UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF AN INDUSTRIALISED BUILDING SYSTEM FOR FACILITATING 3D MODULAR DESIGN PROCESS IN MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

July 2012

DEDICATION

With All My Love, I Dedicate this Thesis to:
My Dear Wife – Maryam - for Her Encouragement during My PhD Journey.
My Dear Parents for Their Warmest Support during My Entire Study.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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July 2012

Chairman: **Professor Rahinah bt. Ibrahim, PhD.**

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Industrialised Building System (IBS) is an exclusive construction method that deals with prefabricated building component (known is Malaysia as IBS Components) following by on-site installation. The method is become effective while it is harmonising and managing IBS component in a modular and repetitive manner called Modular Design Process (MDP). The method is supported insistently and requested firmly by Malaysian government from all local stakeholders. However, the IBS Survey 2005 revealed that Malaysian architects still are not willing to incorporate IBS/MDP in their common practices. The critical reason behind this hesitation is addressed: 1) because of lack of awareness from local IBS components & their qualifications; and 2) significant consistency in integration of the new design technologies such as Building Information Modelling (BIM) with the traditional approach of IBS/MDP. The analysis of literature review showed that the BIM and other similar sub-systems require 3D digital information library of building

components, which is lacking in the conventional design process of MDP. Consequently, this research posited that the availability of IBS component information in 3D digital library format would encourage architects to use MDP. The literature review was conducted critical analysis to investigate the integration of MDP and BIM by reviewing the state-of-the-art projects as the Product Information Aggregators (PIAs) do. So, the research proposed to develop the IBS Interface System with exclusive functionality in aggregating and distributing IBS digital component information through a classified naming system in order to assist architects for facilitating MDP in BIM. However, three system requirements should have to be cleared before the system development process. Therefore, the research chose three sequential methods: 1) Identifying System Requirements; 2) Developing IBS Design System; and 3) Evaluating the System using Charrette Test Method (CTM). Firstly, the research found the system requirements through two qualitative interviews, which were conducted among 10 local professional architects in IBS and 50 highly experienced 3D modellers working in multinational architectural firms. The interviews resulted in three system requirements: 1) Seventeen Exclusive Functionalities, 2) Ranking the IBS Component Information and 3) a Classified Component Naming (CCN) for 3D modelling practice includes an application gadget for automating the generation of CCN Codes. Secondly, the research utilised Agile System Development Method for applying system requirements into developing the IBS Interface System. The development of IBS Interface System explained how to develop: 1) A Prototype of IBS Digital Component Information Warehouse; and 2) A Framework of 3D Modular Design Process. Thirdly, the study evaluated the effectives of the new system in comparison to the conventional one by performing CTM. Three groups of architects participated to prove the positive effectiveness of the IBS interface System. Consequently, the results of each individual group were presented for verification and validation of the IBS Interface System by practicing its prototype in the proposed 3D Modular Design Framework. Eventually, the research claims on four contribution areas of knowledge: 1) converting architects' demands into tool functionalities; 2) prioritising the IBS Component Information based on architects' perspective; 3) generating the CCN for enumeration and retention of 3D Prefabricated Building Components; and 4) developing a new design framework for 3D MDP. Results of this study are expected to intensify the use of IBS components among the local architects in line with the national agenda of Malaysian construction industry.

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

PEMBANGUNAN SISTEM PEMBINAAN BERINDUSTRI UNTUK MEMUDAHKAN PROSES REKABENTUK MODULAR 3D DI MALAYSIA

Oleh

MAZIYAR MAMDOOH

Julai 2012

Pengerusi: **Profesor Rahinah bt. Ibrahim, PhD**

Fakulti: **Reka bentuk Dan Seni bina**

Sistem Pembinaan Perindustrian (*Industrialised Building System—IBS)* ialah satu kaedah pembinaan eksklusif yang menghadapi komponen bangunan pasang siap (diketahui ialah Malaysia sebagai IBS Components) diikuti oleh pemasangan pada tapak. Kaedah dijadikan berkesan manakala ia berharmoni dan menguruskan komponen IBS dalam satu cara bermodul dan berulang memanggil Proses Reka Bentuk Modular (*Modular Design Process—MDP).* Kaedah disokong desakan dan meminta dengan kuat oleh kerajaan Malaysia dari semua pemegang-pemegang saham tempatan. Bagaimanapun , IBS Survey 2005 mendedahkan bahawa arkitek-arkitek Malaysia masih tidak bersedia menggabungkan IBS / MDP dalam amalan-amalan biasa mereka. Sebab kritikal di belakang keraguan ini dialamatkan: 1) disebabkan oleh ketiadaan kesedaran tentang dari komponen-komponen IBS tempatan & syarat-syarat mereka; dan 2) ketekalan penting dalam integrasi teknologi-teknologi reka bentuk baru seperti *Building Information Modelling (BIM)* dengan pendekatan tradisional IBS / MDP. Analisis ulasan karya menunjukkan yang

