) in solving multi criteria decision problems including software selection (Ahmad, Azhar, & Lukauskis, 2004; Cebeci, 2009; Chen, Liu, Li, & Lin, 2011; Hendi, 2007; Safa, Shahi, Haas, & Hipel, 2014; Taroun, 2012).

Decision Support System (DSS) is defined as a computer programs that act as supporting tools in extending the abilities of decision makers but not replacing their judgments in decision making (Turban, Aronson, & Liang, 2005). According to Averweg (2008), DSS is capable of solving unstructured problem such as software selection. Rapid development of construction industry has increase the complexity of decision making process that also involved high degree of inherent uncertainty (Goh, 2011) .

The need of effective decision making approach becomes more prevalent in this industry. Furthermore, current practice in BIM software selection is based on recommendation from software vendors or most popular software. Thus, it is illustrates the need of decision aid. Thus, with the existence of decision support tools such as DSS capable of improving decision making process in BIM software selection. Moreover, DSS has gained much attention from researcher in construction domain due to its benefits during the decision making process (Banias, Achillas, Vlachokostas, Moussiopoulos, & Papaioannou, 2011; M. C. Ruiz & Fernández, 2009).

As a result, literature has shown a rapid development in DSS technology (Shim et al., 2002). Furthermore, the existence of a new concept in web development called Web 2.0 has offers an effective and simple framework for the development of web based DSS. According to Aghei et al. (2012), Web 2.0 provide features that beyond the ability of previous generation of web tools such as mass participant ease of use and interactive interface. However, the development of web based DSS through Web 2.0 platform particularly in construction project management is still far from mature.

Recent development in DSS has integrated a decision model called Multi Attribute Decision Making (MADM) as a sub system. The integration of MADM technique in DSS development has significantly improved the ability of DSS in enhancing and structuring the decision making process (Kou, Shi, & Wang, 2011). MADM is a mathematical technique that can assist decision makers in order to making decision over the available decision alternative (Büyüközkan & Çifçi, 2011; Moravveju, 2013; Ozturk & Ozcelik, 2014).

Research suggests that software selection can be assisted to be more efficient and effective through the MADM techniques (Ayağ & Özdemİr, 2007; Büyüközkan & Ruan, 2008; Pekin, Ozkan, Eski, & Karaarslan, 2006). However, MADM method has been criticised because of the vagueness of the judgment from decision maker. Based on aforementioned issues, this research aims to develop a web based DSS which is not only simple, effective and capable of assisting decision makers in uncertainty environment and but also easy to develop.

1.2 Problem Statement

Due to the rapid development of construction industry which leads construction players to gain more complex problem, a lot of research on DSS in construction has been conducted such as a web based DSS for optimal management of construction (Banias et al., 2011), equipment selection (Hendi, 2007), environmental assessment in construction (Ruiz & Fernández, 2009) and risk analysis (Tang, Leung, & Wong, 2010). However, in the context of BIM software selection, most of the construction companies tend to depend on recommendation from software vendor, other companies or simply selecting the most popular software in market (Ruiz, 2009). There is no available tool such as DSS to support decision making process. The unavailability of tools for software selection can increase the probability of choosing the wrong BIM software (Ruiz, 2009).

As mentioned before, the adoption of BIM required high investment in software, hardware and training expenses. Thus, a proper evaluation of BIM software is significant to avoid loss in company investment. Only Ruiz (2009) has proposed an evaluation model in BIM software without further development of DSS. However, the development of decision model alone is not practical and unused as they are complicated or difficult for a layman such as project management to use it (Peters & Zelewski, 2008). Moreover, most of DSS in construction domain were focused on the significant of decision model rather than the usability and practical usage of DSS towards real world (Omar, 2012). In addition, most of DSS development in such as Web based DSS required high technical skill in programming language, high cost and duration for development (Aghaei, Nematbakhsh, & Farsani, 2012). In order to deal with construction issues such as BIM software selection, decision model in DSS is developed through contemporary web technology which can lead to a more simple development process, effective and usable DSS. Thus, by considering the aforementioned issues, the main research problem is identified as follows;

"The lack of decision support framework to assist BIM software selection for construction project".

Due to unavailability for decision support, it is desirable to develop a computerised decision support BIM software selection. In pursuing this objective, the author has identify three key issues. They are:

1. Incomplete attributes for BIM software selection.
2. Unavailability of decision support system prototype for BIM software selection.
3. Lack of utilty and usability evaluation DSS for BIM software selection.

1.2.1 Incomplete Attributes for BIM Software Selection

Based on literature, all the adoption of BIM led to the minimization of cost and time of project, avoiding error and increasing safety and the quality of project outcome (Bryde, Broquetas, & Volm, 2013; Chelson, 2010; Kumar & Mukherjee, 2009; Rohena, 2011; Wong & Fan, 2013). The importance of BIM software selection has been addressed by Eastman et al. (2011) and Ruiz (2009). The selection of the most suitable software is significant in order to fulfill the project needs. However, there is limited study attempt to investigate the attributes for BIM software selection. From literature, there are only a few authors who have listed the general attributes for BIM evaluation (Ruiz, 2009). A completed attributes for BIM is essential to guide construction companies in choosing the most suitable BIM software that can fulfill a project needs and avoid loss of investment in BIM adoption particularly in Malaysia where the cost of BIM adoption is high.

1.2.2 Unavailability of DSS Prototype for BIM Software Selection

The benefits of DSS towards enhancing decision process in construction domain have been addressed by many authors (Chau, Cao, Anson, & Zhang, 2002; Hendi, 2007; Kahkonen, 1995; Marwan, 1986; M. C. Ruiz & Fernández, 2009). However, in BIM software selection problem context there is no available study on the development of DSS. As mentioned before, BIM software selection involves several risks that need to be considered.

However, according to Ruiz (2009) most of the companies tend to purchase BIM software based on recommendation from software vendor, other companies or based on the best software in the market. Even though Ruiz (2009) has proposed an evaluation model, yet according to Peter and Zalewski (2008) the development of decision model alone without DSS is not practical in real world and unused due to complicated or difficult for a layman such as project management to use it. Past research has shown that there is no available DSS for BIM software selection (Ruiz, 2009).

1.2.3 Lack of Utility and Usability Evaluation DSS

Instead of evaluation of decision models for BIM software selection, an evaluation of DSS is also important in DSS development. In construction literature, most of researches neglected user evaluation on how well the system has been implemented (Kinzli et al., 2010; Omar, 2012; Taroun, 2012). This evaluation is significant in order to measure the usability and effectiveness of DSS in real life situation (Hung, Ku, Liang, & Lee, 2007; Taroun, 2012).

1.3 Research Questions

The research questions dervived from the main problem statement are as follows:

1. What are the attributes for BIM software selection?
2. How to support complex decision making for BIM software selection for specific project needs?
3. How to assess the user acceptance of overall decision process and the tool for BIM software selection?

1.4 Research Objectives

The aim of this research is to develop a decision support framework to assist BIM software selection for construction players. To achieve the research aim, three research objectives are underlined as follows:

1. To identify the attributes for BIM software selection

To achieve this objective, this study involves activities such as exploring and identifying the attributes in current practice among Malaysia BIM practitioner in BIM software selection by deployment of case study.

2. To develop a multi-criteria decision support system prototype for BIM software selection

In order to achieve the second objective, this study involves activities such as developing of DSS component such as decision models and user interface for web based DSS.

3. To evaluate the utility and usability of the decision support tool.

After the development of DSS in this study, this study involves activities such as conducting and performing a validation process of DSS in term of sub system and face validation among the decision makers through qualitative approach. This process is significant in order to measure the utility and usability of the proposed DSS towards the problem.

1.5 Scope of Study

This study is limited to the development of DSS prototype in order to enhance the decision process of BIM software selection in construction project management. Detail limitations of this study are as follows:

1. This study is conducted by investigating the aspect of development and evaluation of DSS prototype for BIM software selection in construction project management. Data is collected from stakeholders who are directly involved in the decision making process in case study project which is UTHM Multi Proposed Hall as known as Dewan Sultan Ibrahim.

2. Due to the significant of the BIM software selection in BIM adoption, this study aims to provide the decision makers with an efficient and effective Web based MCDM DSS for BIM software selection.

3. This study is focused on BIM software selection in Malaysia. However, the DSS can be generalized to support other MADM problems with some changes in decision model and data stored.

1.6 Significance of the Study

The fundamental contribution of this propose research is a better understanding on how Multi Attribute Decision Making (MADM) through Decision Support System (DSS) technology could enhance the decision process in the selection of BIM software for the construction company. This includes:

1. Introduce a new generation of web based technology to DSS development.
2. Provide simple framework to develop a web based DSS in MCDM problem such as software selection though Web 2.0 platform.
3. Introduce a new approach of BIM software selection through DSS.
4. Minimised the assessment time taken for BIM software evaluation and selection.

1.7 Organisation of the Thesis

This study is divided into six chapters starting with an introduction of research project that consist of problem statement, research objectives and questions, scope of research, and significant of research. Chapter Two contains a comprehensive review of literature in two different areas. The first is construction project management which focus on the adoption of BIM software. Thus, a decision problem is identified in BIM software selection and web based DSS is proposed as a solution. This chapter also covers the investigation into decision making techniques and DSS area in construction project management. The deficiency of web DSS development was present here. Overall this chapter identifies the research gap.

Chapter Three describes the research methodology in this research in detail such as the research methodology, data collection and research process framework. Chapter Four describes the design based on case study result and implementation of proposed DSS (decision model, the architecture of topsis4BIM and its features) in this research. Chapter Four illustrates the design and implementation of topsis4BIM. For example, the development of decision model and the architecture of topsis4BIM. This process has been conducted during case study among the decision makers. This chapter also discusses background Dewan Sultan Ibrahim project and a brief profile of decision maker who involved in this study.

Chapter Five illustrates the validation process of topsis4BIM in detail such as sub system validation and face validation. This validation process has been conducted in quantitative and qualitative nature among the decision maker involved in this study.

A discussion on the research finding is presented at the end of this chapter. Finally, Chapter Six describes the conclusion of the research. This chapter reviews the research objective and questions with findings and summarised the contribution of this study towards body of knowledge and construction area. This chapter ends with some recommendations for future research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter describes an intensive literature review for the research. The literature review covers two different areas. These are Building Information Modeling (BIM) software in construction project management and Decision Support System (DSS). The first area is focused on the adoption of BIM in construction particularly in BIM software selection process. The second area is focused on the integration of Multi Criteria Decision Making (MCDM) with web based DSS as a solution to BIM software selection decision making problem.

2.2 Construction Project Management

Project Management Institute (PMI) has defined a project as "a temporary endeavour undertaken to create a unique product, service or result". The word "temporary" refer to characteristics of the project that has a beginning and end. Meanwhile, according to Project management Book of Knowledge (PMBOK) (2001), "unique" means that a project is involved in doing something different that has not been done before. There might be some similarity to the previous project but there are slightly differences in term of resources, business environment and others (PMBOK, 2001). Project Life Cycle (PLC) is generally known as the overall process in a project due to accomplishment of project. The stages are traditionally separated into planning, design, construction, commissioning, etc. The successful of a project life cycle mostly depends on collaboration among the project stakeholders particularly at design stage.

2.2.1 Construction Project Stakeholders at Design Stage

A project stakeholder refers to any individual or organisation that is involved and has an interest in the project completion (Taylan, Bafail, Abdulaal, & Kabli, 2014). Each of the stakeholders has a different influence on the construction project. In construction the stakeholder collaborations is one of the factors that would determine the successful of the project (Sebastian, 2011). Thus, stakeholder management is significant in project management to achieve the project goal (Bourne & Walker, 2008).

Unfortunately, the current practice such as 2D AutoCAD in construction is based on fragmentations process that leads to less communication and collaboration between their project stakeholders (Azhar et al., 2011). Moreover, any stakeholder such as client or contractor who does not fully understand 2D drawing may cause problem during the project construction. There are several of project deliveries available to carry out construction project. Each of project delivery offers different procurement process through PLC.

2.2.2 Type of Project Delivery

Project Delivery Method (PDM) is significant issues of interest for many researchers, mostly in terms of comparison and selection of the appropriate PDM (Chen et al., 2011; Ibbs & Chih, 2011; Konchar & Sanvido, 1998). Each PDM offers different advantages and disadvantages in the achieving project objectives (Ibbs & Chih, 2011). Design Bid Build (DBB) is generally known as a ‘traditional’ project delivery system that contains three participants of project; the owner, designer and contractor.

DBB is specifically designed for the public construction project. However, DBB approach which is more on fragmentation process is always causing inefficacy such as high cost and project delay (Kent & Becerik-gerber, 2010).

In order to deal with the fragmentation issues in Project Delivery, Design and Build (DB) was introduced in the 1990s which is a more flexible and cost efficient type of project delivery. The purpose of this approach is to enable owner to have a direct contact with single firm that is capable of performing designing process and construction process (Chen et al., 2011; Ibbs & Chih, 2011). The implementation of DB as project delivery has been shown to be beneficial towards cost reduction, schedule and quality of project outcomes over traditional delivery method (Eastman et al., 2011).

2.3 Building Information Modeling (BIM)

Issues such as the quality, effectiveness of design, sustainability of building, and reducing time and cost of the project have been frequently addressed in the construction management literature. However, the current practice in the construction industry is still based on fragmented process and on out-dated tools such as 2D AutoCAD, which has been considered as a drawback (Eastman et al., 2011). This concept can increase error and omission that can cause the construction problems such as project delay, overrun and so forth (Rohena, 2011; Sebastian, 2011). In a nutshell, the traditional method such as 2D (CAD) that is mostly used in current practice for design process has become inadequate to cater to the current demand of construction requirement. The introduction to the BIM technology has provide an alternative solution in order to deal with this problem (Eastman et al., 2011). From literature, cost and time reduction and increasing the collaboration and quality of project outcomes are the most significant advantages of BIM adoption (Bryde, Broquetas, & Volm, 2013). Figure 2.1 illustrate 16 purpose of BIM used in the United State.

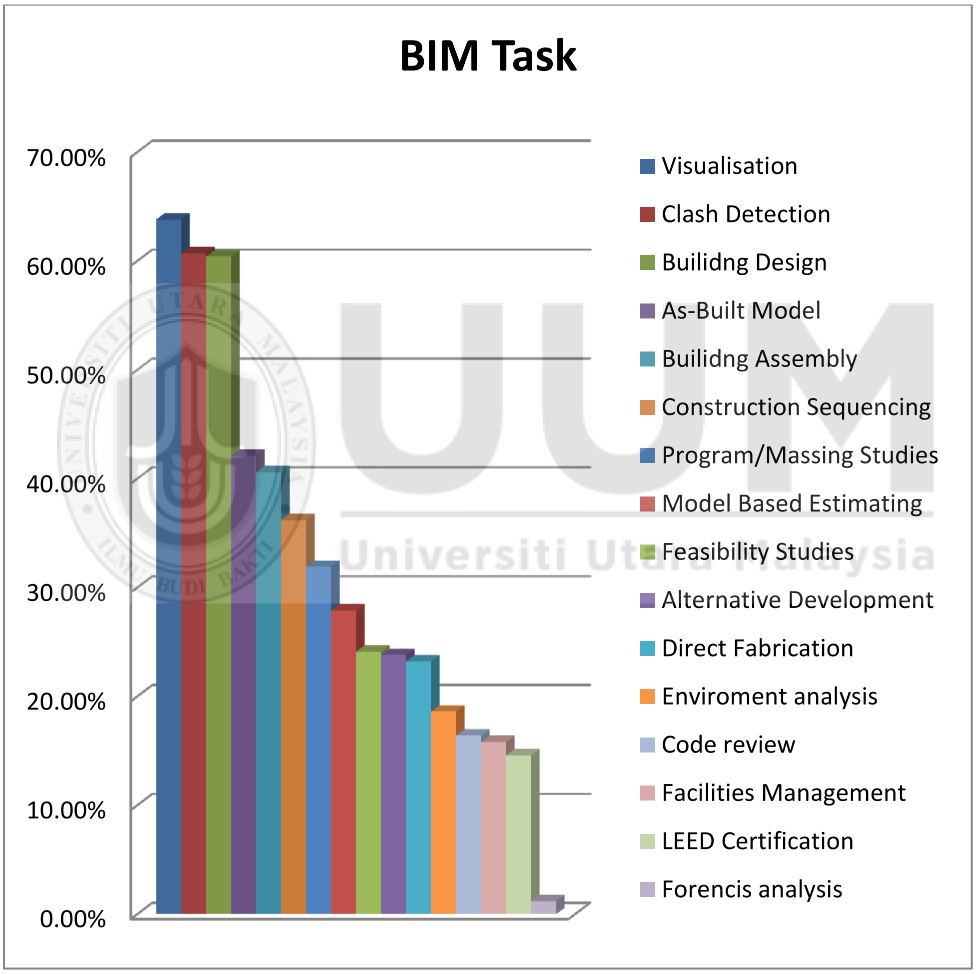

Figure 2.1. Task of BIM used in the USA

(Gerber & Rice, 2010)

As shown in Figure 2.1, BIM has been utilised for numerous tasks in construction industry. As mentioned in previous research, BIM has been mostly used in design phases such as visualisation, clash detection, and building design. Thus, the adoption of BIM has been proven beneficial towards increasing productivity and quality of project outcomes during project life cycle.

2.3.1 The Utilization of BIM Tool during Project Life Cycle

BIM is generally applied throughout the project life cycle, from planning through operating phase. Based on literature in construction management, it shows that ICT technology such as BIM would mostly influence the design phase (Chelson, 2010; Rohena, 2011; Ruiz, 2009). The existence of BIM can extend the ability of 2D CAD into 3D in order to improve the design process (Gu & London, 2010). The 3D visualisation, enable the designer to develop a more accurate and detailed built-in model virtually in design phases. Tasks such as drawing, energy analysis, and coordination in building construction can effectively carried out using virtual features in BIM application through planning and design phases.

Most of the advantages of BIM in design phases mainly emerged from the 3D visualisation and virtual model function (Eastman et al., 2011; Hergunsel, 2011). For example, function such as easy verification of consistency to design intent, efficient improvement of energy efficiently and sustainability. Via 3D visualisation function, it enables the designer to provide early and more accurate cost estimation. Moreover, the ability of linking 3D built in model of a real project with analysis tools allows the designer to evaluate energy use in design phases (Eastman et al., 2011; Hergunsel, 2011). One of the significant analyses that BIM contribute most is the clash detection analysis.

Currently, with the traditional method, Clash analysis can only be conducted at the construction site during or after construction process that can lead to the overrun of cost and time of a project (Haron, 2013). Meanwhile, BIM system allows the user to conduct clash detection analysis in early planning and design phases via 3D virtual model to avoid all possible conflicts during the construction process (Hannele et al., 2012). Moreover, through 4D simulations in BIM, it can allow user to run a simulation on building model virtually before the actual project is constructed (Sebastian, 2011).

This is beneficial towards increasing the understanding of each stakeholder and also minimises the probability of error in the future (Chelson, 2010). Other than that, it also allows the user to make changes to the project and all documentation and building design simultaneously rather than in serially phases. In addition, one of the characteristic of BIM also serves as a sharing knowledge resources for information in order to provide a reliable basic for decision making in the PLC (Sebastian, 2011). Most importantly BIM also provides automatic coordination that can improve the overall quality of work during the design phase (Azhar et al., 2011).

The benefits of BIM characteristic in the design phase can significantly affect other phases in a project. For example, in the execution phase, with BIM, a detailed 3D model of the building will give a most positive influence during onsite construction work (Hannele et al., 2012). This function will encourage most of the fabricated material offsite. Through traditional practice, most of the fabrication material processes take place onsite of construction project with poor environment. Most of the onsite work can increase the cost and time of project and lessen the quality control of the materials (Eastman et al., 2011).

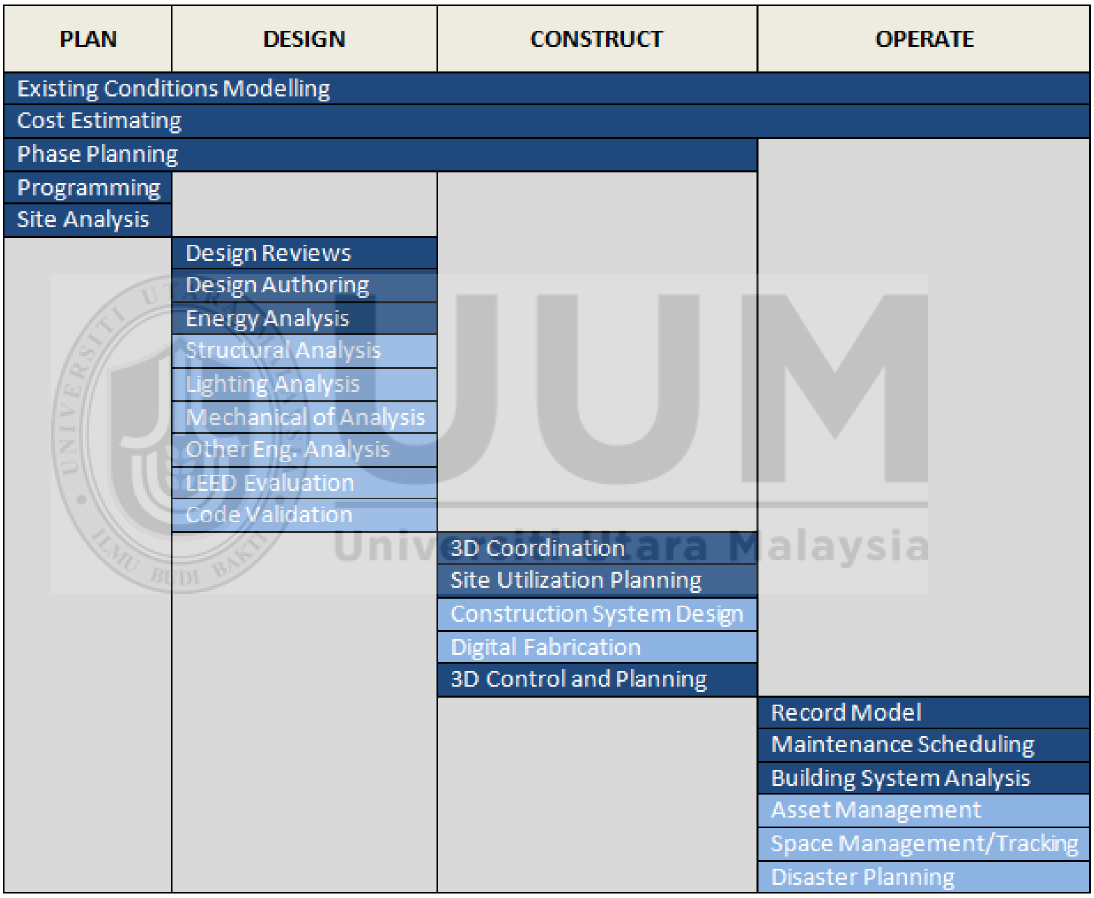

Figure 2.2. *BIM Used Throughout a Building Lifecycle*

(Rohena, 2011)

Figure 2.2 shows the BIM application throughout a building lifecycle. From this figure, it shows that BIM application is capable of assisting all process of a project life cycles starting form planning phases until operate phases. According to Eastman et al., (2011), their research has highlighted three main contributions of BIM in post construction phases:

1. Improved commissioning and handover of facility information.
2. Better management and operation of facilities.
3. Integration with facility operation and management system.

For example, improved commissioning and handover of facility information means that BIM is capable of providing and keeping all information about installed material and maintenance information for the system of the building. This advantage of sharing information can be valuable for the owner to use in their facility management system. BIM has gained much attention from the Malaysian government due to its significant potential in improving construction project management. Thus, according to the Public Work Department (PWD) (2011) government has been attempting to introduce the BIM among the construction companies in Malaysia since 2007 (Department, 2011).

2.3.2 The Availability of BIM software

Prior to embarking on a BIM project, designers need to select the appropriate software for their construction project. Currently, there are numerous software tools available in the market such as Revit, Bentley, Archicad 12, Innovaya, Synchro, Vico, Tekla, Onuma, and Solibri. Each of these software offered different function, features and cost. It is vital to select the appropriate BIM software due to the variability of cost and features as these can affect the overall construction project execution throughout PLC. Ruiz (2009) has highlighted a list of BIM software that is mostly used in the United State (See Appendix B).