BIM dan sistem-sistem sub serupa lain memerlukan perpustakaan maklumat digital 3D komponen-komponen bangunan, yang tidak ada dalam proses reka bentuk konvensional MDP. Akibatnya, penyelidikan ini menganjurkan yang ketersediaan maklumat komponen IBS dalam format perpustakaan digital 3D akan menggalakkan arkitek-arkitek untuk menggunakan MDP. Ulasan literatur telah dijalankan ke atas integrasi *MDP* and *BIM* dengan menyemak projek terkini mengenai *Product Information Aggregators (PIAs)* telah dibuat. Jadi, penyelidikan mencadangkan untuk membangunkan sebuah *IBS Interface System* dengan kefungsian eksklusif dalam mengumpulkan dan mengagihkan maklumat digital komponen *IBS* melalui satu sistem pengkelasan nama agar dapat menyokong arkitek untuk mempermudahkan *MDP* dalam *BIM.* Bagaimanapun, tiga keperluan sistem harus diperjelaskan terdahulu sebelum proses pembangunan sistem dibuat. Lantarannya, penyelidikan memilih tiga kaedah berjujukan: 1) Mengenal pasti keperluan sistem; 2) Membangun sistem reka bentuk *IBS*; dan 3) Menilai sistem menggunakan *Charrette Test Method (CTM).* Pertama sekali, penyelidikan mendapati keperluan sistem melalui dua survei yang telah dijalankan antara arkitek profesional dalam *IBS* dan dalam *3D Modelling*. Kajian survey telah merumuskan tiga keperluan sistem: 1) Lima belas kefungsian eksklusif, 2) Menyusun kepentingan maklumat komponen *IBS* dan 3) *Classified Component Naming (CCN)* untuk amalan permodelan 3D termasuk alatan aplikasi untuk mengautomasikan pengeluaran kod *CCN.* Kedua, penyelidikan menggunakan *Agile System Development Method* untuk menggunakan keperluan sistem ke dalam membangun *IBS Interface System*. Pembangunan *IBS Interface System* pula menerangkan bagaimana untuk membangunkan: 1) Sebuah prototaip *IBS* Gudang Maklumat Komponen Digital; dan 2) Satu rangka kerja *3D Modular Design Process*. Ketiga, kajian mengesahkan keberkesanan sistem baru berbanding konvensional satu dengan melalui *CTM.* Tiga kumpulan arkitek telah menyertai CTM untuk membuktikan keberkesanan positif antara muka *IBS System*. Di akhir kajian, keputusan setiap kumpulan individu telah dibentangkan untuk verifikasi dan pengesahan *IBS Interface System* melalui penggunaan prototaip tersebut di dalam *3D Modular Design Framework* dicadangkan. Kajian ini menghasilkan empat ilmu baharu: 1) mengubah keperluan arkitek kepada aplikasi fungsi alat; 2) mengutamakan maklumat komponen *IBS* berdasarkan perspektif arkitek; 3) menjana *CCN* untuk menghitung dan mengekalkan komponen binaan prefabrikasi *3D*; dan 4) membangun rangka kerja reka bentuk baru untuk *3D MDP*. Keputusan kajian ini dijangka dapat memperhebatkan penggunaan komponen *IBS* di kalangan arkitek tempatan sejajar dengan agenda nasional industri pembinaan Malaysia.

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LIST OF ABBREVIATIONS

4D	Fourth Dimension
5D	Fifth Dimension
Active Cat	Active Catalogue
AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
ARCHIDEX	Malaysia Architecture, Interior Design and Building Exhil
ARROW	Advanced Reusable and Robust Object Warehouse
BCL	Building Component Library
BIM	Building Information Modelling
CAD	Computer Aided Design
CATMS	Catalogue Management System
CCN	Classified Component Naming
CD	Compact Disk
CIDB	Construction Industry Development Board
CIFE	Centre for Integrated Facility Engineering
CIMP	Construction Industry Master Plan
CMS	Content Management System
CSS	Cascade Style Sheets
CTM	Charrette Test Method
CTMS	Catalogue Management System
DFD	Data Flow Diagram
DGN	Design File Format
DSA	Descriptive Statistic Analysis
DSM	Department of Standards Malaysia
DSS	Decision Support System
DWG	Drawing File Format
DXF	Drawing Exchange File Format
e-	Electronic
EDM	Electronic Document Management
ERP	Enterprise Resource Planning
FM	Facility Management
GDL	graphic design language
IAI	Industry Alliance Interoperability
IBS	Industrialised Building System
ICT	Information and Communication Technology
IFC	Industry Foundation Classes
IKEA	International Home Products Retailer
ISO	International Standard Organisation
IT	Information Technology
JKR	Jabatan Kerja Raya (Department of Public Works)