In literature, there is limited study attempt to investigate the attributes and significant of BIM software selection. The selection of BIM software has been considered as one of the crucial process in BIM adoption (Eastman et al., 2011). However, most of the companies choose software by following market trend, software package that they are familiar, and choose software that is more popular in industry, without first having a proper analysis of decision making (Kumar & Mukherjee, 2009; Ruiz, 2009).

2.3.3 The Software Selection Attributes

Due to the increasing various types of BIM software in the market, construction companies are facing problem in choosing the appropriate BIM software that suit the company needs. According to Ruiz (2009), it is significant for a company to have a full knowledge and information (function, cost of software, requirement of hardware and futures) regarding of BIM software that are currently available. The selection of BIM software that suit project needs is not an easy process and there are several factors that need to be consider. In addition, each BIM required different hardware, software cost and training cost based on BIM features and purposed of use (Arayici et al., 2011; Olatunji, 2011; Pena, 2011).

The adoption of BIM for administration features is much lower than technical features in terms of hardware requirement, software cost and training expenses. For example, technical features required higher hard drive of up to 320 GB and RAM capacity of up 20 GB and 64-bit system compared to the administration features. Architecture, Engineering and Construction AECbytes (2007) only proposed general attributes for BIM software selection. The general attributes for the selection of BIM software (AECBytes, 2007);

1. Full support of producing construction documentation, smart objects, which maintain a relationship with another object.
2. Availability of object library.
3. Ability to support distribution of work processes.
4. Quality of help and supporting documentation and other learning results.

Table 2.1 shown summarizes of the attributes gathered from several literature in software selection. From the table, it is clearly shown the importance of attributes for software selection. Till date, there is limited study in identification of attributes in BIM software selection and development of decision analysis in evaluation of BIM software selection. Table 2.1 illustrates the domination of few attributes of software selection in past studies such as usability, performance, technical aspect, and cost.

Table 2.1

The Availability of Software Selection Attributes.

Attributes	**Authors**							
	Ayag and Ozdemir (2007)	Duran (2011)	Buyukozkan & Ruan (2008)	Altug, et al., 2006	Lai, et al., 1999	Soni, 2012	Otamendi, Pastor, & Garcia, 2008	Ribeiro, Moreira, Broek, & Pimentel, 2011
Usability	✓	✓		✓			✓	✓
Performance	✓		✓			✓		✓
Security								✓
Modularity			✓					✓
Decision Support							✓	
Connect (connectivity issues with external software)	✓		✓				✓	
User Interface					✓	✓		
Documentation						✓		
Technical	✓	✓	✓			✓		
Data file support				✓	✓			
System reliability	✓		✓					
Ease of customization			✓				✓	
Methodology system			✓					
Implementation		✓						
Update			✓				✓	
Vendor support								

Table 2.1 Continued

Attributes	Authors: Ayag and Ozdemir (2007)	Duran (2011)	Buyukozkan & Ruan (2008)	Altug, et al., (2006)	Lai, et al., (1999)	Soni, (2012)	Otamendi, Pastor, & Garcia, (2008)	Ribeiro, Moreira, Broek, & Pimentel, (2011)
Market position of the vendor			✓					
Better fit with organization system			✓					
Domain knowledge of the vendor			✓					
Reference of the vendor			✓					
Fit with parent/ allied organization system			✓					
Reputation								
Service								
Cost	✓	✓	✓	✓	✓	✓	✓	✓

2.3.4 BIM Usage in Malaysia

Malaysia was introduced to BIM in 2007, with the Multipurpose Hall of UTHM as the first project that implement BIM (Public Work Department, 2011). BIM has been implemented in two pilot project; HealthCare Center Type 5 at Sri Jaya Maran, Pahang and Admission Complex project of Suruhanjaya Pencegah Rasuah Malaysia (SPRM) at Shah Alam, Selangor. Both projects used of BIM software which was Revit software from Autodesk. Another pilot project is the Malaysia National Cancer Institute. These pilot projects were alternatives from the government in order to expose government officers to BIM (Public Work Department, 2013).

Overall BIM project in Malaysia was developed through the Design Built (DB) project delivery. This is due to the concept of BIM which required high collaboration among the project stakeholders. This situation is different in other countries that has already utilised Integrate Project Delivery (IPD) as a project delivery in BIM project. According to Ruiz (2009), BIM software selection process that fulfils the project need is not an easy task.

This is due to the numerous of BIM software available on market. In addition, the selection process also involved a number of criteria to make sure all the project needs is fulfil by the software (Ruiz, 2009). Furthermore, as mentioned before the adoption of BIM software is also involved high cost, not only in software and hardware, yet also training expenses (Kumar & Mukherjee, 2009). This problem is worsen in Malaysia, although the implementation of BIM brings various benefits to construction industry, but the adoption of BIM still is low in Malaysia. One of the reasons was mentioned by the Public Work Department director:

"It is not a problem of knowledge and information on the usage of ICT; it is always about the cost."

In Malaysia, the cost is the most influential factor in the adoption of BIM among the construction companies. However, the aid of decision in BIM software selection is largely neglected in industry. Most of the company tend to select BIM based on recommendation from software vendor or most popular software without proper analysis. Thus all of the issue illustrates the significant of decision aid in BIM software selection.

This problem can be regarded as a classical problem in Operation Research which is fall under multi criteria decision making problem. Research suggests the decision technique called Multi Criteria Decision Making (MCDM) is proven effective to deal with software selection problem.

2.4 Multi Criteria Decision Making Techniques for BIM Software Selection

Numerous decision techniques have been proposed such as decision tree analysis, statistical approach, data mining, and system dynamic in order to support decision making process. One of the popular decision techniques is Multi Criteria Decision Making (MCDM). MCDM technique acted as decision making tools in multi criteria problems that lead the user to make an effective decision. This type of decision analysis has been used since 1960 as a result of rapid growth in operation research (Alias, Hashim, & Samsudin, 2008).

Most researchers agreed that the general purpose of MCDM is to help the decision makers determine the best alternative that involve process such evaluation and comparison between the alternatives (Ozturk & Ozcelik, 2014; Tan, Lee, & Goh, 2012; Vijayvagy, 2012). MCDM can be divided into two basic approaches, they are Multi Objective Decision Making (MODM) and Multi Attribute Decision Making (MADM) (Alias, Zaiton, Hashim, & Samsudin, 2008; Kabli, 2009). In generally, MODM is more focused on mathematical framework in order to build a set of decision alternative which is not given. On the other hand, MADM is decision analysis that concentrates on problem in which alternative have been predetermined in advance.

In order to answer the research objective, this study would focus on MADM instead of MODM for solving the BIM software selection problem. Research suggests software selection can be assisted to be more effective and reliable by utilisation of MODM methods (Durán, 2011). In past, a few study has been carried out for software selection by deploying MODM method (Durán, 2011; Otamendi, Pastor, & Garcı´a, 2008; Ribeiro, Moreira, van den Broek, & Pimentel, 2011; Soni, 2008). Figure 2.3 illustrates the example of a decision hierarchy for MADM which consist of decision goal and set of criteria.

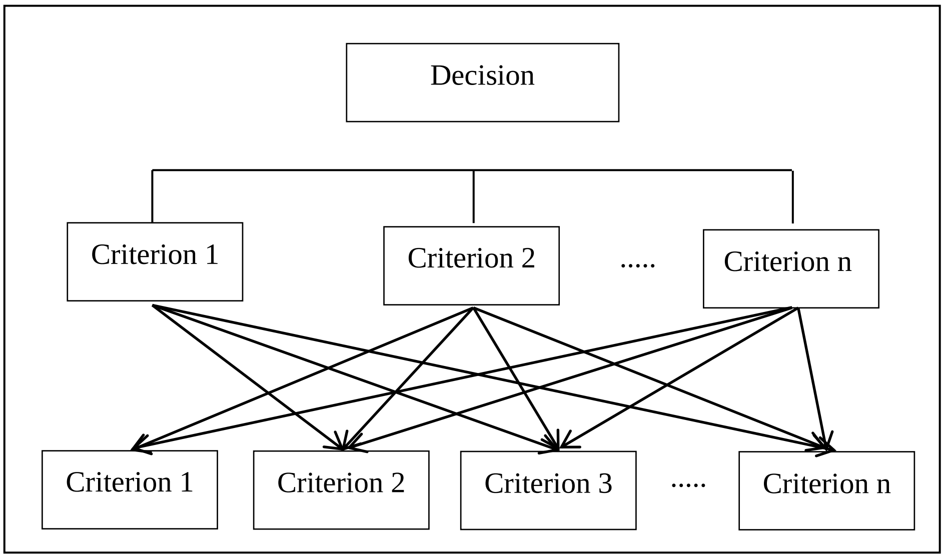

Figure 2.3. Example of Decision Hierarchy of MADM

2.4.1 MADM Methods

MADM is a decision support tools that would assisted decision makers in order to make decision over the available alternative (Kabli, 2009; Mateu, 2002). The objective of this method is to provide a set of criteria aggregation methodology based on decision maker's preferences (Soni, 2008). It focused on providing a satisfaction solution based on decision makers preference (Roh, 2012). There are several MADM methods available in literature as describes in the following section.

2.4.1.1 Simple Addictive Weighting Method (SAW)

Simple Addictive Weighting Method (SAW) is probably the most widely known and used method in MADM problem due to its simplicity advantages. SAW was utilized for the first time by Churchman and Ackoff (1954) in the portfolio selection problem. In literature, a substantial work of the MADM problem through SAW has been performed in the past (Afshari, Mojahed, & Yusuff, 2010; Chou, Chang, & Shen, 2008; Zanakis, Solomon).

2.4.1.2 Elimination Et Choice Translating Reality (ELECTRE)

Elimination Et Choice Translating Reality (ELECTRE) was introduced by Roy (1968). There are four version of Electre method; (1) Electre I, (2) Electre II, (3) Electre III and (4) Electre IV. Various version of Electre model have been developed based on the nature of the problem statement, the degree of significance of the criterion to be considered, and the preferential information. These methods enable the researcher to choose the most suitable alternative in practical decision making context (Tzeng & Huang, 2011). From MADM literature, numerous of studies have been done through Electre methods (Devi & Yadav, 2012; Montazer, Saremi, & Ramezani, 2009; X. Wang & Triantaphyllou, 2008).

2.4.1.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was developed by Saaty (1980). Since then, it has been proven as usefully decision analysis to overcome MADM problem and has been successfully applied in many research including software selection research (Durán, 2011; Lai, Wong, & Cheung, 2002; Pekin et al., 2006). The purpose of AHP is to develop a theory and provide a methodology for modeling unstructured problem. The advantages of AHP are that it easier to understand and it can effectively deal with both quantitative and qualitative data (Abdullah & Egbu, 2011; Ertu & Karaka, 2008). AHP involves pairwise comparison, priority vector generation and synthesis.

2.4.1.4 Analytical Network Process (ANP)

Analytical Network Process (ANP) was proposed by Saaty (1996). It was proposed due to limitation of AHP in releasing the restriction of the hierarchical structure, which indicates that criteria are independent from each other (Tzeng & Huang, 2011). ANP is required in decision problem that cannot be structured as hierarchy due to the interaction of higher level and low level elements (Saaty, 2011).

In a nutshell, the advantages of ANP it is not only suitable for both qualitative and quantitative data types, but it also enable the decision makers to deal with problem of independency and feedback between all features (Tzeng & Huang, 2011). From literature, ANP has been used widely in solving MADM problems (Chang, Wey, & Tseng, 2009; Huang, Tzeng, & Ong, 2005; Yang & Tzeng, 2011).

2.4.1.5 The Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

TOPSIS has been proposed by Hwang and Yoon (1981) to determine the alternative that is closest to an ideal solution (Chu & Lin, 2009; Ertu & Karaka, 2008; Saremi, Mousavi, & Sanayei, 2009; Wang, Cheng, & Huang, 2009). The basic concept of TOPSIS is to choose the alternative that has the shortest distance from Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS) (Chen, 2000).

2.4.1.6 Rank Order Centroid (ROC)

ROC is one of the methods that available for the purpose of giving a weight to a number of items ranked according to their importance. In this method, item ranks are assumed as inputs in order to convert those ranks into weights. The formulation of ROC method is shown in following formula:

$$W_i = \left(\frac{1}{M}\right)\sum_{n=1}^{M}\frac{1}{n}$$

where M is the number of items and W_i is the weight for i^{th} item.

This method is frequently used in MADM studies in the past, for example using the Multi-Attribute Global Inference of Quality technique for software testing (McCaffrey, 2009), and the lean improvement of the chemical of motor vehicles based on preference ranking (Beynon & Wells, 2008).

2.4.2 Rationale of MADM Techniques for BIM Software Selection

According to literatures on MADM, substantial works of general software selection problem have been performed in the past. For example, the selection of multimedia authoring system through AHP (Lai, Trueblood, & Wong, 1999), application of the AHP for selection of forecasting software (Pekin et al., 2006), and a case study using AHP in software selection (Lai et al., 2002). Yet, limited study has been done in the area to evaluate BIM software using MADM technique. Table 2.2 describes related studies for general software selection problem.

Table 2.2

Application of MCDM in Software Selection

Problem Description	MADM	Authors
Hybrid assessment method for software engineering decision	Hybrid Assessment Method (AHP & TOPSIS)	(Ribeiro et al., 2011)
Selection of the simulation software for the management of the operation at an international airport	AHP	(Otamendi et al., 2008)
Evaluation of point cloud software	AHP	(Soni, 2008)
Application of AHP for selection of forecasting software	AHP	(Pekin et al., 2006)
Computer aid maintenance management system selection	Fuzzy AHP	(Durán, 2011)
An intelligent approach to ERP software selection	Fuzzy ANP	(Ayağ & Özdemİr, 2007)

Due to the numerous techniques available in the literature, it is important to identify the strengths and weaknesses of the mostly used technique for BIM software selection problem. For instance, simple technique such as Weighted Sum Method (WSM) and Weighted Product Method (WPM) are an example of methods that have always been considered for solving selection problem. However, literature reveals the limitation of these methods, where it required all the criteria to be of the same type (cost or benefit) (Caterino, Iunio, Manfredi, & Consenza, 2009).

Based on this concept, it seems that this method is not suitable for the selection of BIM that involve different criteria and variable. On the other hand, TOPSIS is capable of managing each kind of judgment criteria and variable. Instead of TOPSIS, ELECTRE can also be easily applied to solve this type of problem (Caterino et al., 2009).

However, it is not possible in this study, due to some of the limitation in ELECTRE, which is that it is not able to give a complete ranking of alternative. From this limitation, Caterino et al (2008) has concluded that ELECTRE is more suitable for decision problem which consist of several alternatives and fewer criteria involve. The other method that has been considered is Simple Additive Weighting (SAW). Due to the ranking and priorities of TOPSIS, SAW and VIKOR are the same, but TOPSIS and VIKOR are better in term of distinguishing ability (Chu, Shyu, Tzeng, & Khosla, 2007). The priority setting is the same between TOPSIS and SAW, but SAW values all extremely close and it is very hard to identify the different.

AHP is the most popular MCDM methods that is widely used as a decision analysis in this type of problem. Unlike TOPSIS, AHP work through pair wise comparison for criteria and alternative instead of utilizing weight value (Ertugrul & Karakasoglu, 2008). According to Shih, Shyur, and Lee (2007) TOPSIS is better in term of handling more criterion and alternative compare to AHP. Analytical Network Process (ANP) is the extension of AHP. Thorough ANP, it not only allows decision hierarchy but also decision networks.

According to Belton and Gear (1983), ANP is better at representing reality in decision making compare to AHP. However, when the problem involves high number of criteria and alternatives and also reliability is not considered as much, then the use of ANP should be avoided (Chang et al., 2009). Moreover, mathematical demand in ANP often cause an uncomfortable issue among the decision makers (Peters & Zelewski, 2008). The development of DSS might be influenced and disrupted by these weakness (Omar, 2012). TOPSIS, on the other hand provides a better technique to help decision makers in order to select the best alternative. From literatures it has been proved that TOPSIS is more capable in dealing with more criteria and alternatives of choice.

Compared to others MADM methods, TOPSIS has been chosen as the decision analysis in this study due to its promising advantages that suit the objective of the proposed DSS. Generally, TOPSIS method involve crisp value in the evaluation process (Ertugrul & Karakasoglu, 2008; Opricovic & Tzeng, 2007; Shih et al., 2007). Under many chances crisp data are inadequate to model real life situation (Buyukozkan & Ruan, 2008). Therefore there is a need to integrate TOPSIS method with fuzzy set in decision model.

Based on the aforementioned arguments, TOPSIS is regarded as a simple yet effective analytical technique for BIM software selection due to its promising advantages as follows: (1) its concept easier to understand, (2) compared to other MADM methods, TOPSIS requires less computational effort. These characteristic of TOPSIS which is suit the criteria of DSS development. Review from literature evidence the benefits of utilizing TOPSIS in MADM problems (Chen, 2000; Chu & Lin, 2009; Saremi et al., 2009; Taylan, Bafail, Abdulaal, & Kabli, 2014; Wang et al., 2009).

2.4.3 Extension of TOPSIS under Fuzzy Environment

Fuzzy set was introduced by Zadeh (1965), a fuzzy set is a class of object with grade of memberships ranking between zero and one. The main contribution of Fuzzy set it is the ability of fuzzy set in term of representing vagueness and ambiguity data through mathematical operator and programming for the more convincing and effective evaluation process (Buyukozkan & Ruan, 2008). TOPSIS is one of the MCDM methods that has been widely implemented under fuzzy environment. The traditional TOPSIS has been proven as effective method to deal with MADM problem. This is due to the evaluation in TOPSIS process involved crisp value (Ertugrul & Karakasoglu, 2008; Opricovic & Tzeng, 2007; Shih et al., 2007).

However, under many conditions, crisp data are inadequate to model real-life situations. Therefore, Chen (2000) has proposed the extension of TOPSIS method under fuzzy environment to overcome these issues. Through his model, linguistic term has been deployed to describe the rating alternative and weight of attributes which can be expressed in triangular fuzzy numbers. According to Chen (2000), compare with other method, the vertex method is the easier ways to measure the distance between two triangular fuzzy numbers. Table 2.3 shown several integration of TOPSIS with Fuzzy elements have been done in past.

Table 2.3

Integration of TOPSIS and Fuzzy Element

Authors	Problem description
(Taylan et al., 2014)	Construction project selection and risk assessment
(Saremi et al., 2009)	TQM consultant selection in SMEs
(Wang et al., 2009	Supplier selection
(Chu & Lin, 2009).	Evaluating the competitive advantages of shopping websites
(Chu, 2009)	An interval arithmetic based fuzzy TOPSIS model

2.4.4 Preliminaries of Fuzzy TOPSIS

Chen (2000) has proposed an extension of TOPSIS for group decision making under fuzzy environment. This method has been chosen as for the selection of BIM software. Compared to traditional TOPSIS, the importance of weight of numerous criteria and the ratings of qualitative criteria are recognized as linguistic variable (Chen, 2000).

Definition of 2.1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each elementr x in X a real number in interval [0,1].The function value $\mu_{\tilde{A}}(x)$ is term the grade of membership of x in $\tilde{A}$.

Definition 2.2. A triangular fuzzy number *n* can be defined by triplet (n_1, n_2, n_3)

$$\mu_{\widetilde{A}}(x) = \begin{cases} 0 & x < n_1 \\ \frac{x-n_1}{n_2-n_1} & n_1 \leq x \leq n_2 \\ \frac{x-n_3}{n_3-n_2} & n_2 \leq x \leq n_3 \\ 0 & x > n_3 \end{cases} \tag{2.1}$$

Definition 2.3. Let $m = (m_1, m_2, m_3)$ and $n = (n_1, n_2, n_3)$ be two triangular fuzzy numbers.

If $m = n$, then $m_1 = n_1, m_2 = n_2$, and $m_3 = n_3$.

Definition 2.4. Let $m = (m_1, m_2, m_3)$ and $n = (n_1, n_2, n_3)$ be two triangular fuzzy numbers.

Then the vertex method is defined to calculated the distance between them as

$$d(m, nn) = \left[\frac{1}{3}((m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2)\right]^{\frac{1}{2}}. \tag{2.2}$$

Definition 2.5 Matrix *D* is called a fuzzy matrix if at least an entry in *D* is a fuzzy number

Definition 2.6. A linguistic variable is a variable that holds a value of linguistic terms.

The concept of linguistic variable is very useful in dealing with situations which are too complex to be reasonably described in conventional quantitative expression. For example "expertise" is linguistic variable and its values are very low, low, medium, high, and very high. These linguistic values can also be represented by fuzzy numbers.

2.4.5 Fuzzy TOPSIS Procedure

Basically "selection" problem in MCDM consist of p alternatives $A_1, A_2, A_3, \dots A_P$ and q criteria $CR_1, CR_2, CR_3, \dots CR_q$. Each alternative will take a consideration with respect to criterion q. The rating of criteria and weight with respect to each criterion can be accurately represented in the form of matrices such as

$$\text{Fuzzy Decision Matrix, } D = \left(x_{ij}\right)_{p\times q} \tag{2.3}$$

$$\text{Fuzzy weight Matrix, } W = \left(w_1, w_2, \dots w_q\right) \tag{2.4}$$

Where $x_{ij}(i = 1, \dots, p; j = 1, \dots., q)$ and $w_{j=}(j = 1, \dots., q)$. Fuzzy TOPSIS is executed by using the following steps:

Step 1:

Construct a fuzzy weight matrix, W and fuzzy decision matrix, D where x_{ij} and w_j are linguistic variables that can be shown by triangular fuzzy number as the followings:

$$X_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right) \tag{2.5}$$

$$w_j = (w_{j1}, w_{j2}, w_{j3}) \tag{2.6}$$

Step 2:

Perform normalized fuzzy decision matrix. Linear scale transformation is used to transform into comparable scale. The normalization approach preserves the property that range from [0,1] in normalized triangular fuzzy numbers. It is noted by

$$\widetilde{R} = [\tilde{r}_{p\times q}], \tag{2.7}$$

where B and C are the set of benefit attributes and cost attributes, respectively and

$$\tilde{r}_{ij} = \left[\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}, \right], j \in B; \tag{2.8}$$

$$\tilde{r}_{ij} = \left[\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a}\right], j \in C; \tag{2.9}$$

$$c_j^+ = \max_i C_{ij}, j \in B; \tag{3.0}$$

$$a_j^- = \min_i a_{ij}, \text{if } j \in C; \tag{3.1}$$

Step 3:

Construct weight normalized fuzzy decision matrix, $\tilde{V}$

$$\tilde{V} = \left[\widetilde{V_{ij}}\right]_{p\times q} \tag{3.2}$$

where $\tilde{v}_{ij} = \tilde{r}_{ij}\,(.)w_j$

Step 4

This step attempts to determine distance measurement between the Fuzzy Positive Ideal Solution (FPIS), A^{+} and Fuzzy Negative Ideal Solution (FNIS), A^{-}. Having $\tilde{V}$ as a normalized positive triangular fuzzy that ranges from 0 to 1, we can easily group the member as follows:

$$A^{+} = \left(\tilde{v}_1^{+}, \tilde{v}_2^{+}, \dots \tilde{v}_q^{+}\right) \tag{3.4}$$

$$A^{-} = \left(\tilde{v}_1^{-}, \tilde{v}_2^{-}, \dots \tilde{v}_q^{-}\right) \tag{3.5}$$

where $\tilde{v}_j^{+}$= (1.0, 1.0, 1.0) and $\tilde{v}_j^{-}$= (0.0, 0.0, 0.0). Thus, the distance measurement can be obtained by using the following equation:

$$d_i^{+} = \sum_{j=1}^{q} d\left(\tilde{v}_{ij}, \tilde{v}_j^{+}\right), \forall i = 1,2, \dots\dots, p. \tag{3.6}$$

$$d_i^{-} = \sum_{j=1}^{q} d\left(\tilde{v}_{ij}, \tilde{v}_j^{-}\right), \forall i = 1,2, \dots\dots, p. \tag{3.7}$$

Step 5

Calculate relative closeness coefficient. Choose an alternative with the maximum CC_i or rank alternatives to CC_i in descending order base on the following expression:

$$CC_i = \frac{d_i^-}{(d_i^+ + d_i^-)}, \forall i = 1,2, \ldots, p. \quad (3.8)$$

With the assumption that topsis4BIM will be used by group decision making, the final result will be calculated through group aggregation as followed:

$$x_{ij=\frac{1}{N}(CC_i^1 + CC_i^2 + \cdots + CC_i^N)} \quad (3.9)$$

2.5 Decision Support System

In the early era, DSS is only serve as an individual decision or stand-alone application, but with the current technology available, it has successfully extend the DSS technology to workgroup or teams, especially virtual teams (Bessedik, Taghezout, & Saidi, 2012; Bhargava, Power, & Sun, 2007; Sheng, Lei-shan, & Yi-xiang, 2010). According to Power (2007) , DSS can be categorised into five categories such as:

1. Data driven DSS

Types of DSS that provide the user with a summary of information from database that use different application. It enables user to analyse mostly using OLAP (Online Analytical Analysis) tools or data mining tools.