CHAPTER I

INTRODUCTION

1.1 Introduction

Malaysian Vision 2020 encourages construction industry to be more systematic and mechanised by employing the latest technology in construction (Anonymous, 2006). Hence, the "Industrialised Building System" or IBS was introduced as a favourite construction method to support the nation's development. Optimum implementation of IBS is a key to facilitate development process (Nizar Shaari, 2006). The term IBS is dedicated to a kind of construction process, which is quite same as global term "Prefabricated Building System" (PreBS), that utilises various techniques and products with specialised components under building systems, which involves prefabricated components following the on-site installation (CIDB, 2002; Trikha, 1999). In addition, United Nation (1992) describes IBS as a well-known term for sustainability in construction worldwide (United-Nations, 1992). Construction in most developing countries utilises prefabricated method for rapid, accurate and cost effective development (Elliott, 2003b). Shaari (2003) highlights several advantages in fostering and implementing IBS in universal construction, which are: manpower reduction, wastage minimisation, cleanliness, controlled quality, reasonable price, and construction process expedition (Shaari, 2003).

In Malaysia, the Construction Industry Master Plan (CIMP) provides 21 strategic recommendations aimed at achieving the vision of the construction industry to integrate world-class knowledge into local projects. The CIMP framework sets out the implementation process, responsibilities, performance monitoring and communication programme through its strategies. This CIMP has been developed by the Construction Industry Development Board (CIDB) in collaboration with various organisations representing the construction industry. The Master Plan incorporates the Seven Strategic Thrusts to ensure the build-ability in the local construction. Among these strategies, the third and the fifth Strategic Thrusts highlights the role of IBS in the realisation of CIMP vision. The third thrust specifies the application of the highest standard of quality, safety, health and environmental practise, which are identified as the IBS privileges. The fifth thrust aims to increase the usage level of IBS to over 80% by the year 2015 (CIDB, 2007).

Moreover, the 9th development plan of Malaysia encourages the use of alternative construction material and technology under the IBS and designs based on the modular design concept in housing construction. The utilisation of IBS components in construction for affordable homes is promoted through government building projects and the enforcement of Uniformed Building By-Laws (UBBL-1998) (CIDB, 2001). The Department of Standards Malaysia (DSM) introduced Modular Coordination (MC) in building as the major step towards proper metrication in building planning, design, construction, assembly and manufacture of building materials and components (DSM & SIRIM, 2001a). DSM aims for MC to facilitate the productivity process in the building industry by disciplining the dimensional and spatial coordination of a building and its components. Mahmud (2001) argued that MC allows a more flexible open industrial system to take shape for unexpected changes at construction (Mahmud, 2001). Additionally, CIDB Malaysia published several books, notes and schemes such as the IBS Roadmap 2003-2010, to support construction groups and encourage them to apply modular construction and work together with other industry players as well.

According to the IBS Roadmap 2003-2010, the IBS construction in Malaysia is currently classified into five main groups namely Precast Concrete Framing, Panel and Box Systems, Steel Formwork Systems, Steel Framing Systems, Prefabricated Timber and Block Work Systems (CIDB, 2002). The IBS Roadmap 2003-2010 also outlined five priority areas for the construction industry to embed in their own plans as follows:

1) Adoption of new construction techniques and technology;
2) Development of manpower to support adoption of IBS/MC;
3) Development of materials (components and machines) to support the application of IBS;
4) Enhancement of management processes and methods to encourage application of IBS; and
5) Provision of monetary (economic and financial) support to encourage IBS application (CIDB, 2002).

In the same way, CIDB officially launched the Modular Coordination Verification Scheme on 28th March 2002 to help designers in implementing IBS disciplines. Nevertheless, IBS implementation in conventional construction still has a long way to go (MBAM, 2004) but the efforts taken are starting to show an effect in the present time.

Trikha (1999) explains that although IBS was introduced in Malaysia in the 1960's, the construction industry is not quite successful in implementing IBS methods. The appreciation for IBS today is different compared to the 1960s (Trikha, 1999). Elliott (2003) supports Trikha (1999) by mentioning that in the 1960s, most IBS buildings were considered low quality buildings, mostly abandoned projects, buildings exhibiting unpleasant architectural appearances and other drawbacks (Elliott, 2003a). However, in the present times, many countries are currently witnessing the building of monumental buildings and mega construction projects, which are quite brilliant by themselves. They are unique and brilliant in terms of construction method because they are closely engaged with the advanced technology of other industries when built. IBS as a component-based development process is complex, sophisticated and often difficult to practice. Richard (2005) explains that IBS is a building system that forecasts building details before construction in terms of building components, procurements, logistics, manufacturing and design (Richard, 2005). That's why IBS system is usually involved in unique prefabricated construction and tends to be used in mass construction.

Regretfully, IBS is not encouraged to be applied in small construction projects. Baharuddin and Omar (2006) argued that one of the issues and challenges of IBS implementation in building industry is that small projects usually involve foreign labours who have lack of advanced technological knowledge (Baharuddin Abd. R. & Omar, 2006). Therefore, the Malaysian government is trying to facilitate mass IBS implementation for construction players by publishing annual plans and training courses to stakeholders (CIDB, 2004). However, according to IBS Survey 2005, in the design part, these efforts seem to be insufficient (CIDB, 2005a). IBS Survey 2005 was conducted among professional Malaysian architects from 75 architectural firms in order to measure the influences of IBS in national architectural practice. Based on IBS

Survey 2005, Malaysian architects are hesitating in following IBS rules and regulations during design development process. Therefore, as it is shown in Figure 1.1, this research is concentrating this phase of design in a typical workflow of an IBS project. The workflow consists of Schematic Design, Design Development, Construction Documentation, Bidding and Construction Administration. Baharuddin and Omar (2006) state that currently, IBS enters in the construction stage rather than in the design stage because of several reasons namely: common innovation in manufacturing system and construction system; manufacturers are more interested to sell rather than promote their design of products; and manufacturers guarantee their products, an issue more important for contactors than designers (Baharuddin Abd. R. & Omar, 2006). This fact was also mentioned previously in the IBS Survey 2003 that contractors are using IBS more than the architects (CIDB, 2003).

Figure 1.1: The workflow of IBS Project from design to construction

This research posits that in the design part, there is a lack of enthusiasm to practice IBS and its instructions, because the process includes sophisticated standards to follow. In fact, standardisations and roadmaps are just directions; designer needs motivation rather than propulsion to utilise IBS in their design. IBS in design is all about a modularisation (DSM & SIRIM, 2001a). Modular Design Process (MDP) is a unique method that brings harmony, aesthetic and fragmentation to architectural design (Nikravan Mofrad, 2004). However, designers believe it is a kind of discipline that they have to implement in their design (CIDB, 2005a). Furthermore, they believe MC in IBS is a barrier to their design. Although the government sector, through various research, tries to reverse this mentality as it seems to persist. The Government highlights that designing in compliance with IBS rules, should spur several positive consequences in to the construction industry with and the contractors, suppliers and labourers (Elliott, 2003b). However, designers prefer to spend their time conceptualising designs rather than applying IBS requirements into their designs (Sandberg *et al.*, 2008). Although Malaysia has been witnessing the incoming of many solutions in design practice such as Building Information Modelling (BIM) technology in design, but the improper integration of new design technique with the local practice is causing more hesitation in using IBS design process. This research focuses on BIM because its implementation is still rare in Malaysian construction and the study agrees with many pioneers in BIM development such as Lee, Laiserin and Tse who stated that if architects, engineers and contractors know about the BIM advantages, they would not hesitate in accepting it in their practices (Lee, Sacks, *et al.*, 2006).

1.2 Research Motivation

This research aims at finding the potential fusion points to better integrate the latest design solutions with IBS design principles. It is the research intent to utilise Information Technology (IT) and information and communication technology (ICT) for this purpose. One of the famous derivations of IT/ICT is Computer Aided Design (CAD). It is frequently utilised in drafting and modelling instead of particular design endeavours and logical capabilities. Pour Rahimian et al. (2008) explains that CAD systems have many benefits such as the opportunity of generation of huge quantity of drawings in a restricted time and the possibility of creating highly realistic and professional representations of the design solution. It can strongly support interaction and data transition among design society members and it can offer them better culture of communication (Pour Rahimian *et al.*, 2008). Nowadays, there is a great challenge in construction to improve the efficiency and effectiveness of the design and construction process using CAD tools. Aouad et al. (2005) stated that in recent years, many research on design and construction are conducted in this approach especially in Europe and North America. They also mentioned that there has been a huge interest, from both the academe and industrial communities, on the development of a single building/product model in modelling process with other design attributes (Aouad *et al.*, 2005). CAD systems have been used in the Architecture, Engineering and Construction (AEC) industry for decades and information fragmentation within CAD drawings has always been an obstacle to information sharing and exchange in construction among different design aspects and different design phases forcing scholars to improve their effective integration. Lee et al. (2005) introduced BIM as one of the research interests in incorporating all the design attributes such as time, cost, accessibility, sustainability, maintainability, acoustics, thermal, etc. (Lee *et al.*, 2005). Although this concept is more emphasised on the construction phase, it can be extended much wider in the entire AEC fields in relation to build environmental development.