2. Model- driven DSS

A system built for the use of accounting and financial models, representation models and optimization model. It is more focused on the manipulation of a model.

3. Knowledge-driven DSS

This type of DSS was built for specialized problem solving which based on artificial intelligent technology. It is capable in giving a recommendation and suggestion to the decision makers.

4. Document-driven DSS

Documents retrieve and analysis.

5. Communication driven DSS

The system builds for the use of communication, collaboration and decision support technologies.

The evolution in DSS keep continues through the emergence of data warehouse, executive information system, OLAP and business intelligent. In early 2000's, the improvement in technology led to the evolution of DSS through knowledge driven DSS and the implementation of web DSS (Power & Sharda, 2007).

In recent trend, most of the studies in development of DSS are more focus on current technology of Information Technology (IT) such as Web 2.0 platform (Barassi & Trere, 2012; Reilly & Media, 2007). Table 2.4 list the type of problems that DSS and other AI technique deal with. Research indicates, DSS enables user to evaluate goals, explaining and predicting behaviour, evaluating alternative, making decision under conditions of risk, and allocating scarce resource to activities (Taroun, 2012).

Therefore, DSS has a great contribution to support decision makers in numerous of field including construction industry. DSS helps decision makers to make a transparent decision on an unstructured problem in construction such as delay, overrun cost, and scheduling. BIM software selection is also one of the unstructured problems in the construction industry.

Moreover, the numerous number of BIM software available on market, high cost of BIM software, and a number of attributes involved in BIM software selection has increase the complexity of BIM software selection process (Eastman et al., 2011; Ruiz, 2009). Therefore in order to deal with this issue, the need of decision tools such as DSS is necessary in BIM software selection. Furthermore, the integration of MCDM method as a decision analysis in DSS can increase the abilities of DSS in order to provide an effective solution for the decision maker.

Table 2.4

Decision Support Framework

Type of decision	Operational Control	Managerial Control	Strategic Planning	Support Needed
	Type of Control			
Structured	Account receivable, order entry	Budget analysis, short-term forecasting, personnel reports, make-or-buy analysis	Financial management (investment), warehouse location, dist ribution system.	MIS, OR models, transaction processing.
Semi-Structured	Production scheduling, inventory control	Credit evaluation, budget preparation, plant layout, project scheduling, reward system design	Building of new plant, mergers and acquisitions, new product planning, quality assurance planning,	DSS
Unstructu red	Selecting a cover for a magazine, buying software, approving loans	Negotiating, recruiting an executive, buying hardware	R&D planning, new technology development, social responsibility planning	DSS, A techniques
Support Needed	MIS, management science	Management Science, DSS, ES, EIS	EIS, ES, DSS, neural networks	

(Adopted from Averweg (2008))

2.5.1 Components of DSS Development

According to Turban et al. (2005) a standard model of DSS contains four basic components they are; database management subsystem, model management subsystem, user interface, and knowledge base management subsystem. Figure 2.4 shows the standard model of DSS model.

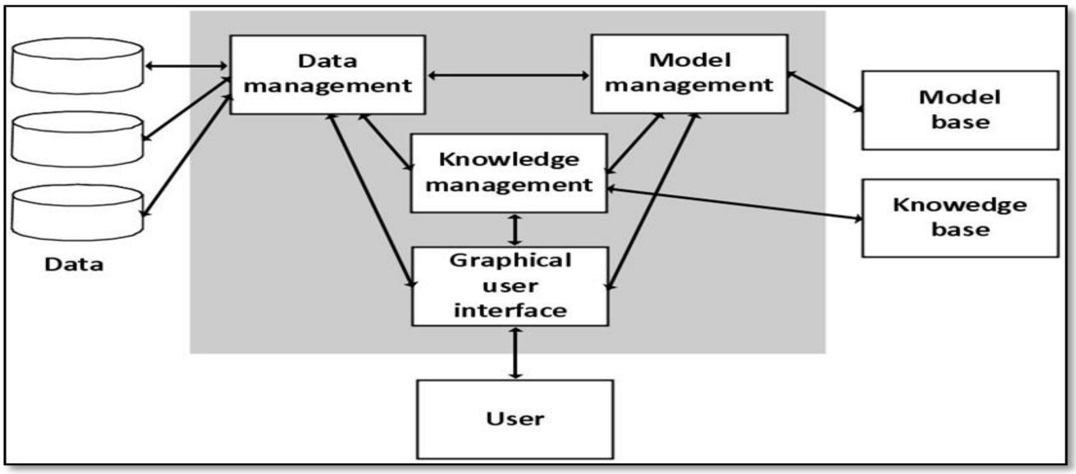

Figure 2.4. Standard Model of DSS

(Turban et al. 2005)

1. Data Management

According to Turban et al. (2005), the existence of database is significant in the development of DSS. Data based acted as storage for data, information and knowledge data that have been organized in a manner to provide the user with something that user know and also enable the user to reveal unknown value. The literature showed several database modelling techniques. One of the commonly used techniques is the Hierarchical model. Hierarchical model is a second model after the development of file system model in the 1970. The development of database in topsis4BIM was based on hierarchical model. Hierarchical model represent data by upside-down tree. Hierarchical tree can be formed based on top layer (as a level or root) and the existence of segment as children below top layer. Figure 2.5 illustrates the hierarchical data model

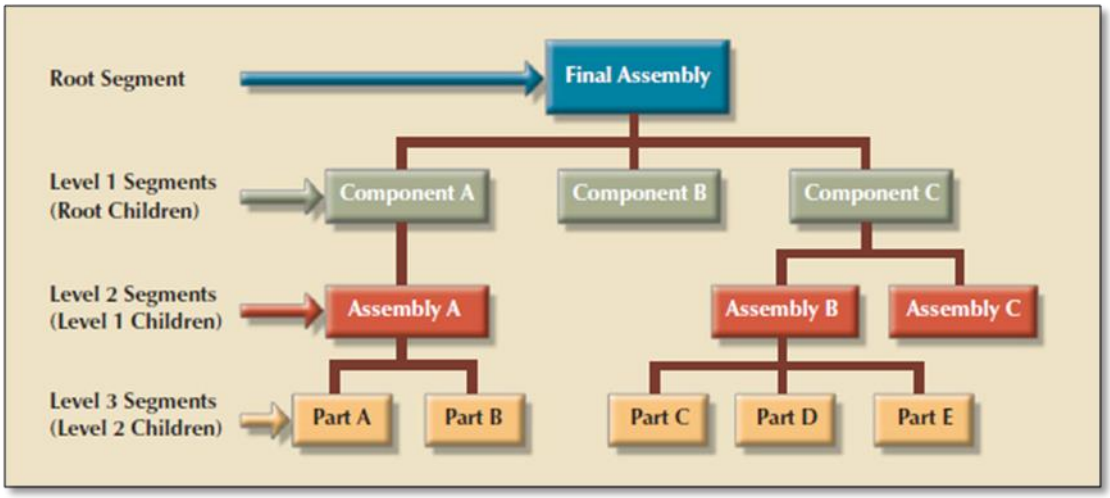

Figure 2.5. Hierarchical Database Model

(Rob & Coronel, 2009)

2. Model Management

As shown in literature, spread sheets have been frequently used as a model management in DSS. According to Power and Sharda (2007), spread sheet is a major technology for development of model driven DSS. This is due to the abilities of spread sheet packages such as Microsoft Excel which is capable of handling data and graphic capability, enable user to run “What if” analysis, and the high potential in facilitating the building of DSS (Power & Sharda, 2007).

3. User Interface

The innovation of DSS towards the World Wide Web (WWW) technology has attracted much attention from researcher worldwide. The existence of WWW technology has not only provided interactive user interface but also expended the features of DSS (Power & Sharda, 2007). In addition, the development of web-based DSS costly less, there is no requirement for specific software on the user is computer in order to run it, it would work on a web browser and internet connection to deliver the DSS support functionality to the user (Power & Sharda, 2007).

Furthermore, all type of DSS can be implement through the web technology (Banias et al., 2011; Samuel, Omisore, & Ojokoh, 2013). However, due to the rapid development of web technology, the emergence of a new concept of web technology called Web 2.0 in 2004 has simplified the development of web based DSS. Theoretically, the development of web based DSS through Web 2.0 is more simple, without any heavy programming language and yet effective.

2.5.2 Web 2.0 Technology

In year 2004, a new concept has emerged in web development which is Web 2.0. It is a generation of web that emphasizes collective intelligent, collaboration and community services (Hoegg, Martignoni, Meckel, & Stanoevska, 2006). The existence of Web 2.0 was based on user oriented, mass participant, and large of data scale and network effect (Anderson, 2007). Web 2.0 has also been addressed as a set of tools for individual to publish, share information and collaborate through web (Lee & Lan, 2007). Web 2.0 also has been known as the “read/write Web”, which allows online individual to have control over their own data and information through web (Anderson, 2007). Even through Web 2.0 has been addressed in numerous of definition in literature, there is still no clear definition of Web 2.0. Previous study only focused on Web 2.0 principle (Bessedik et al., 2012). Table 2.5 below which compare the differences between Web 1.0 and 2.0 generation. Furthermore, Web 2.0 generation was established with web MashupsAPI features (Reilly & Media, 2007). Through this feature, user can access or connect to other information from multiple sources on the web.

An example is Google Map, which allows user to drag selected map to view to see any information available (such as coordinated, weathers, distance etc.) of the region. Web 2.0 also offered flexible web design, creative reuse, and update (Aghaei et al., 2012). Web 2.0 also provides several development tools such as blog software and Wiki engines. This kind of tools allows user to create and manage their own without requiring any technical knowledge such as programming language. These tools make the web design to become easier, quicker and cheaper (Aghaei et al., 2012).

Table 2.5

General Comparison between Web 1.0 and 2.0

Criteria	**Web 1.0**	**Web 2.0**
Mode of usage	Read	Write and contribute
Unit of content	Page	Record
State	Static	Dynamic
How to content is viewed	Web browser	Browser, RSS readers, Mobile device, etc.
Creation of Content	By website authors	By everyone
Domain of	Web designer and geeks	A new culture of public research

2.5.3 Decision Support System and Web 2.0

Due to the characteristics and concept of Web 2.0 which is to enable the exchange and sharing of experience it could provide new idea and useful information that has high potential to extent the ability of (Bessedik et al., 2012). According to Power (2007) Web 2.0 is an evolving technology that seems to promise full potential and useful platform for a new generation of DSS. To date, there are several research that has been done to investigate the influence of web 2.0 towards DSS development (Aghaei et al., 2012; Bessedik et al., 2012; Chua, Goh, & Ang, 2012; Lee & Lan, 2007; Wright et al., 2009).

2.5.4 Validation of Decision Support System

According to Khazanchi (1991), the validation of DSS should be focused on DSS design, decision methodology and decision result. In parallel with his study, Borenstein (1998) also highly stressed that the validation of DSS should be focused in two main components of DSS such as subsystem validation and face validation. The main idea behind sub system validation process is to ensure the quality of component in DSS. Thus, to measure the quality in the sub system of proposed DSS which is fuzzy TOPSIS, a comparison of decision result from DMs through DSS and without DSS will be conducted. In this study, DMs were asked to rank BIM software based on their importance towards them manually without DSS.

Meanwhile, face validation can achieve consistency between designer view and user view in a timely and cost effective way (Omar, 2012). Validation of DSS is not only significant in improving the decision quality, it is also highly considered user satisfaction and acceptance (Hung et al., 2007; Lu et al., 2001). From literature in DSS field, a substantial work of DSS evaluation criteria has been performed in past. Table 2.6 gathered the common criteria used for DSS evaluation in the previous study.

Table 2.6

Measurement Criteria for DSS Evaluation

Criteria	Description	References
Perceive ease of use	Measuring the software in terms of three aspect such as 'it's easy to use', 'the process is understandable and 'it's easy to learn'	(Lu et al., 2001)
Perceive usefulness	Level of believe in methodology used towards decision making process.	(Lu et al., 2001)
Preferences	Decision making expectation and satisfaction of user	(Bharati & Chaudhury, 2004; Lu et al., 2001)
Willingness	The probability of use the model in future decision process	(Lu et al., 2001)
System Quality	Overall system quality that include the methodology and design approach	(Bharati & Chaudhury, 2004; Borenstein, 1998; Taroun, 2012)
Information presentation	Overall information about the visibility of the information such as interface design	(Bharati & Chaudhury, 2004)

DSS validation approach can be divided into three categories, they are quantitative, qualitative approach and integration of both of these approaches (Taroun, 2012). Furthermore, a combination of quantitative and qualitative approach is more effective during the development of a prototype (O'Leary, Goul, Moffitt, & Radwan, 1990). As mentioned by Nielson (2000), through qualitative validation such as heuristic evaluation is best to be evaluated by three to five evaluators. This is due to the repetition of same behaviour at the first three to five users (Nielson, 2000).

One of the qualitative approaches is validation of DSS through case study evaluation (Taroun, 2012). As mentioned by Taroun (2012), DSS validation through case study require two steps; the first is comparing result between proposed DSS with current practice method, and the second is external validation for purposed of evaluating the DSS design and methodology rather than its result. From DSS validation literature, several of studies has been utilized case study approach as medium for DSS validation (Omar, 2012; Taroun, 2012).

2.6 Chapter Summary

Decision making is the most crucial process in management in many fields including construction project management. This is due to the weakness of human decision making caused by vagueness and bias. Thus, a lot of tools have been developed in order to assist human decision making in this field. However, from literature, the need of decision aid in BIM software selection has been largely neglected. There is limited study in evaluation of BIM software selection.

Thus, this chapter has highlighted the motivation which leads to the research gaps and the approach to address the problem through the integration of Fuzzy Multi Criteria Decision Making techniques (FMCDM) and DSS for BIM software selection. This chapter also discussed the emerging technology of Web 2.0 in order to foster a better DSS development. It is identified that limited study attempt to develop DSS through Web 2.0 in construction project management.

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, a detail explanation regarding the research methodology such as research approach and data collection methods are presented.

3.2 Reasoning of Choosing Research Method

Case study methodology enables a researcher to perform a deep investigation on contemporary real-life phenomenon that enable this study method to provide a better insight into detail behaviour of the research problem (Zainal, 2007). The adoption of this research methodology has been decided due to its advantages in allows employing multiple methods for data collection purpose whether from one or more entities (people, group or organization) (Yin, 2003). Moreover, the advantages of case study are not only limited to assist the researcher to describe the data in real-life environment, but it is also capable in guiding the researcher to explain the complexity of real-life scenario (Zainal, 2007).

Furthermore, case study is also capable in dealing with numerous evident such as documents, interview and observation (Baxter & Jack, 2008). It is suitable in case of BIM software selection that required depth investigation in term of identification of attributes, selection process, and validation of proposed DSS. Baxter and Jack (2008) also highlighted that the case study is also suitable for a study that has small sample size. This is in line with current situation of BIM in Malaysia. Although, BIM has been introduced in Malaysia since 2007, but the adoption of BIM among the construction players BIM is still far from matured (Haron, 2013). In addition, the used of the case study is in line with the research objective which is to develop a Web based DSS prototype for BIM software selection problem in industry. Thus, an adoption of are real case study is significant in order to developed, demonstrate and evaluate the usability of the proposed DSS. Thus, case study method has been chosen as a research design in order to understand the problem, requirement and decision making scenario for development of DSS for BIM software selection.

A real case project which is Dewan Sultan Ibrahim project has been selected to demonstrate the proposed decision support tool. In Malaysia, there are several of BIM project in Malaysia such as Healthcare Centre Type 5 project in Pahang, Primary school of Meru Raya project in Perak, National Cancer Institute of Malaysia project, Educity Sport Complex in Nusajaya project in Johor and Ancasa Hotel in Pahang (Latiffi, Mohd, Kasim, & Fathi, 2013). However, Multi-Purpose Hall project as known as Dewan Sultan Ibrahim project in Johor has been selected to demonstrate the proposed decision support tool in this study. This is due to its project backgrounds. Construction Research Institute of Malaysia (CREAM, 2012), considered Dewan Sultan Ibrahim project as fast track BIM with Design Built project. Thus, this project has been expected can be used as a guide for government, higher education and institute project BIM by CREAM.

In literature, the selection of software through case study has been widely used from literature in the past (Gencer & Gürpinar, 2007; Mulebeke & Zheng, 2006; Ziaee, Fathian, & Sadjadi, 2006). There are four steps in the case study research method as proposed by Yin (2003):

1. Design case study
2. Conduct case study
3. Analyse the case study
4. Develop the conclusion, recommendation and implication

This study follows the step as indicated by Yin (2003).

3.3 Research Process Framework

The following Figure 3.1 illustrates each phase and its research activities.

Phase	Activity	Method	Output
One	Literature Review	• Extensive search of literature	Awareness of the problem
	Data Collection (Decision making requirement)	Case study (Requirement) • Documented analysis • Semi structured interview with decision makers	To achieve the 1st objective of this study
Two	Conceptual Decision Model development	Level of detail, example of preference from the user (Test decision model in MS Excel)	To achieve 2nd objective of this study
Three	DSS development	Programming • Web base development • Database development	
Four	Evaluation of DSS	Validation of the DSS Prototype: • System Validation • Face Validation	Case study - User input and testing of the prototype - To achieve 3rd objective of this study
	Conclusion and findings	Conclusion, finding and future research	

Figure 3.1. Research Process Framework

This research framework consists of four main phases in order to complete:

1. Phase One: The Literature review and Data collection
2. Phase Two: Conceptual Decision Model Development
3. Phase Three: Decision Support System Development
4. Phases Four: An Evaluation of DSS and Conclusion

All these phases will be briefly discussed in the next sub section.

3.3.1 Phase One: Literature Review and Data Collection

1. Literature Review

There are two sections in chapter two. Section one is more on BIM and its related topics. This is where the gap in this research was found. Extensive analyses of literature of BIM in construction led to identifying the need of decision aid in BIM software selection.

Since the adoption of BIM through the project life cycle, the investigation starts with a general scope which is the fundamental of construction project management. The next sub-section focuses on the BIM related issue. The literature review has revealed numerous of BIM software available and much of the advantages of BIM in the effectiveness of construction project. An intensive review on attributes of software selection particularly in BIM software selection is performed. In addition, in order to developed database features, document analysis through literature, software manual in order to identify the attribute for BIM software selection and retrieve the software information (function, features, and system requirement) have also been conducted.

Section two was the literature review on proposed methods for the selection of BIM software which is the integration of DSS and MCDM. Literature showed that a sustainable work of MCDM of general software selection has been done in the past. This is significant in order to prove the effectiveness of MCDM method to deal with this type of problem. The literatures also review numerous DSS applications that have been implemented in construction field in the past. This has identified that the needs of DSS in order to enhance construction management.

2. Data collection

In this study, there are two types of data involved in data collection. The primary data would be obtained from semi structured interview among the BIM users within the company and organization document procedure. The semi structured interview has been chosen due its characteristics. Semi structured interview enable the researcher to gain foreseen information through a combination of specific and open ended question (Hove & Anda, 2005). This study has utilized case study protocol by Yin (2003) which consists of design case study, conduct case study, analyse the evident and case study report.

Case Study procedure for Phase One:

1. Designing case study protocol

The protocol involves an overview of case study project, data collection and its instrument and a guide for the case study report. The purpose of case study protocol is to increase the reliability of case study research (Yin, 2003).

2. Conduct the case study

Due to the advantages of the case study methodology, the data used in this research were mainly collected through several sources such as semi-structured interview, software manual and website. Regarding the research objectives, three respondents who were involved directly with selection of BIM software in Dewan Sultan Ibrahim project were chosen as decision makers (DMs). For the first objective, the DMs were asked to validate and suggest any attributes for BIM software selection that are relevant in Malaysia.

The semi-structured interview has been conducted with the purpose of acquiring primary data (real attributes) which is significant in solving BIM software selection problem. According to Yin (2003), semi-structured interview will enable interviewer for further enquiries by asking open-ended questions. The selection process of BIM software has been be discussed during the interview. In addition, DMs were asked regarding the attributes and decision criteria on BIM software selection (Appendix C).

3. Analyse the case study evidence:

According to Yin (2003), data analysis in case study includes examining, categorizing, tabulating or other evident to address the purpose of a study. In this research, the data gathered has been transformed into decision hierarchy for the development of subsystem.

4. Case Study Report

The purpose of case study report is to develop the conclusion, recommendations and implication of this research.

3.3.2 Phase Two: Conceptual Model and DSS Development

Result from case study was utilized in development of conceptual model for the DSS. Output of case study is significant in providing an in depth understanding of BIM related issues from the company perspective for development conceptual model. This will link up with the first objective of this study, which is to identify attributes for BIM software selection. All attributes of the BIM gathered from previous phases was transformed into formulation of a decision model through MCDM method which was Fuzzy TOPSIS. Decision model was built in Google Spread sheet.

3.3.3 Phase Three: DSS development

Next, in order to provide a more powerful decision support tools, integration of MCDM in web DSS has been deployed in this study. Due to the emergence of Web 2.0 through cloud technology, the web based DSS is designed and developed. In addition, a database features BIM software information such as function, features, and system requirement. This phase addressed the second objective of this study, which is to develop DSS prototype namely topsis4BIM for BIM software selection.

The topsis4BIM does not only provide analytical decision tools, yet it also provides a database features consisting of profiling of BIM software such as function, features and system requirement. The development of database in this study was conducted through hierarchical database model as mentioned in 2.5.1. All information was gathered through document analysis such as software brochure, literature and vendor website.

3.3.4 Phase Four: Evaluation of DSS and Conclusion

1. Validation and evaluation process

Once the development of proposed DSS is completed, it needs to be evaluated and validated by the DMs in order to measure the effectiveness and usability of the DSS which is the third objective in this research. The significant of DSS validation has been discussed in Chapter Two.

From literature, the integration of case study and user tester has been widely used in DSS validation. For example, Taroun (2012) used case study and user tester in qualitative approach in DSS validation. The instruments for data collection are user tester and semi structured interview. The framework of DSS validation in this study involved two level of validation; these are sub system validation and face validation (Borenstein, 1998). Moreover, validation of DSS should be focused on DSS design, decision methodology and decision result (Khazanchi, 1991).

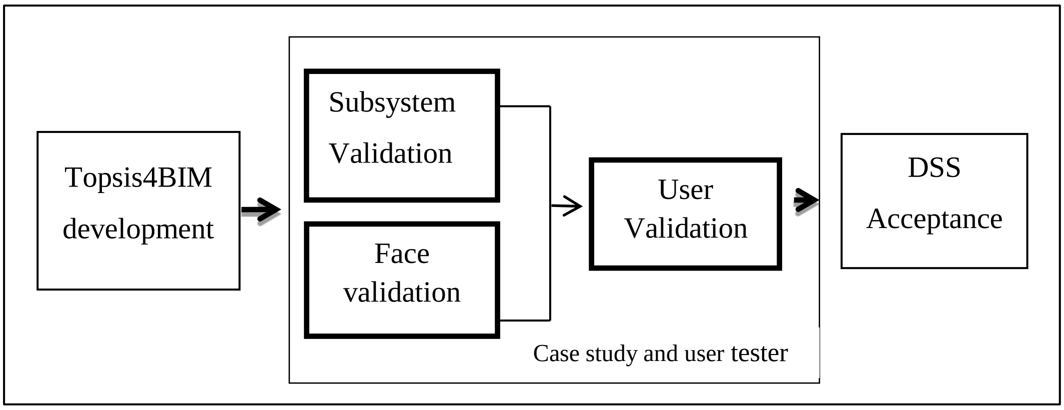

Figure 3.2. The Validation Framework for topsis4BIM

Case study protocol for phase four:

1. Design case study protocol

The same DMs in phase 1 are involved in this phase. Before the evaluation of topsis4BIM, they are debriefed orally and with some questionnaire due to the purpose and procedure of DSS evaluation. Thus, DMs acted as evaluators in this section.