The development and use of computer-based models for the AEC industry have been discussed in various international research and development communities since 1992 by G.A Van Naderveen and F. Tolman (van Nederveen & Tolman, 1992). However, the background of Building Description System was mentioned in 1975 in Charls Eastman's essay, which is quite similar to the latest modelling technology (Koivu, 2002). Different terms and concepts are used in the discussions to refer to these models and modelling systems. In the global market, there is another line of CAD products referred to as object-based or object-oriented CAD modelling. These products allow construction of a building model with parametric objects such as walls, columns and windows. Within the same period, the first versions of Autodesk® AutoCAD® and Bentley® MicroStation® were also shipped in 1983 and 1984, respectively (Eastman, 2008). This indicates that the development of object-based modelling and entity-based modelling began at a similar point in time. This object-based CAD software is now commonly known as BIM, although Virtual Building, Parametric Modelling and Model-Based Design also refer to the same line of products. Tse et al. (2005) believe that the concepts of BIM, product modelling and Virtual Building Environment (VBE) have been added to the terminology describing information models for the AEC industry, recently. BIM was launched by major vendors of CAD applications such as Autodesk®, Graphisoft®, Bentley and Nemetschek®. According to Laiserin (2003), a BIM is a computer model database of building design information, which may also contain information about the building's construction, management, operations and maintenance issues (Laiserin, 2003). This technology is theoretically pre-adapted to those types of architectural design where the information is pre-set and defined, such as design process in the case of IBS and any other PreBS.

IBS is introduced as an economic construction method through Open Building practice in order to increase productivity and affordability. The Open Building discussed in 1998 about exchangeability of building component in a systematic format (Cuperus, 2001). In fact, Open Building strategy, nowadays, has been realised in MDP. Therefore, designer's tasks, in either Open Building or MDP, are very important in terms of selecting the right building component from the right manufacturer. Torngren et al. (2005) state that designing in prefabricated method has two main strategic approaches: 1) model-based and 2) component-based. In the current state of model-based approach, order-to-build strategy in construction is chosen, which usually incur extra costs to the projects due to numerous customisations. They argued that in contrast, the component-based approach, the latest method in the prefabricated strategy, heavily relies on manufactured products. It is also becoming the most economical design system because architects design based on stock available at factories in accordance to modular rules and regulation (Torngren *et al.*, 2005). This study concurs that the cost redundancy in this type of design depends on maximising repetition and minimising the variation of modular component. Consequently, this research investigated the importance of critical information in the earlier stage of IBS projects in order to support component-based design process. In addition, the similarity between component-based design in IBS/MDP with object-based design in BIM can lead towards the feasibility of integration of BIM and IBS/MDP. However, the study suspects that there are some concealed reasons why this coincidence has not occurred until now.

It is required to know that IBS manufacturers have two main categories of customers namely architects and contractors. Architects need specific information that is slightly different with the rest of stakeholders in order to be motivated in selecting products. Usually, manufacturers present their product information based on paper works. However, the paper-based catalogue is obsolete for the architect to practice as new design system inventions are the increasing trend. That's why in current practice of IBS, paper-based documentation seems to be pervasive while in other countries, the latest documentation method in the 3D format is used. The paper-based documentation indicates many redundancies in information display and it is difficult to adjust since the same information must be revised at all locations in the documents (Björk, 2002). Designing works always involve sketches and drawings throughout the design process in 2D and 3D rendering but the process shall commence and finish in the 3D model (Jacoski & Lamberts, 2007). It is particularly very inherent that design research is still very much confined to the 3D design as long as researches in construction is moving forward to 4D and 5D (Sriprasert & Dawood, 2002). Hence, 3D documentation is recently being considered by designers, since it supports the construction stakeholders while they are practising on 4D building managements and consequently, 5Ds (3D + Time + Cost) (Dawood *et al.*, 2003). Despite of various methods in construction management, it is noted that architectural tasks are the foundation for other fields like structural, mechanical and electrical tasks to base on. Due to the current practise of designing in 3D format, architects always need product information in a format which is supportive of the architectural design process. In

MDP, the product information about IBS components is recommended to be tailored and localised as Ibrahim (2006) brought up before. Hence, this study is motivated to poses the most reliable method in adjusting the aforementioned type of information based on advanced technique of BIM.

1.3 Problem Statement

The CIDB Interview 2005 revealed that only 30% of Malaysian architects are willing to use IBS in their design. The Interview was conducted through accredited Malaysian architects about the issue of IBS penetration and its performance in the local architectural design (CIDB, 2005a). As Jacoski & Lamberts (2007) along with many others researchers were mentioning that the quality of architectural documents would absolutely determine the succeeding documentation process by other fields (Jacoski & Lamberts, 2007). Therefore, in the design of IBS buildings and MDP, the research posits that current practice of architectural design in 2D-CAD is not suited to the upheaval of recent innovations in BIM. Obviously, demanding of BIM technologies by other stakeholders will increase the hesitation of local architects from practicing based on IBS/MDP. The research is proposing to enhance the common MDP at the design stage by adjusting with BIM requirements. Forecasting the fusion of MDP and BIM will encourage the local architects to utilise more IBS products and distribute the advantages of both technologies in construction. Therefore, the product information about IBS products should be addressed both MDP and BIM requirements. Foremost, the local manufacturers are playing the significant role in providing information in a suitable format for local architects. Furthermore, the unavailability of product information from manufacturers is determined as the fundamental problem for all the explained chaos. The manufacturers are mainly marketing using paper-based product catalogues, which is not suitable for architectural requirements in integration of MDP and BIM. Indeed, architects need proper information in digital format so that they can accurately incorporate them into their design process. Therefore, the purified problem of this research is stated as follows:

"Unavailability of an exclusive 3D digital information about Industrialised Building System component is not encouraging architects to apply modular design concept during Building Information Modelling process"

1.4 Research Questions and Objectives

For overcoming the research problem the main research question is proposed as follows:

> "How can the study develop an IBS Interface System that integrates [HOW] 3D digital IBS component information [WHAT2] for improving Malaysian architects' willingness [WHO] to practice MDP in BIM [WHAT1]?"

The main research question is further divided into six sub-research questions (Sub-RQs):

Sub-RQ1: What are the architectural requirements for modular design practice in BIM?

Sub-RQ2: What are the functional needs of architects to practise modular design in BIM?

Sub-RQ3: What types of IBS component information do architects need to support design decision when selecting IBS products?

Sub-RQ4: What is the recommended classification naming system for retrieving IBS component information during modular design in BIM?

Sub-RQ5: How can digital IBS component information be integrated with modular design practice in BIM?

Sub-RQ6: What is the indicator for the positive effect of the IBS Interface System during Modular Design Process in BIM?

For answering the research Sub-RQs, the following objectives are formulated for the thesis:

RO1: To understand modular design requirements in BIM.

RO2: To identify architects' requirements to practice modular design in BIM.

RO3: To develop an IBS interface system to provide digital IBS component information in 3D modular design.

RO4: To measure the satisfaction and effectiveness of the 3D Modular Design Framework with IBS digital information warehouse.

1.5 Research Methodology

The study conducted sequential mixed research method for answering the Sib-RQs and ROs. The research utilised qualitative approach for identifying system requirements and developing the IBS Interface System and then, quantitative approach was chosen for proving the effectiveness of the system for local practitioners. In the following sections, the research methods are described briefly.

1.5.1 Research Components

All the Research Components were summarised in the following table (1.1). The following table includes Problem Statement (PS), Research Question (RQ), Sub Research Questions (Sub-RQs), Research Objectives (ROs), Strategies for achieving ROs and the Results. The Sub-RQs 2 to 4 are indicating to identify the architect requirements through System Requirement as accomplishment for the second RO. Sub-RQ 2 and Sub-RQ 3 are proposed to identify the functional architectural requirements and IBS Component information requirements from the local professional architects through Interview 1. The Sub-RQ 4 is dedicated for answering the classification requirement by proposing a Classified Component Naming for itemisation of IBS products through Interview 2. The Sub-RQ 5 is for showing how architectural requirements and expectations can be managed systematically and be answered in an automated process. The system development strategy is the proper approach for developing a prototype and a framework for the IBS Interface System as per defined in the third RO. The last Sub-RQ (6) is set to ensure the positive effectiveness of the new proposed system during the IBS design process through CTM as an accomplishment for the last RO. This step is quite important because it's assumed as the validation for IBS interfaces prototype includes the proposed 3D Modular Design system.

Table 1.1: The Eagle Table includes Research Components (Ibrahim, 2009)

Problem Statement:
Unavailability of an exclusive 3D digital information about Industrialised Building System component is not encouraging architects from applying modular design concept during Building Information Modelling process

Main Research Question [RQ]
How can the study develop an IBS Interface System that integrates [HOW] 3D digital IBS component information [WHAT2] for improving Malaysian architects' willingness [WHO] to practice MDP in BIM [WHAT1]?

RQ Construct	Sub-Research Questions [SUBRQs]	Research objectives [ROs]	Strategy of Inquiry	Results
[WHAT 1] MODULAR DESIGN PRACTICE IN BIM	**Sub-RQ1:** What are the requirements for modular design practice in BIM?	Understanding modular design requirements in BIM.	**LITERATURE REVIEW** - Industrialised Building System - Building Information Modelling - Product Information Aggregator	-MDP requirements, -BIM practice requirements, -Classification requirements
[WHAT 2] DIGITAL IBS COMPONENT INFORMATION	**Sub-RQ2:** What are the functional needs for architects to practise modular design in BIM? **Sub-RQ3:** What types of IBS component information do architects need to support design decision when selecting IBS products? **Sub-RQ4:** What is the recommended classification naming system for retrieving IBS component information during modular design in BIM?	Identifying the architects' requirements to practice modular design in BIM.	**INTERVIEW 1** (Participants: Local professionals experienced in IBS projects) **INTERVIEW 2** (Participants:3D modelling experts)	- Functionalities - IBS Components Information - Classified Component Naming System
[HOW] IBS INTERFACE SYSTEM	**Sub-RQ5:** How can digital IBS component information be integrated with modular design practice in BIM?	Developing an IBS Interface System for providing digital IBS component information in 3D modular design.	**SYSTEM DEVELOPMENT** (IBS Interface System) - Tool (Prototype) - Process (Framework)	- IBS Digital Component Information Warehouse Prototype - 3D Modular Design Framework
[WHO] ARCHITECTS' WILLINGNESS	**Sub-RQ6:** What is the evidence for indicating the positive effectiveness of the IBS Interface System during Modular Design Process in BIM?	Measuring the satisfaction and effectiveness of the 3D Modular Design Framework with IBS digital information warehouse.	**CHARRETTE TEST METHOD** -Verifying functionalities; -Validating IBS digital component information warehouse prototype -Validating the 3D modular design framework.	- Verification of the Prototype - Validation of the Prototype - Validation of the Framework

1.5.2 Research Framework

The research framework covers the research components and the research design in order to show how research requirements are organised systematically (Figure 1.2). The research framework, as presented in the following graph, is illustrated based on ROs and RQ and its sequential Sub-RQs (Table 1.1). Based on ROs and RQ, the RM can be divided into three main steps. The first RO, which was about understanding modular design requirements in BIM, has also successfully achieved in Chapter II. Based on the research problem, this study conducted a literature review in three issues: 1) Modular Design Process (MDP), 2) Building Information Modelling (BIM), and 3) Product Information Aggregator (PIA). The theoretical constructs and proposition directed the research towards developing an IBS Interface System for solving the research problem. However, it was required to identify the necessary system requirements for better localising and customising the system. Therefore, two interviews were conducted among professional architects familiar with both IBS practice and 3D modelling practice in order to identify functionality, product information and classification requirements. The results guided the succeeding development of the IBS Interface System that includes a dedicated prototype and a framework. The IBS Interface System was finally validated sequentially through a Charrette Test Method (CTM). The CTM was conducted to show the positive effectiveness of the new design system for encouraging the Malaysian architects in using IBS. In the following, Figure 1.2 demonstrates the entire process of this research.