2. Conduct the case study

The evaluation process of case study started with subsystem validation and continued with face validation.

Subsystem validation: This evaluation is important to test the logic of the decision model. A real construction project namely Dewan Sultan Ibrahim were analysed. The evaluators were asked to fill assessment of BIM software selection by using DSS.

Face validation: This evaluation is more on measurement of methodology and design approach of proposed DSS rather than measurement of result efficiency. This face validation has been conducted in quantitative approach and qualitative approach.

For quantitative, user evaluation forms were distributed to evaluators in two phase, the first one in first iteration (Pre design) and second iteration (Post design) (Appendix F). The evaluators were asked to rate the DSS based on a few criteria provided in the form. According to Borenstein (1998), the rating of each criterion is between Very Good (VG), Good (G), Fair (F) and Poor (P).

Furthermore, the evaluation is also followed up by semi structured interview to collect additional input from evaluators regarding the design approach of this DSS through qualitative approach such as content analysis. The evaluators were asked to answers subjectively. In this validation, the evaluators are also free to browse the system.

3. Analyse case study evident

The analysis methods for both validations are qualitative in nature.

Subsystem validation:

The result based on Fuzzy TOPSIS decision model revealed the pattern of decision among DMs. Group decision ranking of BIM software from DMs were analysed and compared with the result of DMs from the current practice. Then, the evaluators were asked to rank the alternative software based on their experience and judgement without the DSS. Simple calculation such as Rank Order Centroid (ROC) has been done to determine weight from result. Then, a comparison of group decision rank between without DSS and topsis4BIM has been performed.

Face Validation:

For the quantitative approach in face validation, results from the first iteration and second iteration have been calculated by percentage. On the other hand, result in qualitative approach has been analysed through analysis content.

4. Case study report

Develop the conclusions and implication of the case study.

5. Conclusion and Finding

The final activities for this propose study is the conclusion and finding. All activities before this would lead to research conclusion and finding.

3.4 Chapter Summary

This chapter focuses on the research methodology used in this study. The research study carried out here is based on case study. From literature, case study has been recognised as the most approach to present and understand a real world problem. There are four phases which consist of literature review and data collection, conceptual model, DSS development, and evaluation DSS and conclusion. This research methodology is demonstrated by employing Dewan Sultan Ibrahim as the case study. Each phase and research activities will link to research questions and objectives.

CHAPTER FOUR
DESIGN AND IMPLEMENTATION OF DSS

4.1 Introduction

This chapter is focused on phase two of the research process which covers on the conceptual model and development of proposed web DSS called topsis4BIM. In detail, it also represents the implementation of result from data collection for the development of decision model and web based DSS for BIM software selection.

4.2 Case Study Description

As mentioned in the Chapter three, in order to demonstrate our approach, a real case project, which is Dewan Sultan Ibrahim has been chosen as a case study. This is due to the project background and project result through implementation of BIM. This project is the is the first government project through BIM (Latiffi, Mohd, & Brahim, 2014). As mentioned before in previous chapter, Construction Research Institute of Malaysia (CREAM, 2012) considered Dewan Sultan Ibrahim project as fast track BIM with Design Built project. Thus, this project has been expected can be used as a guide for government, higher education and institute project BIM by CREAM. The selection of BIM has been done through current practice which is more on recommendation and campaign from software vendors and recommendation from Construction Industry Development Board (CIDB). Thus, considered these issues, this project has been chosen as case study.

This section will describe the background of this project as a case study in this study and related issues on the BIM system in the project. Dewan Sultan Ibrahim, is located at Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia. Table 4.1 illustrates the details of the case study project.

Table 4.1

Case Project Detail

Project	**Dewan Sultan Ibrahim**
Cost	RM 30, 555,000
Project Duration	1 ½ Years
Project Delivery	Design and Built (DB)
BIM consultant	Integrated Project Management Solution (IPMS) Sdn. Bhd.

Figure 4.1. Dewan Sultan Ibrahim

4.2.1 Case Study: Dewan Sultan Ibrahim Result

Semi structured interview has been carried out with a few decision makers who were involved as decision makers in this project whom are Consultant, Architect and BIM Coordinator. The interview aim is to identify the real attributes for BIM software selection and focus on understanding of the current practice of BIM software in Malaysia. However, in order to develop a usable DSS, respondents were asked to give their opinion for classification of BIM software that may be relevant to Malaysia construction industry.

There are three decision makers namely DM1, DM2 and DM3 involved in this study. They possess vast experience (at least involved in four or more BIM project in Malaysia) in development of BIM project. Each of them is a different background in construction such as DM 1 (Consultant), DM 2 (Architect) and DM 3 (BIM coordinator). Throughout this thesis, all decision makers will take part in decision of BIM software selection.

Table 4.2

Respondent Profile

Decision Makers	**Background**		
	Position	**Work experience**	**Number of involvement in BIM project**
DM 1	Consultant	12 years	8
DM 2	BIM Coordinator	16 years	12
DM 3	Architect	25 years	5

As mentioned in previous chapter, before conducting a semi-structured interview with the BIM expertise and decision makers, an intensive literature review has been done by filtering and categorizing software selection attribute using MCDM from 8 journals. As a result, there are 58 attributes found and only 50 were related to selection of BIM software. From those journals, 35 attributes fall under technical, 11 management and 4 under cost. It also has been identified that there were a few redundant attributes which can be categories to similar group of attributes. Therefore, as a conclusion, the literature review yield 15 technical, 8 managerial and 1 cost as illustrated in Appendix A.

Figure 4.2 shown the graph indicating the frequency of criteria found and filtered in software selection literature. Meanwhile, Figure 4.3 illustrates the decision hierarchies for software selection based on attributes that have been collected from Appendix C. There are three main attributes i.e. technical with 15 sub criteria, managerial with 8 sub criteria, and cost. In addition, an alternative is denoted as BIM software A_n.

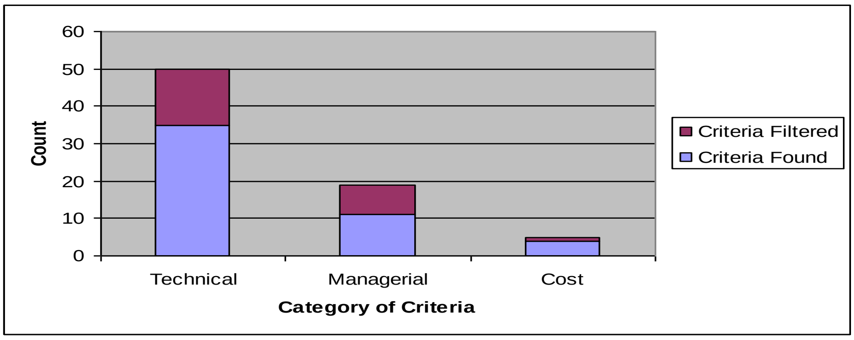

Figure 4.2. Frequency Attributes found in some Literature

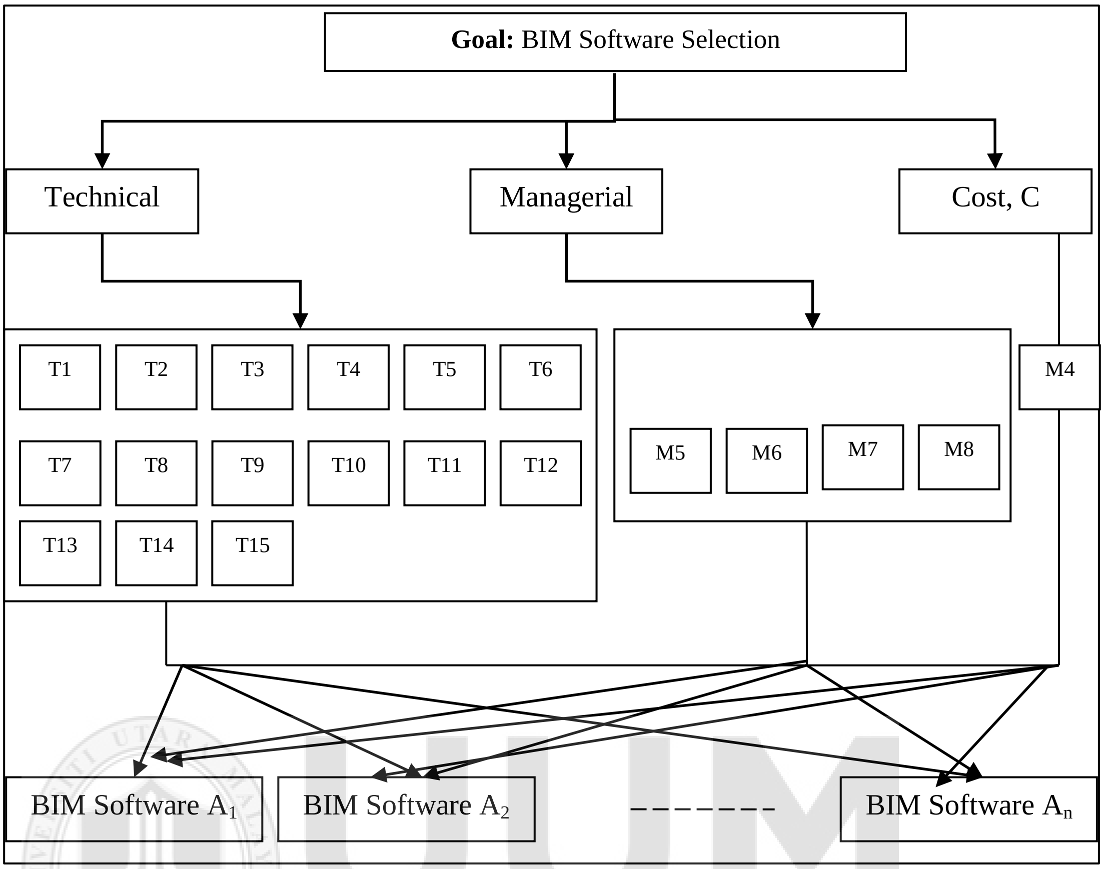

Figure 4.3. Hierarchical of Selection Attributes

A set attributes of software selection was gathered and filtered from literature for the development of questionnaire. Based on that, a brief questionnaire was distributed to decision makers. During the session, decision makers were asked to select attributes that are relevant to BIM software selection in Malaysia. They were also asked to suggest any additional attributes that relevant to BIM software selection in Malaysian construction project. Table 4.3 summarize the attributes selection from the respondents.

Table 4.3

Attributes for BIM Software Selection

Categories	Selection attribute	DM 1	DM 2	DM 3
Technical	Usability	✓	✓	✓
	Performance	✓	✓	✓
	Security			
	Modularity			
	Decision Support			
	Connect (connectivity issues with external software)	✓		✓
	User Interface			
	Documentation			
	Technical Futures			
	Data file support	✓	✓	✓
	System reliability			
	Ease of customization			
	Methodology system			
	Implementation			
Managerial	Update			✓
	Vendor support	✓	✓	✓
	Market position of the vendor			
	Better fit with organization system			
	Domain knowledge of the vendor	✓		
	Reference of the vendor			
	Fit with parent/ allied organization system			
	Reputation			
	Service			
Cost	Cost	✓	✓	✓
Additional attributes	Collaboration	✓	✓	✓
	Facility Management	✓	✓	✓

In the Table 4.3, there are ten attributes selected by the decision makers namely as A1, A2, A3 and A4 are from technical attributes, A5, A6, A7 are from managerial attributes, and A8 is from cost attribute. In addition, two attributes namely A9 and A10 have been suggested by decision makers fall under technical categories. The Table 4.3 shows that respondents are more focused on the technical categories. The table also shows that there are differences in attributes selection while accomplishing the assessment. The preferences among the decision makers varied and are mostly based on their background, existing knowledge and skills. However, they agreed that the suggested two additional attributes such as collaboration and facility management were mostly used for BIM software selection in Malaysia. The reason behind these two attributes is due to the most of the BIM vendor in Malaysia such as Autodesk and Bentley categorised their entire product according to these attributes. Table 4.4 describes the selected attributes of BIM software selection.

Table 4.4

Description of Selection Attributes

Attributes	Label	Descriptions
Usability	A1	Measurement usability of software.
Performance	A2	Performance of software in task.
Connect (connectivity issues)	A3	Connectivity issues with external software (such as spread sheet, and pdf).
Data file support	A4	Ability to support numerous of data file used in BIM such as DWG, DWF, DXF and DGN.
Update	A5	The availability of update and improve software (R&D capability).
Vendor support	A6	The support from vendor in term of consultancy, communication, and guide.
Domain knowledge of the vendor	A7	Including length of experience, software history and vendor popularity.
Cost	A8	This attributes include required cost for software adoption (such as software, hardware and training expenses).
Collaboration	A9	Ability of software to perform collaboration function.
Facility Management	A10	Ability of software to perform facility management function (In term of scheduling, and documentation).

Apart from decision attributes used in BIM software selection, it is also important to identify the available BIM software in Malaysia. Table 4.5 summarized brief profile software vendor that is available within the construction industry in considered for the UTHM project. There are five BIM software that has been suggested by decision makers which Autodesk Revit (S1), eMRIS (S2), Autodesk Naviswork (S3), TEKLA structures (S4) and AECOsim Building Designer (S5). All the information in the Table 4.5 was gathered from software vendor website, brochure and literature.

Table 4.5

Brief Profile of BIM Software Vendors

Software vendor	Description
Autodesk	- Autodesk is an American multinational corporation that was founded in 1982. This corporation is involved in 2D and 3D design software, particularly in architecture, building construction and manufacturing. - This corporation name is already synonym within the construction players due to its software AutoCaD and it is still widely used nowadays.
Bentley	- This company was founded in 1984, and it is already becoming an important competitor in construction industry due to its popular software Microstation. - Nowadays, this company is intensively involved in the development of BIM software that is capable of drawing, modelling and analysis ability digitally.
Tekla	- Tekla Corporation was founded in 1966 in Espoo, Finland. This corporation is recognised as a structural design software company, however it moves on to the BIM environment. - To date, Tekla has been widely used in 100 countries and since 2011, Tekla has been a part of the Trimble Group.
Ascension Technology	- This software was developed by Ascension Technology SDN.BHD located in Kuala Lumpur. This company is the technology provider for construction industry in Malaysia. - eMCRIS is the first home-ground affordable BIM software in Malaysia

As a result, there were ten attributes were used in the evaluation and a decision hierarchy is established accordingly. There are three level in the decision hierarchy structured for BIM software selection. The overall goal of the decision process determined as “BIM software selection” is in the first level of the hierarchy. Next is the attributes in the second level (A1, A2, A3, A4, A5, A6, A7, A8, A9, and A10) while third level is for the alternative BIM software (S1, S2, S3, S4, S5). Decision hierarchy structured with determined alternative for BIM software selection is provided in Figure 4.4.

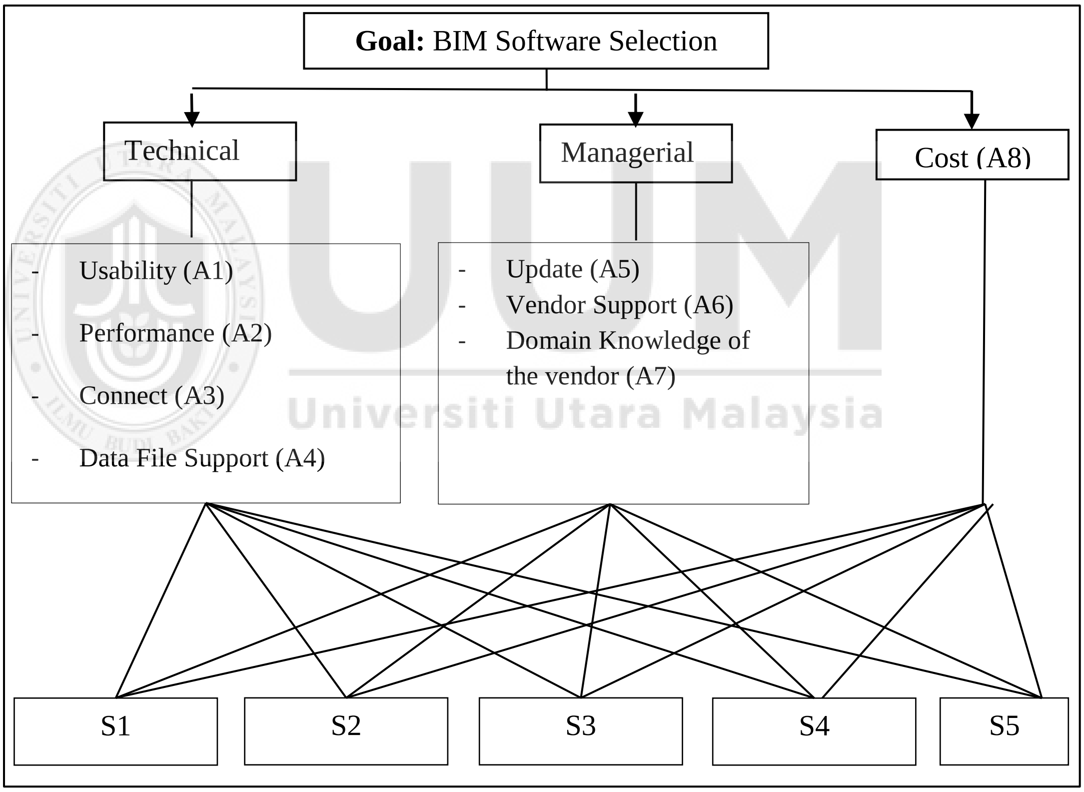

Figure 4.4. Decision Hierarchy for BIM Software Selection

Within the interview session, instead of selection attributes (Q1) and additional attributes (Q2) in BIM software selection questions, decision makers were also asked a few additional questions (Q3, Q4 and Q5) regarding BIM software within their organization. Table 4.6 illustrates the semi structure interview results among the decision makers.

Table 4.6

Semi-structured Result

Other Questions	Description
Q3: Please state what is the main purpose BIM use in your project?	- "We used BIM to support project management decision process such design demo (Dewan Sultan Ibrahim project), modelling, scheduling, analysis, cost and time"… (DM1) - "As a BIM practitioner, our company used BIM to design demo model (Dewan Sultan Ibrahim project), modelling, coordination, and clash analysis"... (DM2) - "To date we only used BIM for design demo model (Dewan Sultan Ibrahim project), modelling and some of building analysis"...(DM3)
Q4: Who is responsible party in BIM software selection decision making?	- "Architect or Project manager who have significant influence in decision of BIM adoption. Because these people who are going to use it "...(DM1) - "Contractor and owner"…(DM2) - "Suggestion comes from architect, but the final decision is made by owner, the one would make an investment in BIM adoption"...(DM3)
Q5: Please name the BIM software that involve in your project?	- "Autodesk Revit and Naviswork"... (DM1) - "Autodesk Revit and Naviswork"...(DM2) - "Autodesk Revit"...(DM3)

Based on this semi-structured result, the decision makers in this study have similar purpose when using BIM which is for modelling, design and building analysis. For Question 4 (Q4), DM 2 and DM 3 responded that the suggestions to purchase software usually came from architecture or contractor, but the final decision is up to the owner of the company. On the other hand, DM 1 addressed that the one who are responsible for decision making in BIM software are the architect and project manager. This is due to the fact that most of the BIM features are related with architect and project manager line of work. The decision makers in this study have used Autodesk in their project.

4.3 The Implementation of topsis4BIM

This section continued with the implementation of Fuzzy TOPSIS and Web based DSS. The purpose of this section is to address the second objective in this study. As been mentioned in Chapter Two, MCDM techniques such as TOPSIS have been proven to yield a reliable decision making output. However, the original TOPSIS have been developed by Hwang & Yoon (1981) consist of crisp data in evaluation process which inadequate to model real life situation.

By considering this, a fuzzy TOPSIS model has been developed to handle the issue of uncertainty. In order to generate reliable result in BIM software selection, instead of crisp value, linguistics variable has been used in fuzzy TOPSIS assessment. The used of linguistics variables such as very high, high, fair, poor, can help decision maker to give a precise judgement in weighting and rating process of BIM software selection.

4.3.1 Decision Model Development

A basic preliminary of Fuzzy TOPSIS has been discussed in previous Chapter 3. In this study, Fuzzy TOPSIS algorithm has been developed based on formal definition in section 2.4.4. Figure 4.5 shows the overall TOPSIS process for BIM software selection.

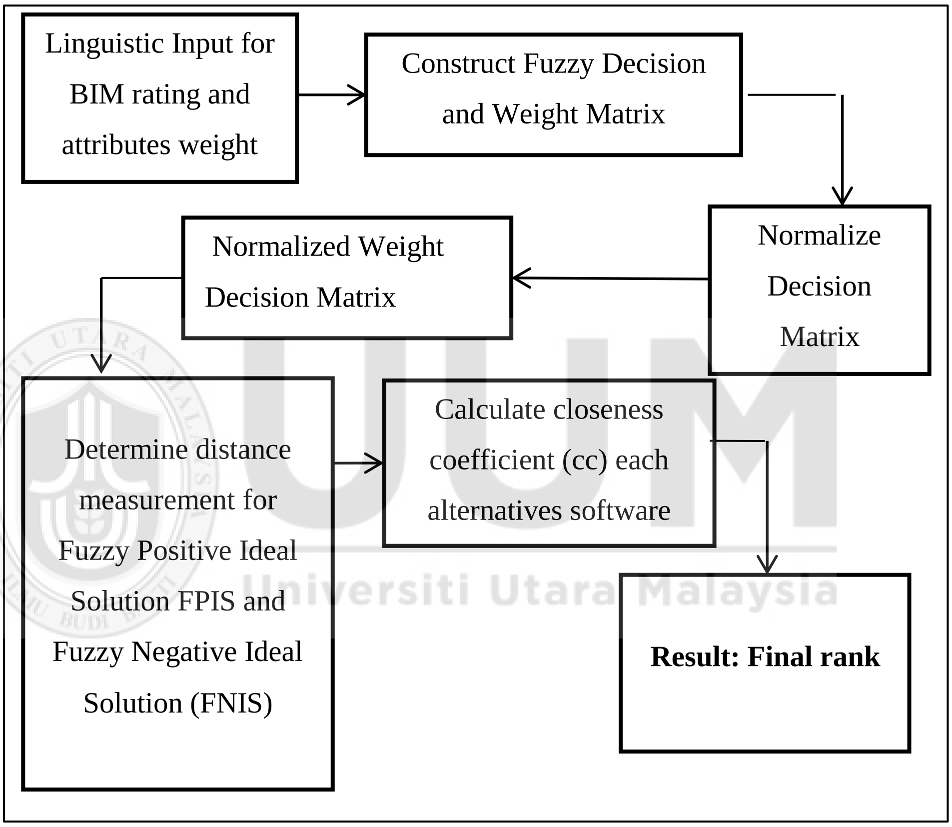

Figure 4.5. Fuzzy TOPSIS in topsis4BIM DSS

In this study, DSS is designed through fuzzy environment in order to deal with the vagueness of human judgment. Thus, the input in topsis4BIM is based on linguistic input. This membership function is used to store the linguistic input from user. The fuzzy numbers are generated as input for the purpose of weight and rating as shown in Table 4.7 and Table 4.8.

Table 4.7

Linguistic Variable for the Importance of Weight of Attributes

Linguistic variables	**Fuzzy Number**
Very Low	(0,0,0.1)
Low	(0,0.1,0.3)
Medium Low	(0.1, 0.3, 0.5)
Medium	(0.3, 0.5, 0.7)
Medium High	(0.5, 0.7, 0.9)
High	(0.7, 0.9, 1.0)
Very High	(0.9, 1.0, 1.0)

Table 4.8

Linguistic Variable for the Importance of Rating for Alternative Software

Linguistic variables	**Fuzzy Number**
Very Poor	(0, 0, 1)
Poor	(0, 1, 3)
Medium Poor	(1, 3, 5)
Fair	(3, 5, 7)
Medium Good	(5, 7, 9)
Good	(7, 9, 10)
Very Good	(9, 10, 10)

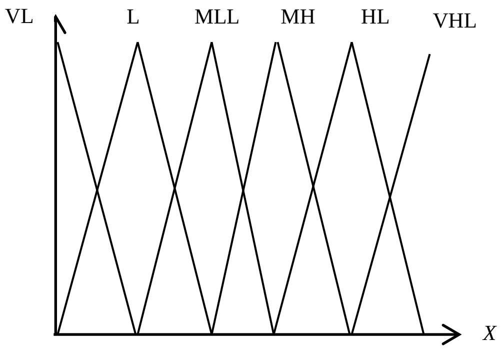

Figure 4.6. Linguistic Variables for the Importance of Weight

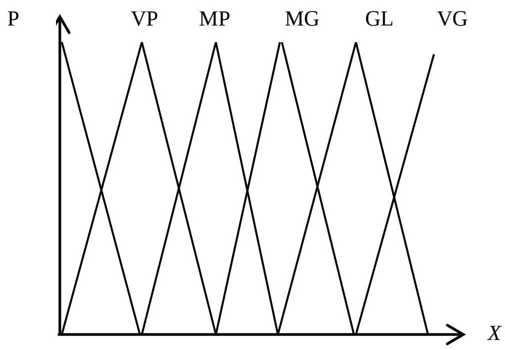

Figure 4.7. Linguistic Variables for the Rating

The above abstraction can be depicted into user interface as follows. In Figure 4.8, decision makers are required to assign linguistic weight for each attributes such as VL, L, ML, M, MH, H, or VH.

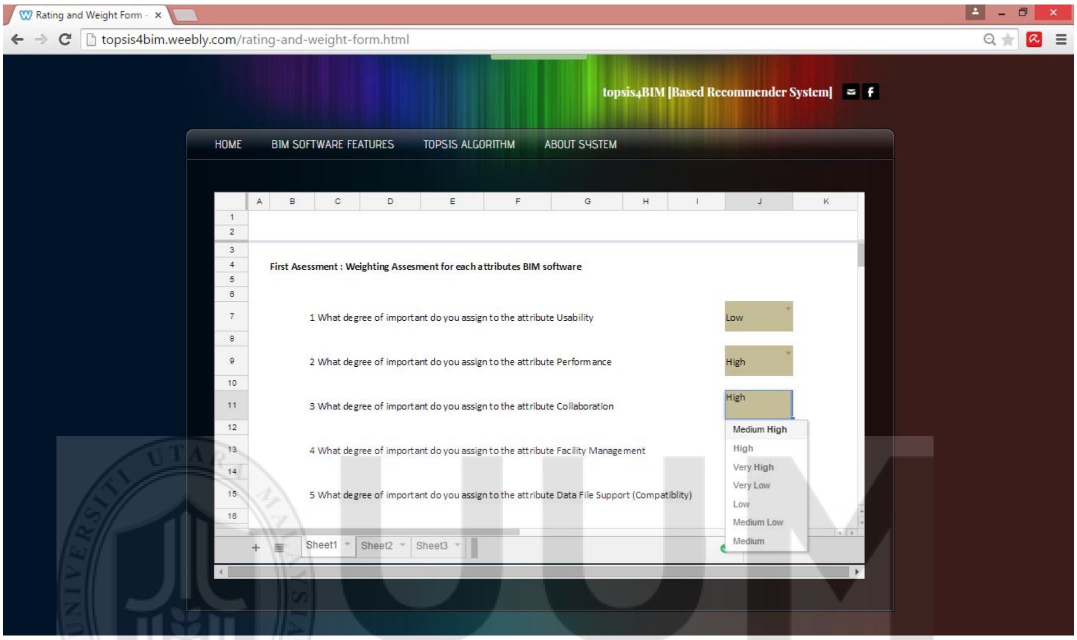

Figure 4.8. Linguistic Inputs for Weight Assessment

Figure 4.9 depicts the linguistic input for rating assessment. Each of BIM software is assigned variable VP, P, MP, F, MG, G, or VG. During this assessment, software details (such as features and function) are viewed to access software with respect to each attribute.

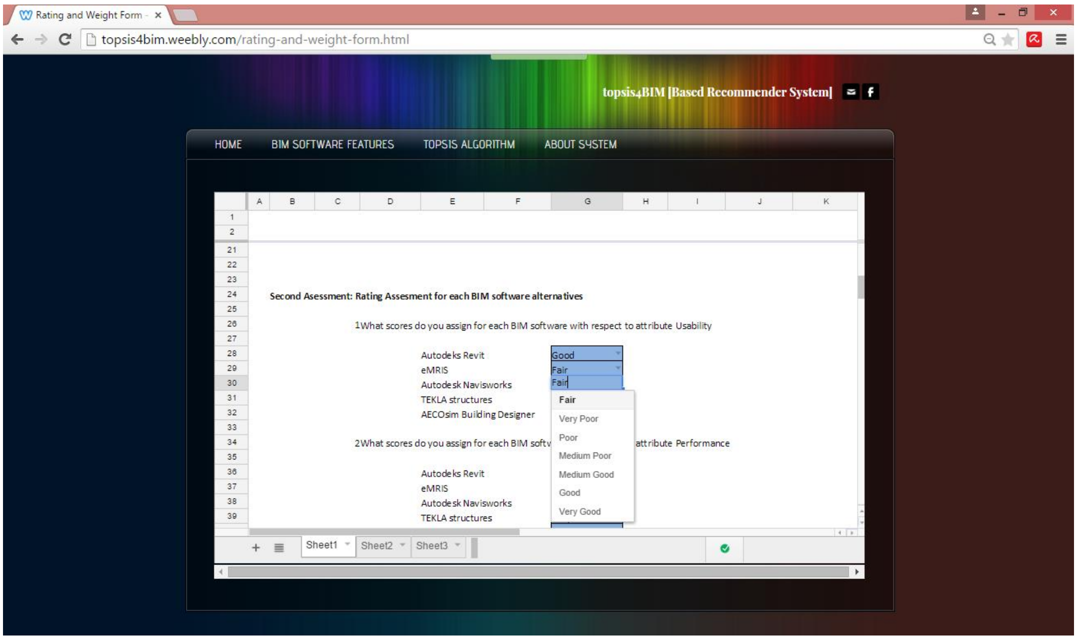

Figure 4.9. Linguistic Inputs for Software Rating

4.3.2 The Architecture of topsis4BIM

After the development of the decision model Fuzzy TOPSIS, the next phase is the development of topsis4BIM. As mentioned in Chapter Two, due to the promising advantages of Web 2.0 technology in enhancing the DSS development, topsis4BIM was developed by using cloud computing technology. Figure 4.10 has shown the architecture of topsis4BIM that are involved in the main component; they are Model Management, Database and User Interface.

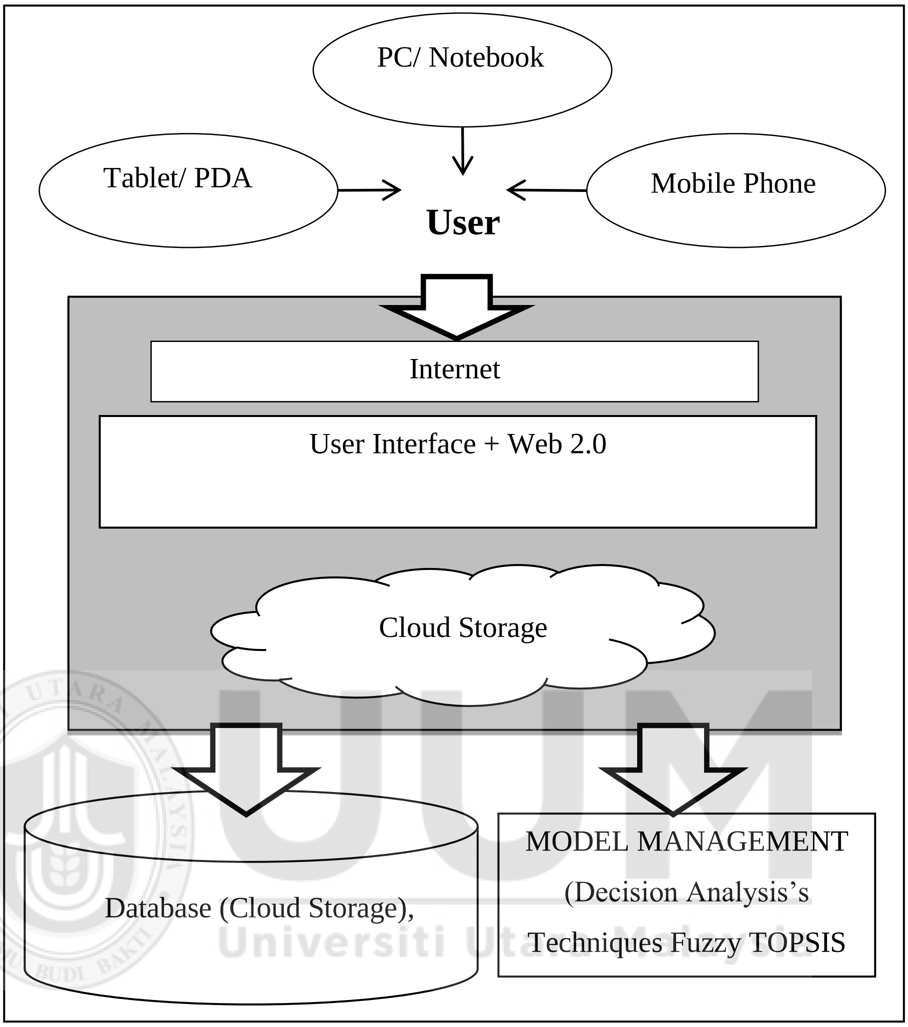

Figure 4.10. The Architecture of topsis4BIM

The development of DSS through Web 2.0 provides numerous of advantages such as easy to developed, light programming language, interactive user interface and remote access. As a sub-system in this DSS, a fuzzy TOPSIS decision model has been developed through one of the product from Google product called Google Spread sheet. Literature review revealed the domination of Microsoft Excel as DSS generator in the past. This is due to the ability of MS Excel in handling data, graphic, and enabling user to performed "what is analysis" and etc. However, in order to increase the usability and utility of topsis4BIM DSS, Google Spread sheet offered more advantages than Ms Excel which is more of a standalone application.

Unlike traditional DSS, topsis4BIM can be easily access through web. In order to enhance the decision making process for decision makers during BIM software selection, topsis4BIM also provides database function, to keep information of BIM software profile such as its features, function and system requirement. Document analysis is performed by filtering and categorizing BIM software information in hierarchical database model through vendor website, software template and literature. Figure 4.11 represents the hierarchical database model in developing in topsis4BIM.

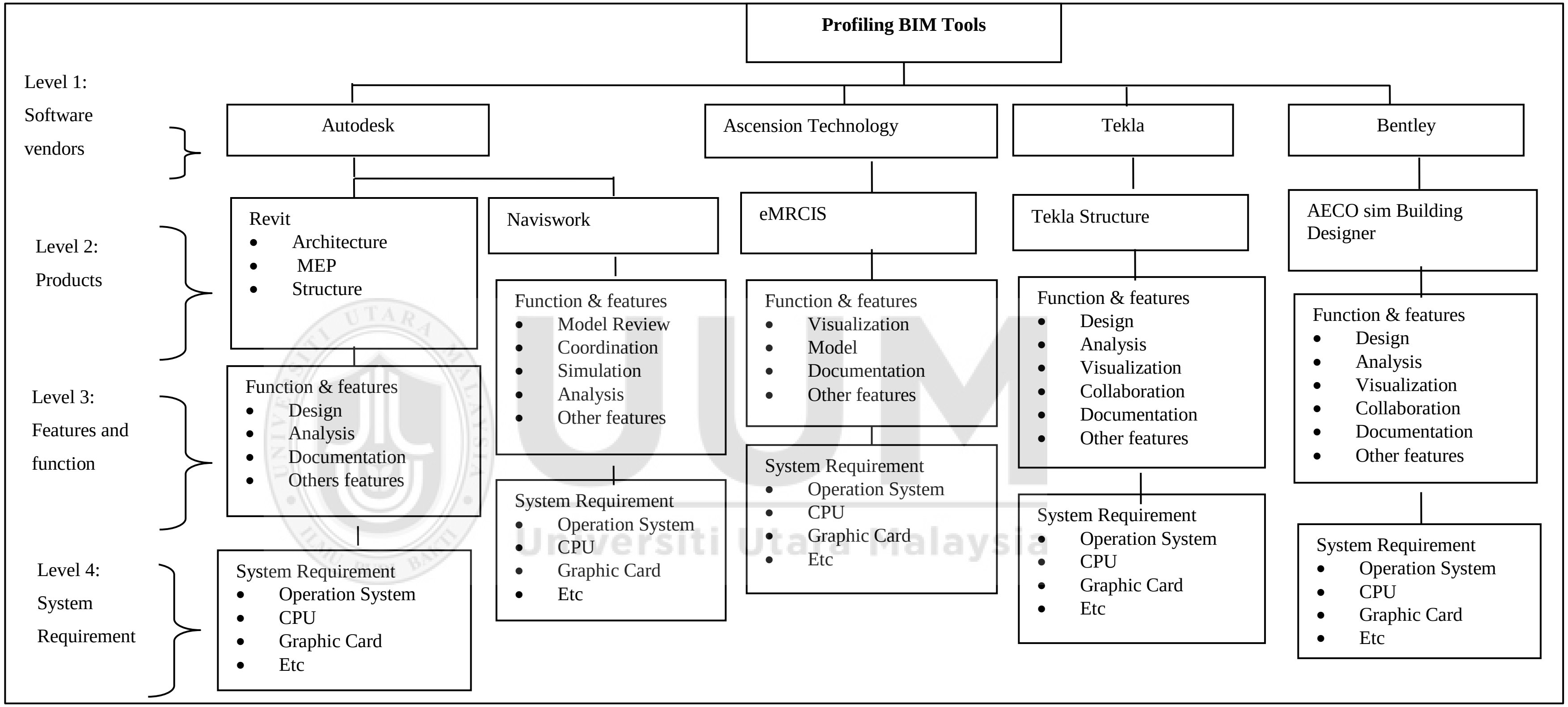

Figure 4.11. Hierarchical database model for profiling BIM software

4.4 Chapter Summary

This chapter reported the result from phase two of the research process that involves documental analysis, interview session, the design of decision model and the architecture of tospis4BIM. Interview session has been conducted among the three decision makers (DM 1, DM 2 and DM 3) through case study project. All the decision makers who are involved in this study are directly related to the Dewan Sultan Ibrahim project. They have at least four years of experience in BIM project and involved in at least four BIM projects in Malaysia.

As a result, ten attributes have been identified from the case study result. These attributes have been categorised into three groups. The first group was technical (Usability (A1), Performance (A2), Connect (A3), Data File Support (A4), Collaboration (A9) and Facility Management (A10). Two of these attributes (A9 and A10) were suggested by the DMs. The next group was managerial (Update (A5), Vendor Support (A6), Domain Knowledge of the vendor (A7). The third group of attributes was Cost (Cost (A8)).

In addition, there were five BIM software, namely Autodesk Revit (S1), eMCRIS (S2), Autodesk Naviswork (S3), TEKLA structures (S4), and AECOsim Building Designer (S5) have been addressed as an alternative in BIM software selection among the decision makers. Based on these findings, a decision hierarchy for BIM software selection has been developed and discussed in section 4.2.1. Finally, section 4.3, it covers the development of decision model based on finding in previous section, the architecture and features of topsis4BIM DSS.

CHAPTER FIVE
VALIDATION AND DISCUSSION

5.1 Introduction

The design aspect of topsis4BIM has been discussed and presented in previous chapter. Thus, there is a need to measure the performance the DSS that has been developed. The primary purpose of this chapter is to validate the topsis4BIM in terms of its logic, effectiveness, usability and utility, which will address the third research objective "To evaluate utility and usability of the decision support tool". The topsis4BIM process evaluation has been conducted in two phase, first is validation of the sub-system of the DSS which is fuzzy TOPSIS. In this phase, the comparison between the result yield from topsis4BIM and without the proposed DSS has been conducted.

Next, for the purpose of validation of the level of satisfaction and preference of decision maker towards this web based DSS, evaluators were asked to use decision model through Google spread sheet and with web based topsis4Bim. Then, the face validation was performed to further evaluate topsis4BIM in terms of usability and utility of the system. Meanwhile, the evaluation process in this phase is more on the physical side of the DSS, regardless of the result evaluation. Hence, the evaluation process and outcomes demonstrate topsis4BIM ability to be utilized in real world application. This chapter ends with a discussion and interpretation on the findings of the overall research activity.

Sub-system evaluation involves an observation of DSS utilization during the decision making process by the decision makers based on UTHM case study in chapter 5. The results were collected from user input and sample set of questionnaire in the system design in Chapter Five (section 5.2). Similar attributes described in section 5.12 (Chapter 5) were used. They included *usability* (A1), *performance* (A2), *connect* (A3), *data file support* (A4), *update* (A5), *vendor support* (A6), *domain knowledge of the vendor* (A7), *cost* (A8) and two suggestions attributes namely *collaboration* (A9) and *facility management* (A10). The same alternatives were used in the development of this sub system i.e. *Autodesk Revit* (S1), *eMCRIS* (S2), *Autodesk Nawiswork* (S3), *Tekla Structures* (S4), and *AECOsim Building Designer* (S5). The next paragraph illustrates the application of decision model using topsis4BIM by decision maker for the Dewan Sultan Ibrahim.

As stated before, the decision model in topsis4BIM was developed based on the ten attributes and five alternatives in BIM software. Initially, the assessment in fuzzy TOPSIS decision model requires a set of linguistic input from the decision makers (DM 1, DM 2, DM 3) for weight assignment with respect to each validate attributes. Then, decision makers were required to enter the rating for each BIM software alternatives. Result for weight and rating assignment were presented in Table 5.1 and Table 5.2. Once all the assessment was completed by the decision maker, topsis4BIM activates the decision model that utilized fuzzy TOPSIS procedure as follows:

1. Develop fuzzy decision matrix and fuzzy weight.
2. Develop fuzzy normalized decision matrix.

3. Develop fuzzy weighted normalized decision matrix.
4. Determined separation from ideal solution, S^+.
5. Determined separation for negative ideal solution, S^-.
6. Calculate distance measurement.
7. Calculate relative closeness coefficient to ideal solution (cc_i).

The final result for Dewan Sultan Ibrahim is shown in Table 5.3.

5.2 Decision Model Evaluation

As mentioned in section 4.3.1 in previous chapter, decision maker were asked to weight attributes and rate alternative via linguistic variable. For example, Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (ML), High (H), and Very High (VH) and rate alternative (Very Poor (VP), Poor (P), Medium Poor (MP), Fair (F), Medium Good (MG), Good (G), and Very Good (VG) as follows;

Table 5.1

Weight of Attributes by Decision Makers

Attributes	**Linguistic Variables**		
	DM1	DM2	DM3
A1	VH	H	MG
A2	H	H	VH
A3	H	-	VH
A4	H	VH	VH
A5	-	-	MH
A6	MH	M	MH
A7	M	-	-
A8	MH	VH	M
A9	VH	H	VH
A10	M	M	M

Table 5.2

Rating for Software Alternative by Decision Makers

Attributes	**Software alternatives**	**Rating**		
		DM 1	DM 2	DM 3
A1	S1	F	G	MG
	S2	F	F	MP
	S3	G	F	G
	S4	G	G	MG
	S5	G	G	G
A2	S1	VG	VG	F
	S2	F	F	G
	S3	F	F	G
	S4	VG	VG	MG
	S5	G	VG	G
A3	S1	G	-	F
	S2	F	-	F
	S3	G	-	MP
	S4	G	-	G
	S5	MG	-	VG
A4	S1	G	G	G
	S2	F	F	F
	S3	G	F	F
	S4	G	G	G
	S5	G	G	G
A5	S1	-	-	MG
	S2	-	-	MG
	S3	-	-	F
	S4	-	-	MG
	S5	-	-	G
A6	S1	G	P	MG
	S2	F	P	F
	S3	G	P	F
	S4	G	P	F

Table 5.2 continued

	S5	G	P	F
A7	S1	G	-	-
	S2	F	-	-
	S3	G	-	-
	S4	G	-	-
	S5	F	-	-
A8	S1	G	F	F
	S2	P	F	F
	S3	P	MG	MG
	S4	G	G	G
	S5	G	VG	VG
A9	S1	G	VG	MG
	S2	F	F	F
	S3	G	VG	MG
	S4	F	VP	MG
	S5	G	G	F
A10	S1	G	F	F
	S2	F	P	MP
	S3	G	G	G
	S4	F	P	P
	S5	MG	F	F

Table 5.3

Result for Each Decision Makers

Alternatives	DM 1		DM 2		DM 3	
	Closeness coefficient	Rank	Closeness coefficient	Rank	Closeness coefficient	Rank
S1	0.69	2	0.68	1	0.63	2
S2	0.44	5	0.33	5	0.49	5
S3	0.76	1	0.46	3	0.58	4
S4	0.65	4	0.41	4	0.63	3
S5	0.66	3	0.57	2	0.69	1

The abstraction of fuzzy TOPSIS calculation is compiled in appendix D. Table 5.3 illustrates the differences of ranking obtained between the decision makers. For DM 1, it is identified that S3 ranked the highest CC valued followed by S1, S4, S2, and S5. Meanwhile, for DM 2, it is slightly different, where S1 ranked the highest followed by S5, S3, S4 and S2. On the other hand, for DM3, S5 has the highest CC value followed by S1, S4, S3 and S2.

These differences resulted due to the differences of decision maker background and differences objective of using BIM software. However, there was a similarity in result of decision makers, with S2 score the least. This is due to the fact that S2 is still new in the market leading to less implementation evident from industry. Next, the group aggregation result is presented in Table 5.4.

Table 5.4

Group Aggregation Result

Alternatives	**DM 1**	**DM 2**	**DM3**	**Group closeness coefficient**	**Group Rank**
	Closeness coefficient for each DMs				
S1	0.69	0.68	0.63	0.666	1
S2	0.44	0.33	0.49	0.42	5
S3	0.76	0.46	0.58	0.6	3
S4	0.65	0.41	0.63	0.5633	4
S5	0.66	0.57	0.69	0.64	2

This group aggregation result shows that; Software S1> Software S5> Software S3> Software S4> Software S5. The group rank result yield software S1 as the best software for this case study. Software 1 is the same software that has been used in the Dewan Sultan Ismail project.

5.3 Sub-system Validation

The development of topsis4BIM is not for predicting value or recommending actions. Its main purpose is assisting the decision makers in organizing the decision making problem and doing the required calculation. Although some of the DMs are using the same attributes, it is may still yield a different result when using different weighting for each attribute and rating assessment. Moreover, each DMs in this study came from different background in construction that has different needs of BIM application. For these reasons, topsis4BIM has been validated by comparing the result from DSS with current practice result (Without DSS).

It is significant to perform a comparison between the current practice (without DSS) and topsis4BIM. The results of current practice were obtained during the interview session with the decision makers. The decision makers were asked to rank BIM software based on their intuition (without using topsis4BIM). Thus, in order to determined weight from DMs, Rank Order Centroid (ROC) has been utilized. Table 5.5 below illustrates the result from DMs without DSS, followed by Table 5.6 which demonstrated the comparison between the decision making result without DSS and topsis4BIM.

Table 5.5

Decision Pattern without DSS

Decision Approach	**Software**	**Ranking Position**					
		DM 1		DM 2		DM 3	
		Rank	ROC	Rank	ROC	Rank	ROC
Without DSS	S1	2	0.26	1	0.46	2	0.26
	S2	5	0.04	5	0.04	4	0.09
	S3	3	0.16	3	0.16	5	0.04
	S4	1	0.46	4	0.09	3	0.16
	S5	4	0.09	2	0.26	1	0.46

Table 5.6

Decision Pattern in Group Decision Approach

Decision Approach	Software	Group ROC	Group Rank
Without DSS	S1	0.33	1
	S2	0.056	5
	S3	0.12	4
	S4	0.24	3
	S5	0.27	2
	Software	**Group closeness coefficient**	**Group Rank**
topsis4BIM	S1	0.66	1
	S2	0.42	5
	S3	0.6	3
	S4	0.56	4
	S5	0.64	2

Table 5.6 shows the comparison of pattern of decision making output among the decision makers without DSS and with DSS. The comparison table shows that topsis4BIM yield almost similar result compare to current practice. Therefore, this demonstrates decision model can be considered as valid in term of its logic.

5.4 Face Validation

The comparison result between topsis4BIM and current practice were presented in the previous section. Next, topsis4BIM it is validated through face validation. The topsis4BIM face validation involves quantitative and qualitative instruments.