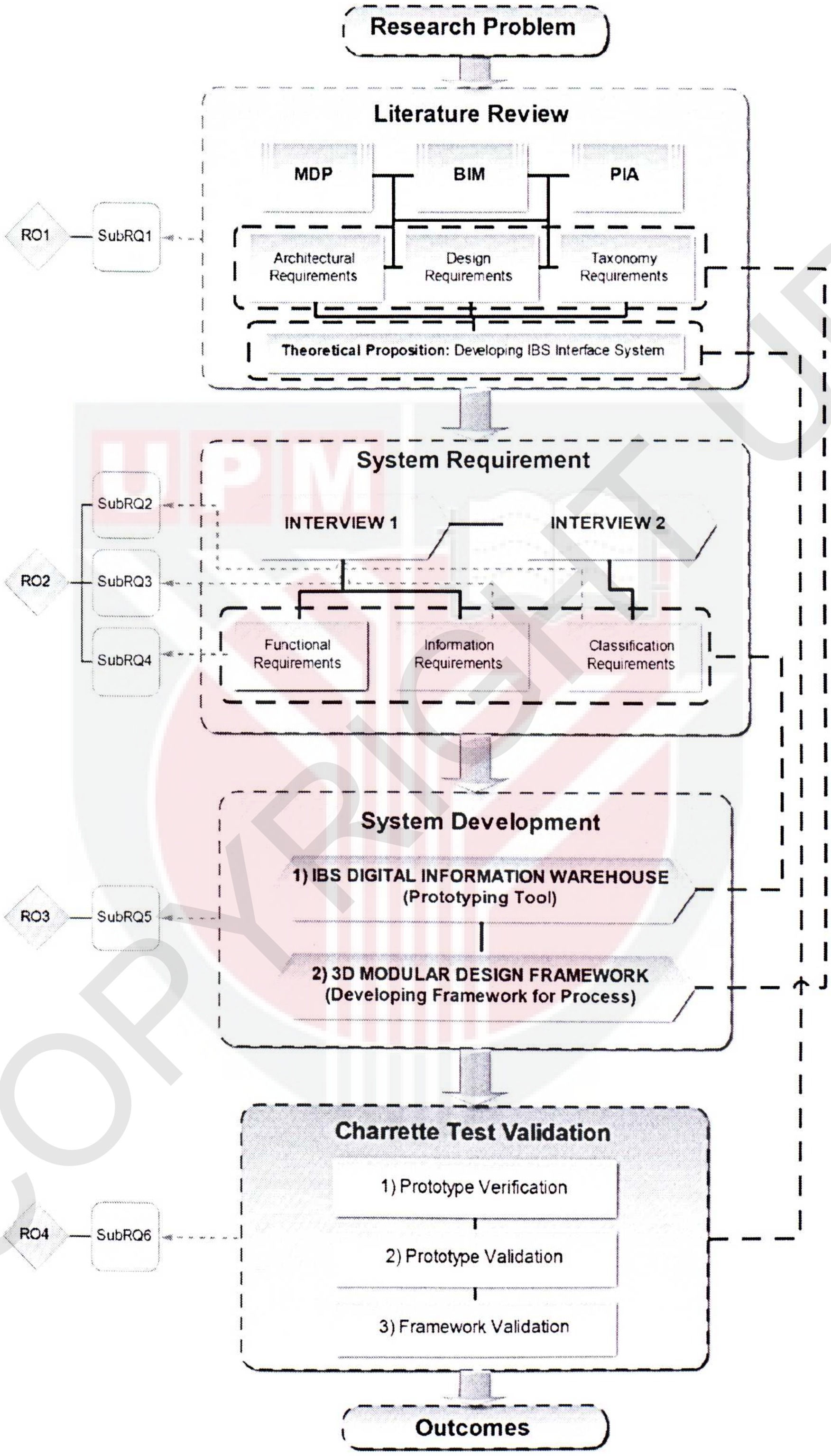

Figure 1.2: The Research Framework.

1.6 Scope of Study

As a result of IBS Survey 2005, this study focuses on Malaysian IBS performances among Malaysian Architects and the potential motivations and solutions that can increase its application in the construction industry. It is limited to the design development phase where the most crucial decisions ha to be made for selecting the IBS components from the variety of similar products. The study concentrated facilitating design practice in IBS projects by integrating the Modular Design Process with the Building Information Modelling in line with Malaysia Vision 2020.

1.7 Research Limitations

This section discussed about the limitations in each chapter of the study. In the following, some of several limitations are summarised in terms of limitations in study direction and system development:

1.7.1 Limitation of Study

The direction of this research is limited to the following issues:

- design development phases in design timeline while most critical decisions have to be made; and
- the Malaysian architects' issues and challenges during IBS project.
- The local Industrialised building System and applying modular design concept in Malaysia;

- Building Information Modelling as the latest technology in product modelling; and
- Product Information Aggregators who are practising and activated in the internet.

1.7.2 Limitation of IBS Interface System

This research is limited to the architectural design practice in IBS. Therefore, although, the IBS Interface System contains two kinds of users, architect and manufacturer, the study concern more on the application of architects' requirements to the prototype. In addition, the prototype is limited Joomla®'s capability as the main platform of the prototype. Joomla has its own limitation as well; however, the outcomes satisfy research requirements. In the research recommendation, this study will explain what deliberation should be considered in future development process. The technical limitations of the prototype are as follows:

- The prototype requires bigger learning curve in comparison to the other CMS.
- The prototype doesn't have friendly Search Engine Optimisation out of the box
- The prototype may get bulky in JavaScript and Cascade Style Sheet (CSS) customisation
- The prototype may become slower in loading time if the sever becomes busy
- The prototype needs additional hosting if its data become bigger than its capability
- The prototype may become clumsy if its layout is changed

- Although the Joomla is free and Open Sources but it imposes extra cost, if technical plug-ins are required

1.8 Organisation of Thesis

This thesis has six chapters. A summary of their content is described, hereunder:

Chapter One defines the research problem and briefly describes research the objectives, research question, research methods as well as research scope and Limitations.

Chapter Two presents the literature review about determining: 1) architectural requirements in practicing Modular Design Process (MDP); 2) architectural requirements in practicing Building Information Modelling (BIM) requirements; and 3) the effect of Product Information Aggregators (PIAs) in architecture. At the end of this chapter, theoretical constructs were concluded from the point of departures of each section regarding: 1) System Functionality Requirements; 2) Component Information Requirements; and Component Classification Requirements. The theoretical proposition was concluded to test the positive effectiveness of an IBS interface system includes application of all the theoretical constructs for encouraging architects in IBS.

Chapter Three explains the research approach for answering all the research needs, which are: 1) System Requirement Interviews for localising the development process;

2) IBS Design System Development for developing the process and tool; and 3) Charrette Test Method (CTM) for testing and validating the system.

Chapter Four is dedicated to the results and analysis of the System Requirements from the two main interviews that are essential in the development of the proposed design system. The interviews were conducted in order to find the System Functionality, type of Building Component Information and Classified Component Naming (CCN) in using IBS products.

Chapter Five explains the system development, including the new prototype development and the architectural design process. At the end of this chapter, the results of the CTM were presented to verify and validate the positive effects of IBS Interface System in comparison to the conventional one.

Chapter Six summarises the whole dissertation and presents the knowledge contributions and benefits of this study. It concludes with recommendations for the future extension of this research.

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