5.4.1 Quantitative Result

The level of satisfaction of decision makers toward topsis4BIM was measured through four level of satisfaction there are Very Good (VG), Good (G), Fair (F) and Poor (P). Four criteria were adopted from literature for this purpose (Perceive ease of use, perceived usefulness, preference and willingness). 12 sub-criteria derived from the literature were gathered as follows:

1. Perceive ease of use:
    - 1.1: Easy to use
    - 1.2: The process is understandable
    - 1.3: It is easy to learn
2. Perceived usefulness
    - 2.1: This model helps me control the whole decision process
    - 2.2: It makes the decision process easier
    - 2.3: It is useful to me in making a decision
3. Preferences
    - 3.1: I like to make a decision with this model
    - 3.2: I like to analyse information with this model
    - 3.3: I like to judge in this way
4. Willingness
    - 4.1: I accept the procedure of this decision model for future decisions
    - 4.2: I will apply this model for hard decisions in the future
    - 4.3: It is worthwhile to use this model in the future

Table 5.7 illustrates the decision maker's response to assess the ability of topsis4BIM.

Table 5.7

Result of Face Validation in terms of Decision Methodology

Validation criteria	Sub questions	Iteration 1 (Pre Design)				Iteration 2 (Post Design)			
		VG	G	F	P	VG	G	F	P
C1	Easy to use	0	100	0	0	0	100	0	0
	Understandable	0	33.4	66.666	0	0	100	0	0
	Easy to learn	0	100	0	0	0	100	0	0
C2	Decision control	0	66.6	33.4	0	0	66.6	33.4	0
	Decision process easier	0	66.66	33.4	0	0	100	0	0
	Useful	0	66.66	33.4	0	0	100	0	0
C3	Like to make decision	0	66.66	33.4	0	0	66.66	33.4	0
	Like to analyse	0	66.66	33.4	0	0	66.66	33.4	0
	Like to judge	0	66.66	33.4	0	66.6	33.4	0	0
C4	Accept the procedure	0	66.66	33.4	0	0	66.66	33.4	0
	Will apply	0	33.4	66.66	0	0	33.4	66.66	0
	Worthwhile	0	33.4	66.6	0	0	100	0	0

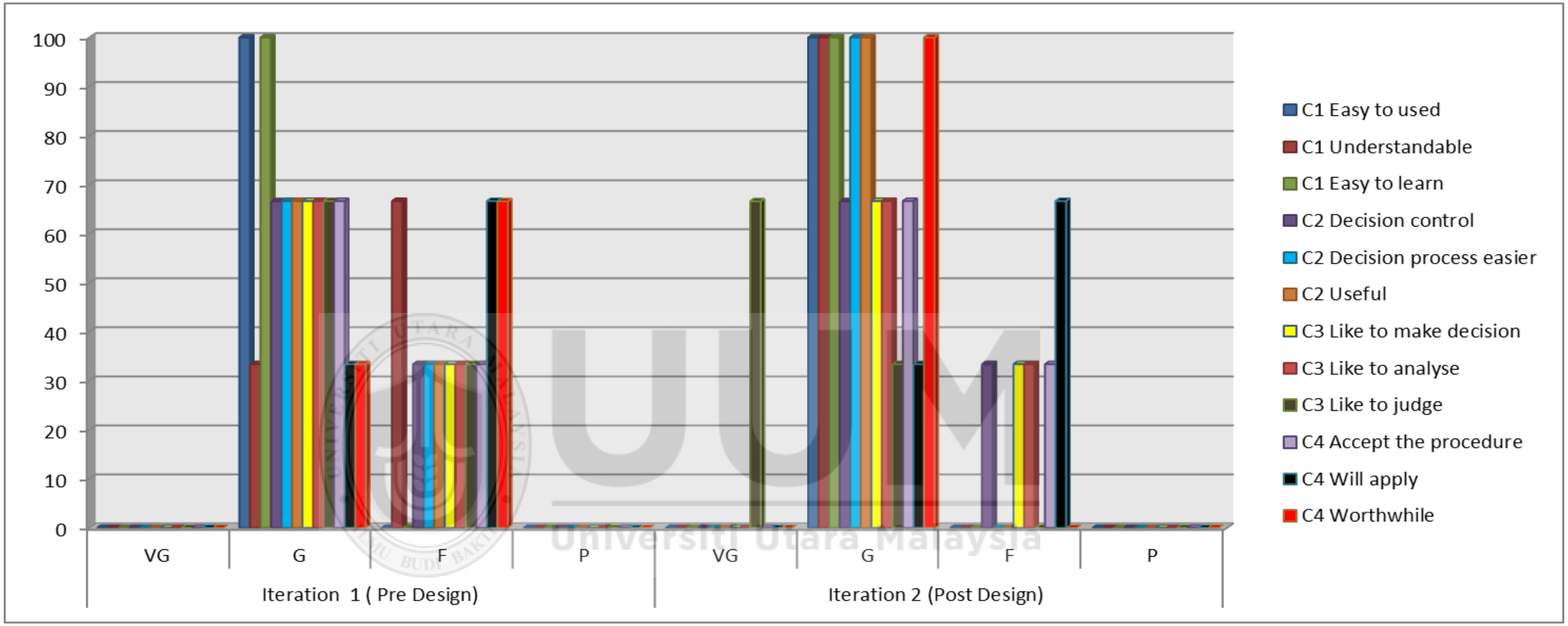

Figure 5.1 Result of Face Validation in 1st Iteration and 2nd Iteration

In Figure 5.1, the result shows the satisfaction of decision making process among the evaluators. In the post design, several of sub questions criteria show significant improvement in terms of ease to use, easier decision process, usefulness and worthwhile.

5.4.2 Qualitative Result

The semi structured interview focused on the other dimension in topsis4BIM. The questionnaire considers the following attributes to measure the validation of this DSS:

1. System Quality
2. Information Presentation

Evaluators were asked to give their feedback and responds towards their perception of topsis4BIM usability. The interview session results are briefly transcribed in Table 5.8.

Table 5.8

System Quality and Information Presentation Face Validation Result

Validation attributes	**Answers**
System Quality	- "The development of this DSS is quiet practical, straight forward, and also convenient to access. What important is we really need to know what to input. I really interest to seen what value this DSS would generated. Moreover, as a user I can access this DSS with any device that connect to internet and all data are store through could storage. That is pretty update technology used. In term of decision used Fuzzy TOPSIS has a potential as for structuring problem and worth of trying as decision tools for BIM software selection in future"...DM1 - "This DSS and its methodology behind it is easy to understand, easy to learn, remote, plus it help you structured your problem, and do the calculation, it's interesting and got potential, but I still need time to build confident on the Fuzzy TOPSIS, coz I am not familiar with this kind of decision techniques. The design approach of this DSS is interesting, accessible and form it not required high cost"...DM2 - "It is simple DSS, easy to learn and used, plus the integration with social network is interesting. For the decision process methodology, before using this DSS, a few more things need to be set first. For example, for example, I need to know all the alternative software before using this method. The problem is, not all the user has experience variety of BIM software in Malaysia. I mean, I cannot simply evaluated each of the alternative software without has experience it first, right? This issue, I think it would affect the result of this decision model. Other than that, I think this DSS has a potential"...DM3.

Table 5.8 Continued

Validation Attributes	Answer
Information Presentation	- "It is good to see a web based that user friendly, simple, informative and not to colourful. For me, I like the way of this web based presented. The interface look simple but interesting, the portion of each option is nicely organized. I don't know what other people think, for me the information presentation in this DSS was good"...DM1. - "For the information presentation I think this DSS still lack of something. The idea of using and display information thorough Google Doc is interesting. For example the way of this DSS present all information on BIM software. This section is good, however the way decision model presented in this DSS, the user interface of Google spread sheet is not impress me. It would be better if try to hide the Google spread sheet interface. Other than that, it quite good"... DM2. - "All the information presented (display format, graphic, interface) in this DSS for me it's clear, simple yet interesting and suit it purposed. However, there still has space for improvement. It would be better if this DSS come out with login form, instead of log in in Google account its self"...DM3.

System Quality

The objective of topsis4BIM is to assist DMs in BIM software selection decision making process. The topsis4BIM offers web decision approach that is simple, accessible and capable of dealing with uncertainty environment. Thus, each of the DMs agreed that the topsis4BIM is easy to use and convenient to access, and the methodology behind it which is fuzzy TOPSIS has a potential as a decision making tool for BIM software selection. However, beside DM1, DM2 and DM3 have expressed their concern in the effectiveness of fuzzy TOPSIS.

Even though they believed that fuzzy TOPSIS is capable of structuring the problem, but they required more time to have the confident in it. This due to the risk involved in BIM software selection such as high investment. DM3 also adds if the evaluator has already experience all the alternatives, and evaluate them wisely, then the effectiveness of the result will be increase.

Information Presentation

Information presentation is significant in order to measure the effectiveness of adoption Web 2.0 tools in web DSS. In conclusion, DM1 and DM3 gave positive answers regarding the design of web based interface, display format and graphics in this topsis4BIM. However, DM3 also came out with the suggestion to add login form as one of the web based features. On the other hand, DM2 seemed not satisfied with the way the decision model was presented. He argued that the decision model presented in this topsis4BIM can be improved in the future.

5.5 Discussion of Research Finding

This section provides discussions of the results and findings based on the accomplishment of research framework in this study. The analysis and discussion are focus point on the clarification of the quantitative and qualitative data contained in Chapter Five (design and implementation of DSS) and Chapter Six (the validation of DSS) and understanding of the concept identified in the literature review. The accomplishment of research framework in this study has enabled the author to answer research objectives in this study which is to develop decision support for BIM software selection in Construction Project Management. This section has been organized as follows:

1. Identify attributes for BIM software selection in Malaysia (5.5.1)
2. An alternative approach of BIM software selection (5.1.2)
3. A new generation of Web based DSS architecture (5.1.3)
4. Model finalization (5.5.4)

Three phases of this study have been conducted in order to achieve research objectives and also to answer research questions. Phase one was divided into two activities which were literature review and data collection. The literature review aimed to investigate the implication of BIM software selection towards construction project management. Based on the review of literature in software selection domain, this study has managed to identify 26 attributes related to software selection (see Figure 4.3). The data collection in this phase through case study was to identify and validate real attributes for BIM software selection in Malaysia.

Result from previous phase was used in phase two for further development of conceptual model and DSS for BIM software selection. Phase three in this study concentrated on the evaluation and validation of decision support system for evaluating BIM software. The accomplishment of research framework in this study has led to three main achievements which are:

1. Identification of attributes for BIM software selection in Malaysia

The discussion and clarification in this achievement was based on the interview findings in identification and verification of attributes that are relevant to BIM software selection. (Answer the first objective)

2. An alternative approach of BIM software selection

The discussion and interpretation involved the integration of quantitative data and model development from case study for development of topsis4BIM. (Answer second objective)

3. A new generation of web based DSS architecture

The discussion and interpretation in this achievement related to the contribution to knowledge in DSS field by development of topsis4BIM.

From the literature, it is suggested that developing a decision model for BIM software in Malaysia project construction management is possible. Moreover, the literature from DSS and MCDM domain have shown the potential of Web based as a decision tools for BIM software selection.

5.5.1 Identify attributes for BIM software selection in Malaysia

Due to the complexity in BIM software selection decision making, this study has employed simple questionnaire to identify and validate the critical attributes for BIM software selection in Malaysia. As mentioned by Soni (2008), a set of attributes in software selection is the most important element that can affects the software acquisition decision. However, there is limited study that attempts to investigate crucial attributes for BIM software selection in literature. Figure 5.2 below shows the identifications of BIM software attributes in Malaysia.

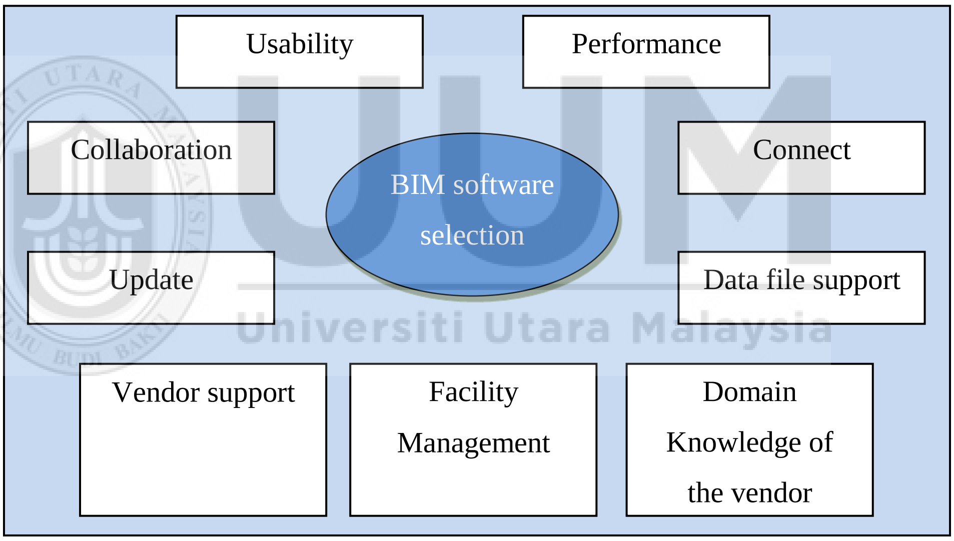

Figure 5.2. Attributes for BIM Software Selection in Malaysia

Result from semi-structured and questionnaire in this study has expanded the general attributes in BIM software selection that was proposed by AEC (2007). It is identified that most DMs in this study are more concern and critical with technical attributes in BIM software selection decision making. This is consistent with Ruiz (2009) who found that the importance of technical attributes to be included in the

BIM adoption and decision process. Moreover, result yield another significant attributes which is cost in BIM software selection in Malaysia.

In line with work by Ruiz (2009), cost has also been highly rated by DMs in this study as the most important attribute that can influence decision making in BIM software selection in Malaysia. This is due to the involvement of high cost in BIM adoption, in term of the software and hardware and training cost. This finding is supported by Enegbuma and Ali (2011) who found that cost has strong relationship in BIM adoption in Malaysia industry. Managerial attributes were also mentioned by DMs in this study. These attributes are usually considered as less of a priority in BIM selection. Two out of three decision makers in this study believed that managerial is a less important attribute influencing their choice. This study also revealed two additional attributes that were suggested by decision makers which are collaboration and facility management.

These attributes are significant in order to provide a guide for construction players in BIM software selection and enhance the adoption of BIM in Malaysia in the future. This finding has answered the first objective which is to identify the critical attributes for BIM software selection. Besides that, this finding is significant to further develop fuzzy TOPSIS decision model as a sub system in topsis4BIM.

5.5.2 An Alternatives Approach for BIM Software Selection

Selection of BIM software for project needs is one of the crucial parts in BIM adoption. In contrast, result from interview in this study has found that Malaysia companies tend to depend on recommendation from CIDB, others company and software vendors, and the most popular software in BIM software selection process without any proper decision making process. In some cases, the company are not aware of the other software that the market is offering, making the company spend money on software that may not fulfil all the company needs. Making a wrong selection of BIM software may also cause investment losses in a company. Figure 5.3 illustrates the decision making of BIM software selection in Malaysia

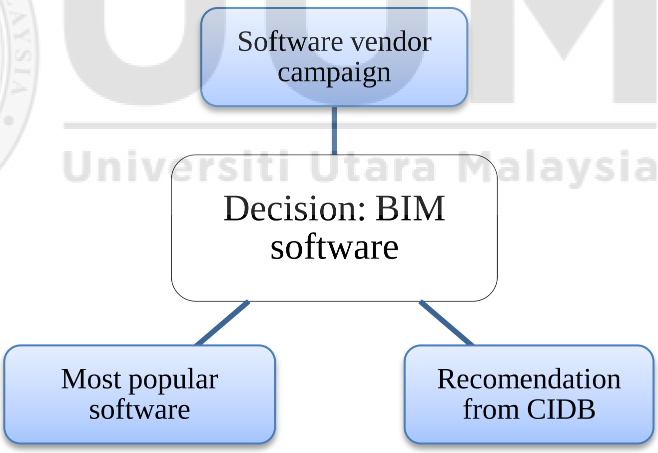

Figure 5.3. Decision Making of BIM Software Selection in Malaysia

The deficiency of decision aid among the construction companies in BIM software selection has also been mentioned by Ruiz (2007). This issue has led to the motivation of the research to solve BIM software selection problem through the development of DSS namely topsis4BIM. With the intention to develop an effective and usable DSS, this study has expand the work on TOPSIS by Hwang and Yoon (1981) by integration with fuzzy approach as suggested by Chen (2000) as a sub-system. According to the Chen (2000), MCDM is a reliable decision technique, however MCDM method such as TOPSIS has been addressed as inadequate to model real world problem due to the implementation of crisp value in evaluation of alternative and weight.

According to Zadeh (1965), fuzzy concept is capable in dealing with human vagueness and uncertainty in decision making process through linguistics language. Instead of dealing with alternative decision problem, topsis4BIM is also capable of dealing with the vagueness of human in decision making for BIM software selection. Moreover, there is no other study that has proposed Fuzzy TOPSIS as a decision model for BIM software selection problem. Result from interview shows that the fuzzy TOPSIS decision model in this study has helped the decision makers to set priority in their attributes and rationally evaluate alternative in uncertainty environment.

Other deficiency in construction literature is the lacking of interactive or web based DSS. Unlike other studies, this study has not only developed a decision model that supports uncertainty environment, it has also extended the development of DSS through web technology. Validation result shown the increased in users satisfaction and acceptance of topsis4BIM as a decision making support through web based DSS. This is supported by work of Shim et al. (2002), web technology has improved the usability of decision model in DSS. Based on result from literature review and interview, this study has managed to demonstrate the application of web based DSS as a new approach of decision making in BIM software selection through development of topsis4BIM.

Table 5.9 that show the features of topsis4BIM in BIM software selection. In comparing to the current practice, topsis4BIM has offered more interesting features in order to yield a reliable result for BIM software selection.

Table 5.9

Advantages and Features of topsis4BIM Approach

DSS component	Criteria
Decision model	- Analytical decision analysis - Supporting fuzzy environment - Interactive user interface for decision model
Data management	- Cloud Data based features - Search facility

5.5.3 A New Generation of DSS Development

Recently, the emergence of a new concept web development called Web 2.0 has shifted the architecture development of DSS with potential promises characteristics such as a lightweight programming language requirement which provides many-to-many relationship, cost effective scalability, and interactive user interface. All these characteristic have increased the popularity of Web 2.0 among the users compared to web 1.0 (Hsu, 2010; Isfandyari-Moghaddam & Hosseini-Shoar, 2014; Murugesan, 2007; Reilly & Media, 2007). However, there is no study that attempt to develop a DSS particularly in MCDM type of application through Web 2.0 platform in the construction domain.

Thus, this study has presented an implementation of MCDM DSS through cloud technology as a platform. The development of topsis4BIM does not require any technical skill in programming language, minimized time and cost of development, and easy access to any devices that can connect to the internet. This is in line with the finding by Aghaei et al. (2012) that highlighted the advantages of Web 2.0 towards developing a web based DSS that is easier, quicker and cheaper compared to previous web generation. Instead of analytical features, topsis4BIM has also offered other features such as database, search button and utilization of Google application in order to enhance the decision making process in BIM software selection.

Philips et al. (2011) argued that the Web 2.0 technology is capable in enhancing the rationality and effectiveness of decision making while at same time can also negatively impact the decision making. Thus, the face validation of topsis4BIM has been done in this study among the DMs (See chapter 6, section 6.3). Result from the questionnaire and interview shows that, the adoption of Web 2.0 in the development of topsis4BIM has increased the satisfaction and acceptance of decision makers towards topsis4BIM methodology.

This is supported by work of Basssedik et al (2012) which shows that the existence of Web 2.0 has extend the ability of DSS toward decision making process. Table 5.10 summarize the features in topsis4BIM compared to previous web generation which is web 1.0 in DSS development.

Table 5.10

Comparison of DSS Features between Web 1.0 and topsis4BIM

DSS criteria	DSS (web 1.0)	topsis4BIM (web 2.0)
How to content view	Web browser	Any device that can connect to internet
Cost of development	Costly	Low cost
Time for development	Required long time	Short time
Technical skill (Programming language)	Yes	No (Drag and drop features)
Embedding of Google app (such as Google doc)	No	Yes (allow embedding with numerous of web application)
Utilize Cloud Storage	No	Yes

5.6 Model finalization

Based on the findings discussed above relating to the development of topsis4BIM for BIM software selection in Malaysia, the framework of topsis4BIM in BIM software selection has been established in this study.

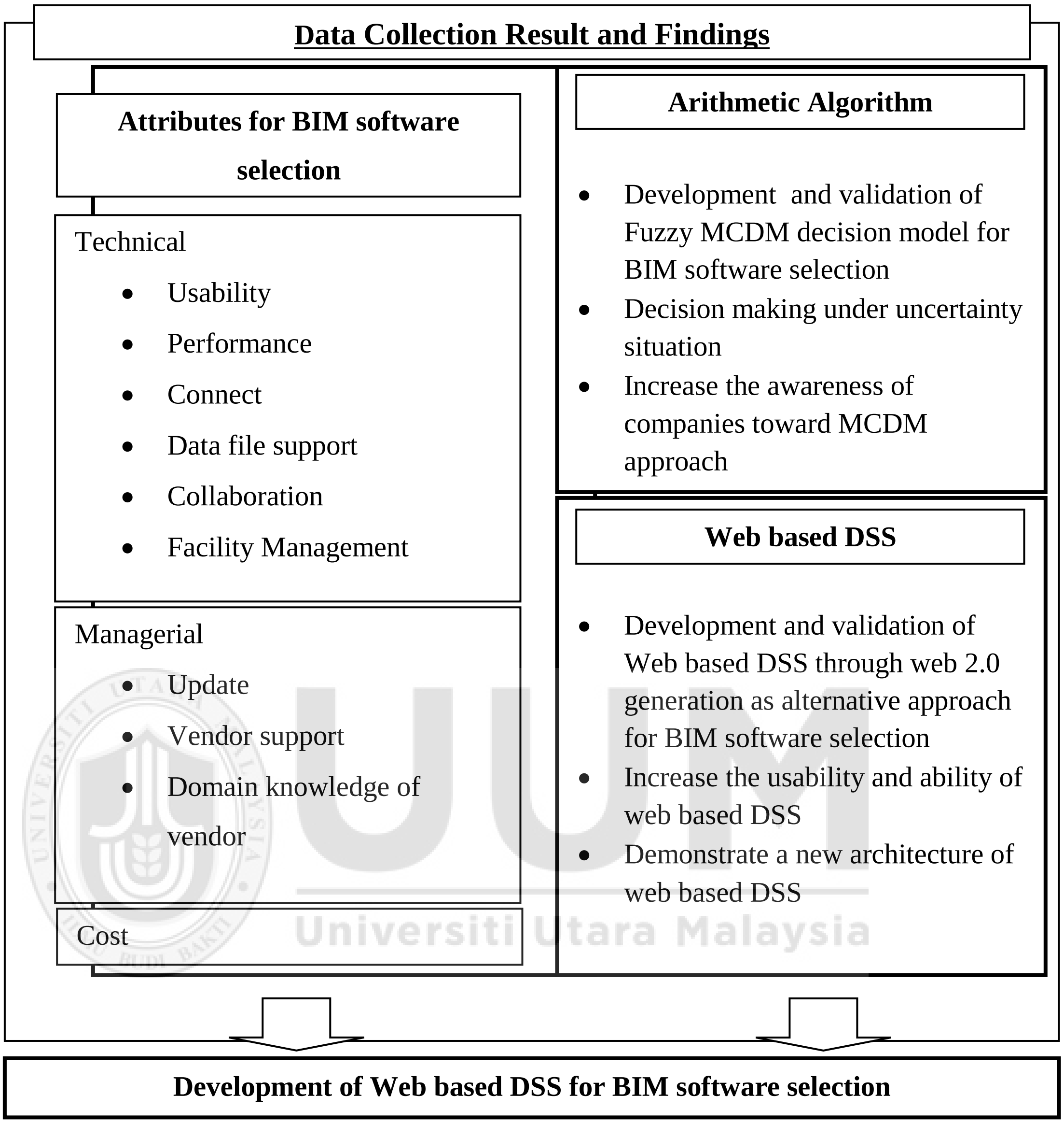

Figure 5.4. Platform for Developing Web based DSS in BIM Software Selection

The framework in Figure 5.4 summarises the linkages of the attributes of BIM software selection, arithmetic algorithm and Web 2.0 platform in the development of topsis4BIM in Malaysia. According to Ruiz (2009), understanding what are attributes based on company needs from BIM software is significant in purchasing of BIM software. Result from case study has revealed the attributes for BIM software selection within the Dewan Sultan Ibrahim project. Thus, the identification of attributes for BIM software selection in this study can be considered as guidance to construction companies in order to improve the BIM software selection decision making process in Malaysia. In addition, the development of topsis4BIM based on arithmetic algorithm which is fuzzy TOPSIS enable decision maker to evaluate BIM software more systematically. Due the integration of fuzzy and TOPSIS, topsis4BIM also capable assists decision maker in fuzzy environment.

In order to increase the accessibility and usability of decision model in this study, topsis4BIM was developed and tested with the application in Dewan Sultan Ibrahim project. Evaluation result indicates that topsis4BIM is capable providing a proper alternative for BIM software selection in this project. This is not only answer the objectives of this study, but it has also contributes to the knowledge of DSS development by demonstrating a new architecture for MCDM DSS development through Web 2.0 technology. Figure 5.5 describes the approach for overall DSS development. This approach is applicable for any problem related to MCDM.

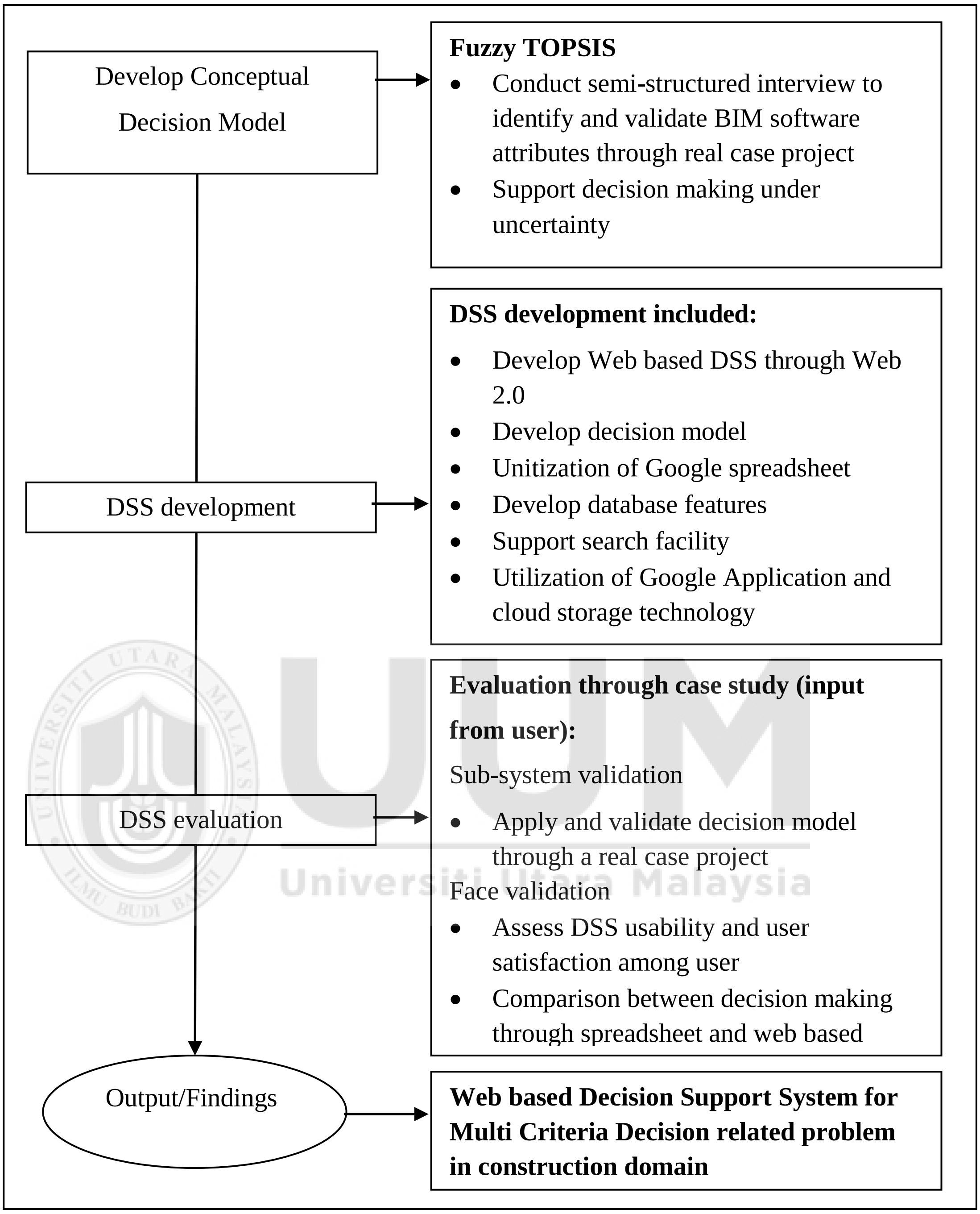

Figure 5.5. A New Framework for Development of Web based DSS through Web 2.0 in Construction MCDM Related Problem

Result from semi-structured interview and questionnaire in validation of DSS indicates that topsis4BIM process is comprised of the following:

1. Theoretically valid in terms of its sub-system, the decision model in this study yields almost similar ranking result without DSS. This shows the DSS is efficient in solving BIM software selection problem.

2. Based on the face validation result, the methodology and design approach in topsis4BIM to emulate a systematic evaluation of BIM software was fulfilled.

3. The ability of the model to provide alternative and innovative solution was also demonstrated.

Result from the evaluation process in this study provides attributes for BIM software selection, evidence to validate the usability and utility of the topis4BIM. Furthermore, semi structured interview and face validation indicates that decision maker's acknowledge that the existence of topsis4BIM could enhance BIM software selection decision making process.

The methodology of fuzzy TOPSIS in decision making process has gained decision makers attention. The systematic nature of evaluation process and the ability of fuzzy TOPSIS in dealing with vagueness of human decision making have shown the ability of topsis4BIM as a decision making tools in BIM software selection. The weighted and rating assessments in topsis4BIM have assist decision makers in setting their priority in BIM software selection to select BIM software that fulfill a project needs. Furthermore, the development of topsis4BIM through Web 2.0 has increased the accessibility and effectiveness of DSS.

5.7 Chapter Summary

This chapter has represented the result of topsis4BIM in terms of sub-system and face validation. In addition, the chapter also discussed research findings of this study. Instead of answering the research objectives, this chapter also highlighted a contribution towards body of knowledge in DSS and construction industry.

CHAPTER SIX
CONCLUSION

6.1 Introduction

As the used of BIM become more prevalent, construction companies facing a market full of option in BIM software that available. Due to the variety of BIM software on the market, the selection of the right BIM software for a certain construction project becoming more apparent. However, the needs to aid the decision making often overlooked. The use of IT such as DSS offered high potential as decision support tools particularly for BIM software selection is proposed. DSS called topsis4BIM is developed to cater the BIM software selection problems within the Malaysia construction industry.

This chapter concludes the achievement of the reserach. A list of work performed in order to completed the thesis is presented in section 6.2. Then, the primary findings and conclusion discovered as a result of this research has been illustrated in section 6.3. Research contribution is provided in section 6.4 and followed by the recommendation for future research in section 6.5.

6.2 Summary of Work Performed

The study lies between the area of Construction Project Management and Decision Support System. A summary of work performed in this follows;

1. Identification of research gaps for BIM software selection in construction project management.

   A review in construction field revealed the needs of aided decision making for BIM software selection. Till date there is limited study attempt to guide decision to select the right software for construction project that utilized BIM. In contrast, there are some of companies tend to make decision making on BIM software selection base on marketing/seminar campaign by software vendor and popular software package rather than having an appropriated analysis for the company needs.

2. Case study: Identification and validation of critical attributes for BIM software selection.

   The proposed of case study is identified and validates attributes by BIM expert who directly involved with Dewan Sultan Ibrahim. The data used in this research were collected through literatures, semi-structured interviews, software manuals and website.

3. Developed conceptual Fuzzy TOPSIS and Web based DSS

   A fuzzy TOPSIS as a decision model was developed based on the case study result. Then a web based DSS for a BIM software selection is implemented. Moreover, additional DSS features are included such as database.

4. Case study: Performed sub-system validation to validate fuzzy TOPSIS decision model.

   A case study is utilized for the validation of decision model. In this study, DSS was validated using sub system validation and face validation. For the subsystem validation, the result from DSS was presented and compared with current practice (without DSS).

5. Case study: Performed quantitative and qualitative validation in face validation to measure the usability and utility.

   Face validation was performed through semi structured interview through quantitative and qualitative nature. In term of quantitative, decision makers were ask to rate topsis4BIM base on some attributes (section 5.4.1). Meanwhile, in qualitative, the decision makers were asked to evaluate the DSS based on system quality and information quality.

6.3 Conclusion

Based on this research, the conclusion was discovered with each of this research objective:

1. Research Objective 1: To identify the critical attributes of BIM software selection

Literature reviews reveal some deficiencies in BIM software selection. Most research in BIM is focused on the advantages and barriers, risk and challenge, acceptance, effect of BIM toward construction management process and others. The BIM software selection is one of the crucial processes. Therefore, there is a need to identify the right attributes to foster better implementation of BIM that fulfill the company and project needs.

This study identifies the critical attributes of BIM software selection based on case study approaches (Dewan Sultan Ibrahim) Ten attributes were identified i.e. usability, performance, connect, data file support, update, vendor support, cost, collaboration and facility management. Two of them (i.e. collaboration and facility management) were suggested by BIM expert. These attributes can be used as a foundation guide for BIM software selection among construction companies.

2. Research Objective 2: To develop a multi-criteria decision support system prototype for BIM software selection.

Research indicates there is limited study attempt to develop a DSS particularly for BIM software selection. Driven by this gap, topsis4BIM was design to efficiency assist BIM software selection. The topsis4BIM offer web based DSS with advance features such as decision model under uncertainty i.e. fuzzy TOPSIS and database facilities. In comparison with current practice in case study, this DSS effectively managed to structured decision process and yield convincing result.

3. Research objective 3: To evaluate utility and usability of the decision support tool.

In construction literature, much of research in DSS development neglected user evaluation on how well the system been implemented. Thus, instead of evaluation of decision models for BIM software selection, an evaluation of DSS is also important in DSS development. This study demonstrates process of DSS evaluation through sub system validation and face validation. As a result, it is identified that decision model (fuzzy TOPSIS) is valid in term of its logic. The level of satisfaction has increase of the level of usability. Positive feedback was identified from the users in term of system quality and information presentation in topsis4BIM.

6.4 Research Contributions

At the end of this thesis, following contributions were highlighted:

1. Identification of real attributes for BIM software selection in Malaysia

Selection the right BIM software is not only significant to fulfill the company and project needs, but also important to fully utilized the software features in order to increase the project successful. However, research shown there is limited study that attempt to investigate the attributes for evaluation of BIM software. Thus, this study has outline of the main attributes such as technical, cost and managerial in BIM software selection in Malaysia. The identification of real attributes in BIM software selection should be able to set a foundation of guidelines in selection of BIM software for companies. This finding represents a contribution towards construction industry.

2. A new fuzzy TOPSIS decision model that support uncertainty environment for BIM software selection

MCDM technique is significant in order to avoid the weakness of human in decision making such as bias and vagueness. Thus, this study has developed and validated a reliable decision technique through Fuzzy TOPSIS for BIM software selection. This model was developed to support decision making under uncertainty environment.

The explanation of decision analysis technique such as Fuzzy TOPSIS in this study is perhaps useful for construction companies to enhance their decision making. This model possesses the potential to be applied in other MCDM problem in construction project management such as contractor selection, equipment selection, vendor selection and others. The proposed model has increase the awareness of MADM method among the construction companies.

3. A new DSS framework

This research has proposed a systematic and structured approach by development web based DSS for BIM software selection. The existence of topsis4BIM allows decision maker to evaluate BIM software in systematic way instead of depending on current practice. This topsis4BIM is significant as prototype to generate a reliable result to select the most suitable BIM software for decision maker.

4. A new architecture and framework of DSS development through Web 2.0

Unlike other study of DSS for MCDM problem, topsis4BIM was developed through contemporary web technology through cloud technology in Web 2.0. This new concept of web development platform has offered more advanced features in DSS development. Thus, the development of topsis4BIM in this research represents a contribution to existence body of knowledge of DSS development in multi criteria problem.

6.5 Limitations of the Research

This research has developed a prototype of Web based DSS with the ability to assist decision making process in BIM software selection. However, there are several of limitations in this research.

1. The findings and view presented in development of topsis4BIM are more reflective of BIM software selection in one case study only which is Dewan Sultan Ibrahim project. An implementation of multiple case studies of BIM construction project in Malaysia would add and enrich the findings.
2. Decision model in this study was developed based on one decision technique only which is Fuzzy TOPSIS. The additional or integration of multiple Multi Attributes Decision Making (MADM) such as AHP, ANP, ELECTRE would enrich the findings.

6.6 Recommendation for Futures Research

1. The findings in this study could be more flexible by conducting multiple case studies in Malaysia.
2. This study has utilised only on basic features of Web 2.0. It can be more valuable for futures researchers to explore the other advanced features of Web 2.0 platform. For example, by considering login form, more flexible databases function. It can promote more reliable Web DSS for BIM software selection.
3. Multiple development of MCDM techniques such as TOPSIS, ANP, SAW and further conduct comparison result between these techniques may yield different result during sub system evaluation. This is more suitable for a theoretical research of MCDM.

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Inovation comeptition

Ahmad Taufik Nursal, Mohd Faizal Omar, Mohd Nasrun Mohd Nawi, and Izwan Nizal Mohd Shaharanee. Peneng Invention, Innovation and Research Design Platform (PIDD 2014), topsis4BIM (Silver medal).

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Appendix A

Filtering and Categories the Attributes

Author	Assessment Criteria	Related BIM Attributes	Category	Variables	Notes
Ribeiro, Moreira, Broek, & Pimentel, 2011	Usability	✓	Technical	T1	
	Performance	✓	Technical	T2	
	Security	✓	Technical	T3	
	Modularity	✓	Technical	T4	
Otamendi, Pastor, & Garcia, 2008	Cost	✓	Technical	T5	
	Update	✓	Managerial	M1	
	Decision Support	✓	Technical	T6	
	Connect (connectivity issues with external software)	✓	Technical	T7	
	Ease (User friendliness)	✓	Technical		Within T1 context
Soni, 2012	User interface	✓	Technical	T8	
	Processing Speed	✓	Technical		Similar to T2
	Speed Requirement				
	Documentation	✓	Technical	T9	
	Technical Features	✓	Technical	T10	
	Lifecycle Cost	✓	Cost		Similar to T5

Lai, et al., 1999	Development interface				
	Graphics support	✓	Technical		Within T8 context
	Multi-media support	✓	Technical		Within T8 context
	Data file support	✓	Technical	T11	
	Cost effectiveness	✓	Cost		Similar to T5
	Vendor support	✓	Managerial	M1	
Altug, et al., 2006	Data preparation	✓	Technical		Within T11 context
	Method selection				
	Method Implementation				
	Method evaluation				
	Assessment of uncertainty				
	Forecast presentation				
	Ease of use	✓	Technical		Within T1 context
Author	Assessment Criteria	Related BIM Software Attributes	Category	Variables	Notes
Buyukozkan & Ruan, 2008	Functionality	✓	Technical		Similar to T10
	Technical aspect	✓	Technical		Similar to T10
	Cost	✓	Cost		Similar to T5
	Service and Support	✓	Managerial		Similar to M1
	Vision				
	System reliability	✓	Technical	T12	
	Compatibility with other system	✓	Technical		Similar to T7

	Ease of customization	✓	Technical	T13	
	Market position of the vendor	✓	Managerial	M2	
	Better fit with organizational structure	✓	Managerial	M3	
	Domain knowledge of the vendor	✓	Managerial	M4	
	References of the vendor	✓	Managerial	M5	
	Methodology of software	✓	Technical	T14	
	Fit with parent/allied organization systems	✓	Managerial	M6	
	Cross module integration	✓	Technical		Within T4 context
	Implementation time	✓	Technical		Within T2 context
Duran (2011)	Functionality	✓	Technical		Within T10 context
	Flexibility	✓	Technical		
	Friendliness	✓	Technical		Within T1 context
	Implementation	✓	Technical	T15	
	Technic capability	✓	Technical		Similar to T10
	Reputation	✓	Managerial	M7	
	Service	✓	Managerial	M8	
Ayag and Ozdemir	System cost	✓	Cost		Similar to T5

(2007)	Vendor support	✓	Managerial		Similar to M1
	Flexibility	✓	Technical		Similar to T7. T7 is suggested to change to "flexibility" to be more representative
	Functionality	✓	Technical		Within T10 context
	Reliability	✓	Technical		Similar to T12
	Ease to use	✓	Technical		Within T1 context
	Technology advance	✓	Technical		Within T10 context

Appendix B

BIM Software Vendor (Ruiz, 2009)

Vendor	BIM Tools	Explanation
Autodesk	Autodesk 3ds Max Design Autodesk Design Review Autodesk Navisworks Revit Architecture Revit Structure Revit MEP	Autodesk is focusing from drafting, model capabilities and clash detection analysis.
Bentley	Bentley architecture V8i Bentley Structural V8i Bentley Building Electrical System V8i Bentley Building Mechanical System V8i ProjectWise Navigator ConstructSim	It is offer tools from drawing and modeling capacity to design rule review and bidirectional capabilities with power and lighting analysis.
Nemetschek AG	Vectorworks Graphisoft Archicad 12	Vetorworks is a drawing and modelling tool. Graphisoft is the first software that implemented BIM technology. Archicad 12, offering upgrade for different solutions.
Innovaya	Innovaya Visual BIM Innovaya Visual Quality Take Off Innovaya Visual Estimating Innovaya Design Estimating Inovaya Design Simulation	It more focus on the BIM environment and specifically to the building construction.
Synchro Ltd	Synchro Project Contruction (basic software) Synchro professional Synchro Express Synchro Server Synchro Workgroup	All of the software from Synchro Ltd focuses on project management and specifically to scheduling.

Vendor	BIM Tools	Explanation
VICO software	Vico Constructor Vico Estimator Vico Control Vico 5D Presenter Vico Cost Explore Vico Change Manager	The company offer complete set of program from design, planning modeling, controlling and analysis.
Gehry Technologies (GT)	Digital Project Software	Design view 2D and 3D model.
Tekla Corporation	Tekla Structure, Full Detailing Tekla, Structure Construction Management. Tekla Structure, Steel detailing. Tekla Structure, Precast Concrete Detailing. Tekla Structure, Reinforced Concrete Detailing. Tekla Structure Engineering.	Offer a division of Building and Construction where it more focuses on structure area.
Onuma	Onuma Planning System (OPS)	It main strength is Onuma Planning System, an internet servers that allows several of users is able to interact during the modeling process. Onuma basically more to design tools.
Solibri	Solibri Model Checker Solibri Issue Locator Solinri Model Viewer Slolibri IFC Optimizer.	Solibri is more to analysis tools that analyze the models in term of integrity, quality and physical security.
Project Blueprint Ltd	Zero Defect	Provide an Internet accessible database and tracking tools for reviewing a project.

Appendix C
Letter of Permission

To Whom It May Concern

Dear Sir/Madam,

I am a Masters candidate at the Faculty of Quantitative Science, Universiti Utara Malaysia (UUM). My research aims to develop a DSS for selection of Building Information Modeling (BIM). This project may benefit your organization where a prototype of DSS will be developed to assist decision maker to select BIM software.

In order to have some information regarding the issue, your relevant experience and expertise in the BIM software selection is required. The opinion and data collected will be confidential without mentioning to a specific person.

Should you have any question regarding this research, you may contact me or my supervisor Dr Faizal Omar at mfaizal.omar@gmail.com

Your cooperation and contribution of this research is mostly appreciated

Yours Sincerely,

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Appendix D

Sample of Questionnaire to Determine BIM Software Attributes

Background

The usage of Building Information Modeling (BIM) is becoming more apparent in construction project's life cycle to ensure the quality and productivity of a project. Due to the effectiveness of BIM, there are numerous BIM software available in the market. Each of this software has a different function, price and features. Moreover, the BIM adoption requires high investment not only for the hardware and software, but also involves training expenses. Hence, the decision on selection of BIM is significant. However, there is a lack of study on the evaluation of BIM software selection. Hence, this study aims to develop a Decision Support System that enables the decision makers to select the appropriate BIM software that fulfill the project and company needs. It will increase the effectiveness of decision maker in BIM software selection process.

Objective: This Questionnaire aims to identify the necessary attributes used during BIM software selection process.

Private and Confidential: All responses will be kept strictly confidential and will only be used for research purposes.

Estimated Time Frame: Please take approximately 5 – 6 minutes to complete the form

1. Please choose the BIM software selection attribute that match with organization and your own interest

Categories	Selection attribute	Please write "X" for the selected criteria
Technical	Usability	
	Performance	
	Security	
	Modularity	
	Cost	
	Decision Support	
	Connect (connectivity issues with external software)	
	User Interface	
	Documentation	
	Technical Futures	
	Data file support	
	System reliability	
	Ease of customization	
	Methodology system	
	Implementation	
Managerial	Update	
	Vendor support	
	Market position of the vendor	
	Better fit with organization system	
	Domain knowledge of the vendor	
	Reference of the vendor	
	Fit with parent/ allied organization system	
	Reputation	
	Service	
Cost	Cost	

2. Please suggest any other criteria that were not listed above which relevant to the department (if any).

____

____

3. Please state what is the main purpose BIM use in your project?

____

____

4. Who is responsible party in BIM software selection decision making?
    a) Contractor
    b) Designer
    c) Project Managers
    d) Others ________________

5. Please name the BIM software that involved in your project?

____

____

Appendix E

Fuzzy TOPSIS Assessment

Decision Maker: DM1
Step 1: Fuzzy Decision Matrix and Fuzzy Weight

Software	A1	A2	A9	A10	A4	A3	A6	A7	A8
S1	3,5,7	9,10,10	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10
S2	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	3,5,7	0,1,3
S3	7,9,10	3,5,7	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10	0,1,3
S4	7,9,10	9,10,10	3,5,7	3,5,7	7,9,10	7,9,10	7,9,10	7,9,10	7,9,10
S5	7,9,10	7,9,10	7,9,10	5,7,9	7,9,10	5,7,9	7,9,10	3,5,7	7,9,10
Weight	0.9,1,1	0.7,0.9,1	0.9,1,1	0.3,0.5,0.7	0.7,0.9,1	0.7,0.9,1	0.5,0.7,0.9	0.3,0.5,0.7	0.5,0.7,0.9

Step 2: Normalize Decision Matrix

Software	**A1**	**A2**	**A9**	**A10**	**A4**	**A3**	**A6**	**A7**	**A8**
S1	0.3,0.5,0.7	0.9,1.0,1.0	0.7,0.9,1	0.7,0.9,1.0	0.7,0.9,1.0	0.7,0.9,1.0	0.7,0.9,1	0.7,0.9,1.0	0.7,0.9,1.0
S2	0.3,0.5,0.7	0.3,0.5,0.7	0.3,0.5,0.7	0.3,0.5,0.7	0.3,0.5.0.7	0.3,0.5,0.7	0.3,0.5,0.7	0.3,0.5,0.7	0.,0.1,0.3
S3	0.7,0.9,1	0.3,0.5,0.7	0.7,0.9,1	0.7,0.9,1.0	0.7,0.9,1.0	0.7,0.9,1.0	0.7,0.9,1	0.7,0.9,1.0	0.0,0.1,0.3
S4	0.7,0.9,1	0.9,1.0,1.0	0.3,0.5,0.7	0.3,0.5,0.7	0.7,0.9,1.00	0.7,0.9,1.0	0.7,0.9,1	0.7,0.9,1.0	0.7,0.9,1.0
S5	0.7,0.9,1	0.7,0.9,1.0	0.7,0.9,1	0.5,0.7,0.9	0.7,0.9,1.0	0.5,0.7,0.9	0.7,0.9,1	0.3,0.5,0.7	0.7,0.9,1.0
Weight	0.9,1,1	0.7,0.9,1	0.9,1,1	0.3,0.5,0.7	0.7,0.9,1	0.7,0.9,1	0.5,0.7,0.9	0.3,0.5,0.7	0.5,0.7,0.9

Step 3: Weighted Normalize Decision Matric

Software	A1	A2	A9	A10	A4	A3	A6	A7	A8
S1	0.27,0.5,0.7	0.63,0.9,1.0	0.63,0.9,1	0.2,0.5,0.7	0.49,0.81,1	0.49,0.81,1	0.35,0.63,0.9	0.21,0.45,0.7	0.35,0.63,0.9
S2	0.27,0.5,0.7	0.21,0.45,0.7	0.27,0.5,0.7	0.1,0.3,0.5	0.21,0.45,0.7	0.21,0.45,0.7	0.15,0.35,0.63	0.09,0.25,0.49	0,0.07,0.27
S3	0.63,0.9,1	0.21,0.45,0.7	0.63,0.9,1	0.2,0.5,0.7	0.49,0.81,1	0.49,0.81,1	0.35,0.63,0.9	0.21,0.45,0.7	0,0.07,0.27
S4	0.63,0.9,1	0.63,0.9,1.0	0.27,0.5,0.7	0.1,0.3,0.5	0.49,0.81,1	0.49,0.81,1	0.35,0.63,0.9	0.21,0.45,0.7	0.35,0.63,0.9
S5	0.63,0.9,1	0.49,0.81,1.0	0.63,0.9,1	0.2,0.4,0.6	0.49,0.81,1	0.35,0.63,0.9	0.35,0.63,0.9	0.09,0.25,0.49	0.35,0.63,0.9

Step 4: Distance Measurement

Software	A+	A-
S1	0.9485167	2.08185
S2	1.5761167	1.2327833
S3	0.7638667	2.3572
S4	1.0542	1.9942
S5	1.0478333	2.0478333

Step 5: Coefficient Closeness

Software	Closeness Coefficient	Rank
S1	0.69	2
S2	0.44	5
S3	0.76	1
S4	0.65	4
S5	0.66	3

Decision Maker: DM2

Step 1: Fuzzy Decision Matrix and Fuzzy Weight

Software	A1	A2	A9	A10	A4	A8	A6
S1	7,9,10	9,10,10	9,10,10	3,5,7	7,9,10	3,5,7	0,1,3
S2	3,5,7	3,5,7	3,5,7	0,1,3	3,5,7	3,5,7	0,1,3
S3	3,5,7	3,5,7	9,10,10	7,9,10	3,5,7	5,7,9	0,1,3
S4	7,9,10	9,10,10	0,0,1	0,1,3	7,9,10	7,9,10	0,1,3
S5	7,9,10	9,10,10	7,9,10	3,5,7	7,9,10	9,10,10	0,1,3
Weight	0.7,0.9,1	0.7,0.9,1	0.7,0.9,1	0.3,0.5,0.7	0.9,1,1	0.9,1,1	0.3,0.5,0.7

Step 2: Normalize Decision Matrix

Software	A1	A2	A9	A10	A4	A8	A6
S1	0.7,0.9,1	0.9,1.0,1.0	0.9,1,1	0.3,0.5,0.7	0.7,0.9,1.0	0.3,0.5,0.7	0,0.33,1
S2	0.3,0.5,0.7	0.3,0.5,0.7	0.3,0.5,0.7	0.0,0.1,0.3	0.3,0.5,0.7	0.3,0.5,0.7	0,0.33,1
S3	0.3,0.5,0.7	0.3,0.5,0.7	0.9,1,1	0.7,0.9,1.0	0.3,0.5,0.7	0.5,0.7,0.9	0,0.33,1
S4	0.7,0.9,1	0.9,1.0,1.0	0,0,0.1	0.0,0.1,0.3	0.7,0.9,1.0	0.7,0.9,1.0	0,0.33,1
S5	0.7,0.9,1	0.9,1.0,1.0	0.7,0.9,1	0.3,0.5,0.7	0.7,0.9,1.0	0.9,1.0,1.0	0,0.33,1
Weight	0.7,0.9,1	0.7,0.9,1	0.7,0.9,1	0.3,0.5,0.7	0.9,1,1	0.9,1,1	0.3,0.5,0.7

Step 3: Weight Normalized Decision Matric

Software	A1	A2	A9	A10	A4	A8	A6
S1	0.49, 0.81,1	0.63,0.9,1	0.63,0.9,1	0.09,0.25,0.49	0.63,0.9,1	0.25,0.5,0.7	0,0.17,0.7
S2	0.21,0.45,0.7	0.21,0.45,0.7	0.21,0.45,0.7	0,0.05,0.21	0.27,0.5,0.7	0.27,0.5,0.7	0,0.17,0.7
S3	0.21,0.45,0.7	0.21,0.45,0.7	0.63,0.9,1	0.21,0.45,0.7	0.27,0.5,0.7	0.45,0.7,0.9	0,0.17,0.7
S4	0.49,0.81,1	0.63,0.9,1	0,0,01	0,0.5,0.21	0.63,0.9,1	0.63,0.9,1	0,0.17,0.7
S5	0.49,0.81,1	0.63,0.9,1	0.49,0.81,1	0.09,0.25,0.49	0.63,0.9,1	0.81,1,1	0,0.17,0.7

Step4: Distance Measurement

Software	A+	A-
S1	0.830824074	1.78637963
S2	1.507774074	0.74332963
S3	1.226090741	1.02497963
S4	1.652990741	1.17187963
S5	1.162907407	1.511796296

Step 5: Coefficient Closeness

Software	Closeness Coefficient	Rank
S1	0.68	1
S2	0.33	5
S3	0.46	3
S4	0.41	4
S5	0.57	2

Decision Maker: DM3

Step 1: Fuzzy Decision Matrix and Fuzzy Weight

Software	A1	A2	A9	A10	A4	A3	A6	A5	A8
S1	5,7,9	3,5,7	5,7,9	3,5,7	7,9,10	3,5,7	5,7,9	5,7,9	3,5,7
S2	1,3,5	7,9,10	3,5,7	1,3,5	3,5,7	3,5,7	3,5,7	5,7,9	3,5,7
S3	7,9,10	7,9,10	5,7,9	7,9,10	3,5,7	1,3,5	3,5,7	3,5,7	3,5,7
S4	5,7,9	5,7,9	5,7,9	0,1,3	7,9,10	7,9,10	3,5,7	5,7,9	5,79
S5	7,9,10	7,9,10	3,5,7	3,5,7	7,9,10	9,10,10	3,5,7	7,9,10	7,9,10
Weight	0.5,0.7,0.9	0.9,1,1	0.9,1,1	0.3,0.5,0.7	0.9,1,1	0.9,1,1	0.5,0.7,0.9	0.5,0.7,0.9	0.3,0.5, 0.7

Step 2: Normalize Decision Matrix

Software	A1	A2	A9	A10	A4	A3	A6	A5	A8
S1	0.5,0.7,0.9	0.3,0.5,0.7	0.56,0.78,1.00	0.3,0.5,0.7	0.7,0.9,1.0	0.3,0.5,0.7	0.56,0.78,1.0	0.5,0.7,0.9	0.3,0.5,0.7
S2	0.1,0.3,0.5	0.7,0.9,1.0	0.33,0.56,0.78	0.1,0.3,0.5	0.3,0.5,0.7	0.3,0.5,0.7	0.33,0.56,0.78	0.5,0.7,0.9	0.3,0.5,0.7
S3	0.7,0.9,1	0.7,0.9,1.0	0.56,0.78,1.0	0.7,0.9,1.0	0.3,0.5,0.7	0.1,0.3,0.5	0.33,0.56,0.78	0.3,0.5,0.7	0.3,0.5,0.7
S4	0.5,0.7,0.9	0.5,0.7,0.9	0.56,0.78,1.0	0.0,0.1,0.3	0.7,0.9,1.0	0.7,0.9,1.0	0.33,0.56,0.78	0.5,0.7,0.9	0.5,0.7,0.9
S5	0.7,0.9,1	0.7,0.9,1.0	0.33,0.56,0.78	0.3,0.5,0.7	0.7,0.9,1.0	0.9,1.0,1.0	0.33,0.56,0.78	0.7,0.9,1.0	0.7,0.9,1.0
Weight	0.5,0.7,0.9	0.9,1,1	0.9,1,1	0.3,0.5,0.7	0.9,1,1	0.9,1,1	0.5,0.7,0.9	0.5,0.7,0.9	0.3,0.5,0.7

Step 3: Weighted Normalize Matrix

Software	A1	A2	A9	A10	A4	A3	A6	A5	A8
S1	0.25,0.49,0.81	0.27,0.5,0.7	0.5,0.78,1.0	0.1,0.3,0.5	0.63,0.9,1	0.27,0.5,0.7	0.28,0.54,0.9	0.25,0.49,0.81	0.09,0.25,0.49
S2	0.05,0.21,0.45	0.63,0.9,1.0	0.3,0.56,0.78	0.0,0.2,0.4	0.27,0.5,0.7	0.27,0.5,0.7	0.17,0.39,0.7	0.25,0.49,0.81	0.09,0.25,0.49
S3	0.35,0.63,0.9	0.63,0.9,1.0	0.5,0.78,1.0	0.2,0.5,0.7	0.27,0.5,0.7	0.09,0.3,0.5	0.17,0.39,0.7	0.15,0.35,0.63	0.09,0.25,0.49
S4	0.25,0.49,0.81	0.45,0.7,0.9	0.5,0.78,1.0	0.0,0.1,0.2	0.63,0.9,1	0.63,0.9,1	0.17,0.39,0.7	0.25,0.49,0.81	0.15,0.35,0.63
S5	0.35,0.63,0.9	0.63,0.9,1.0	0.3,0.56,0.78	0.1,0.3,0.5	0.63,0.9,1	0.81,1,1	0.17,0.39,0.7	0.35,0.63,0.90	0.21,0.45,0.7

Step 4: Distance Measurement

Software	A+	A-
S1	1.10167	1.875003
S2	1.478652	1.418282
S3	1.203964	1.691742
S4	1.156581	1.947692
S5	0.958469	2.121432

Step 5: Coefficient Closeness

Software	Closeness Coefficient	Rank
S1	0.63	2
S2	0.49	5
S3	0.58	4
S4	0.63	3
S5	0.69	1

Appendix F
Sample of Validation Form

This section focused on the evaluation of the decision making between spread sheet (Pre-Design) and web based (Post-Design).

1. Based on decision model usage, please rate the following aspect

Aspect	**Rating**			
	Very Good	Good	Fair	Poor
Perceive ease of use				
It easy to use				
The process in understandable				
It is easy to learn				
Perceived usefulness				
This model helps me control the whole decision process				
It makes the decision process easier				
It is useful to me in making a decision				
Preferences				
I like to make a decision with this model				
I like to analyse information with this model				
I like to judge in this way				
Willingness				
I accept the procedure of this decision model for future decisions				
I will apply this model for hard decisions in the future				
It is worthwhile to use this model in the future				

Attributes	Comment
System Quality	
Information Presentation	

2. Which result do you trust more?

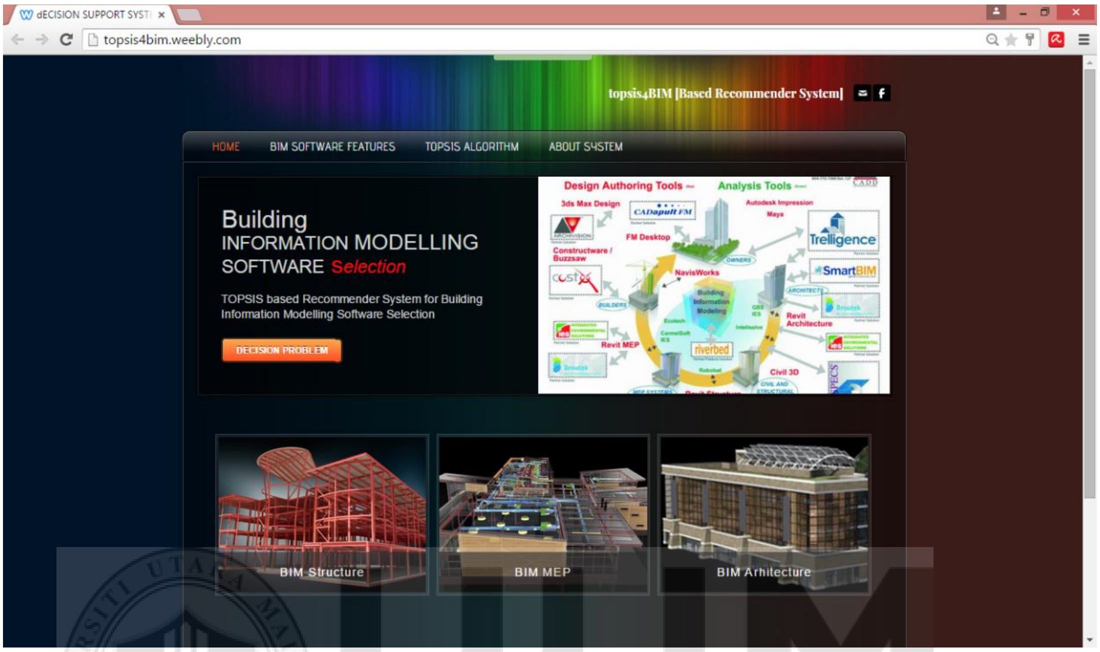
    a) Model

    b) Intuition (Current Practice)

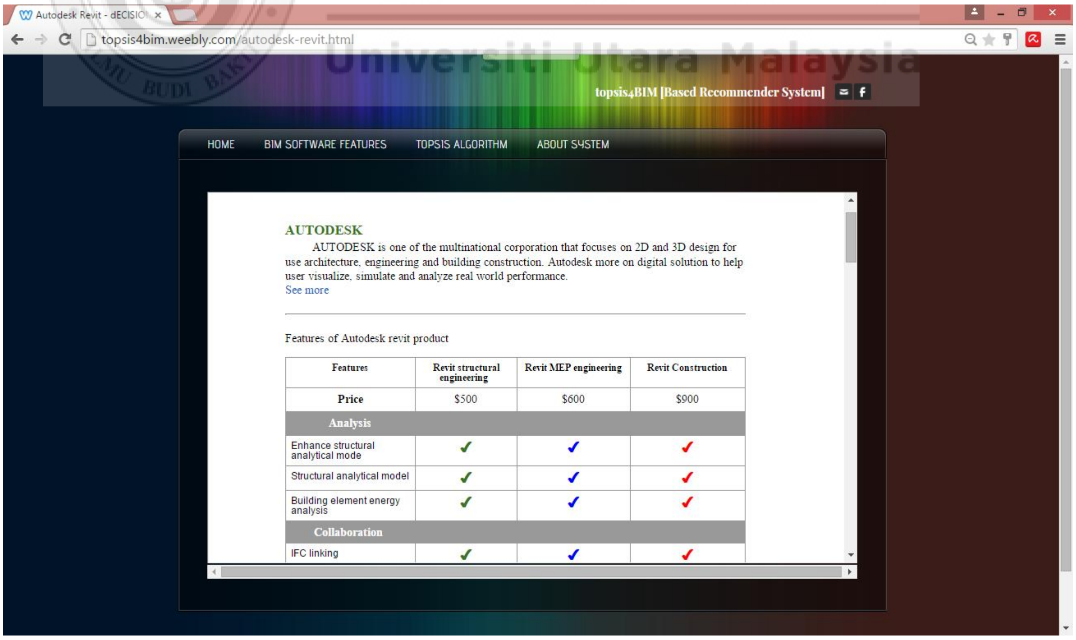
3. If you do not trust the decision made by this model, explain the reason:

Appendix G

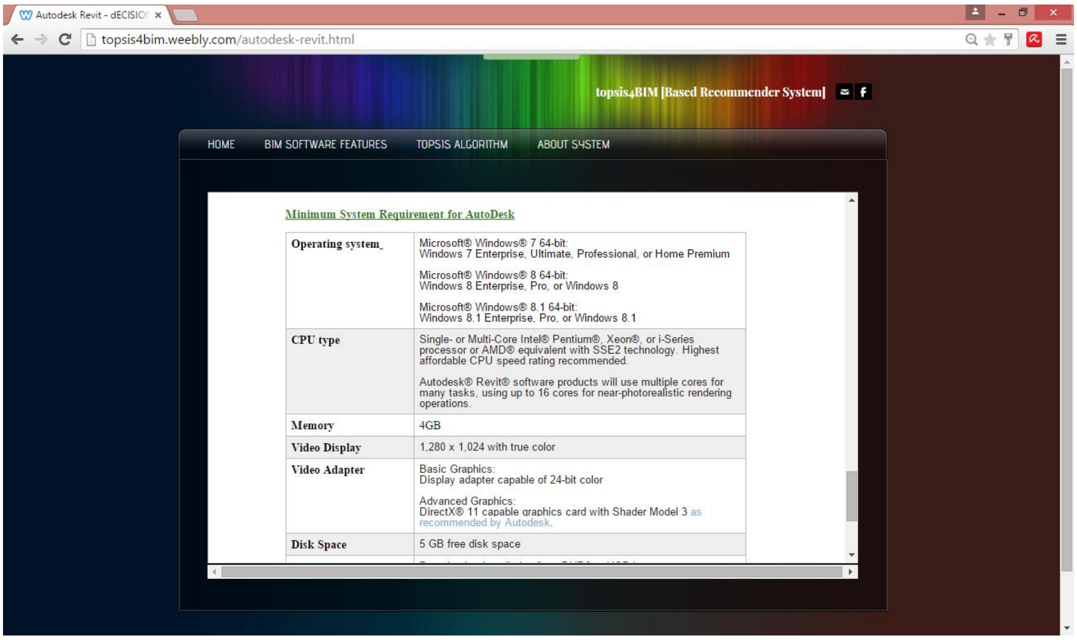
Snapshot from topsis4BIM System



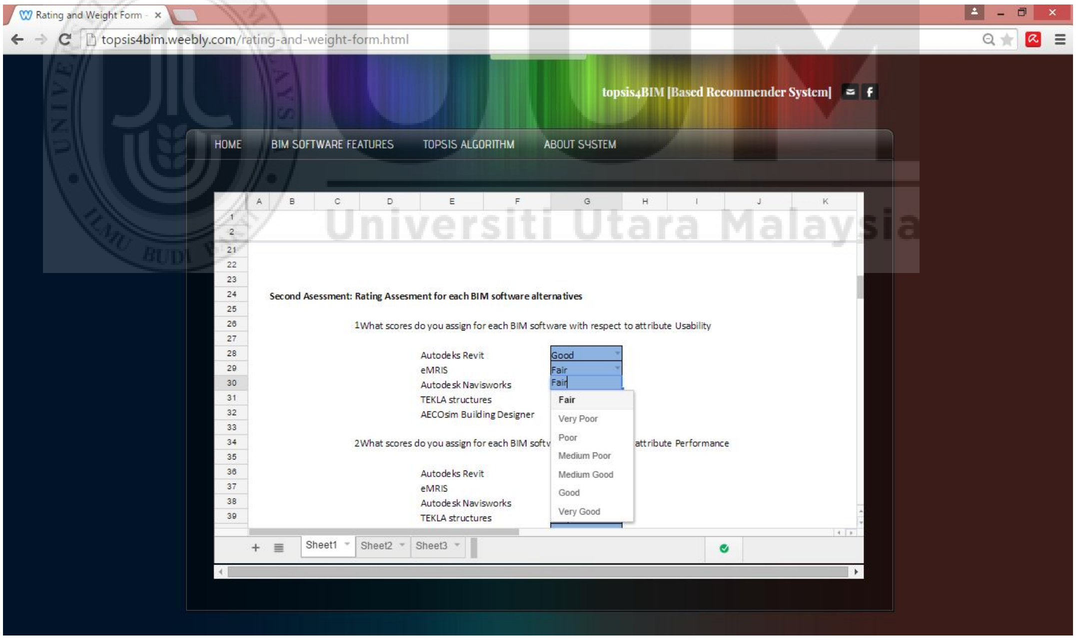
Front Page



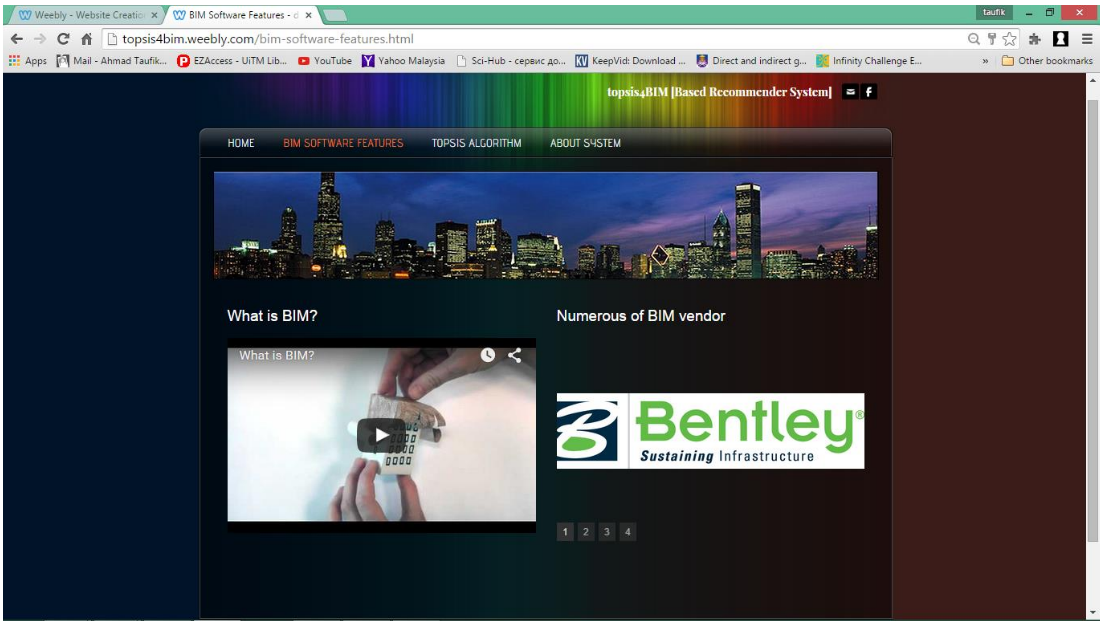
BIM Function & Features



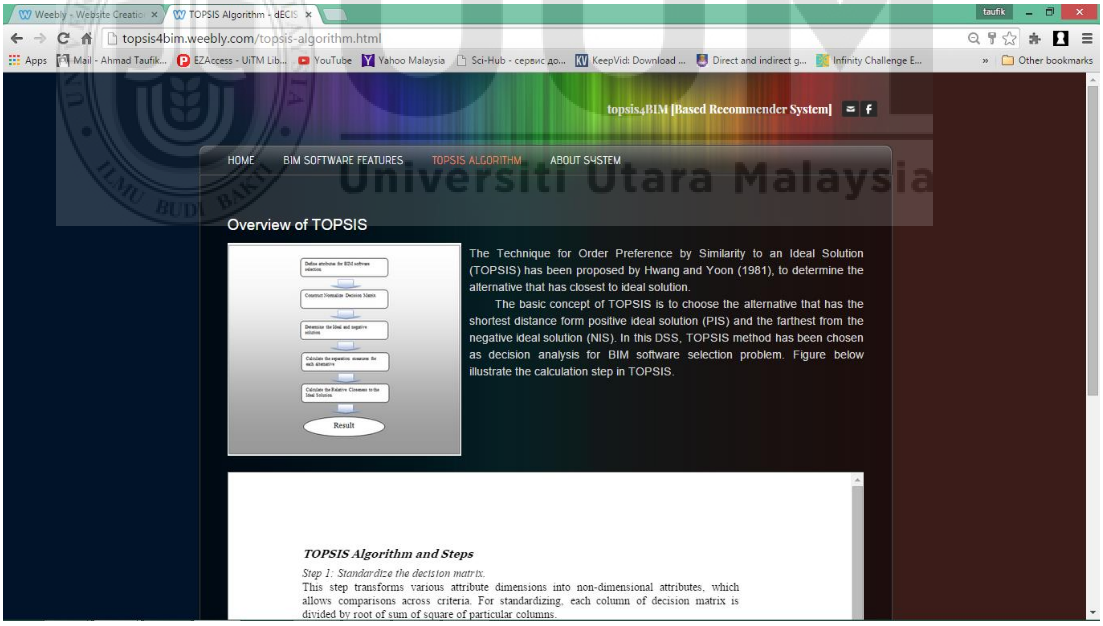
BIM System Requirement



Weight assessment



Introduction of BIM page



Introduction of TOPSIS page