SIMULATION OF INDUSTRIALISED BUILDING SYSTEM FORMATION FOR HOUSING CONSTRUCTION

AHMAD RAZIN B ZAINAL ABIDIN @ MD TAIB

A project report submitted in partial fulfillment of the
requirements for the award of the Degree of
Master of Science (Construction Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

NOVEMBER 2007

Status Declaration Letter

Librarian
Perpustakaan Sultanah Zanariah
UTM, Skudai
Johor.

Date : November, 2007

Sir,

CLASSIFICATION OF THESIS AS RESTRICTED

SIMULATION OF INDUSTRIALISED BUILDING SYSTEM
FORMATION FOR HOUSING CONSTRUCTION
AHMAD RAZIN B ZAINAL ABIDIN @ MD TAIB

Please be informed that the above mentioned thesis entitled "SIMULATION OF INDUSTRIALISED BUILDING SYSTEM FORMATION FOR HOUSING CONSTRUCTION" be classified as RESTRICTED for a period of three (3) years from the date of this letter. The reasons for this classification are

(i) COMMERCIALIZATION OF RESEARCH PRODUCT
(ii) NEGOTIATION STAGE WITH UTSB SDN. BHD. AS BUSINESS CONSULTANT
(iii) NICHE IBS PRODUCT COMPONENTS ARE WAITING TO BE MANUFACTURED

Thank you.

Sincerely yours,

ASSOC. PROF. DR. ABDUL KADIR MARSONO
M46-238, Faculty of Civil Engineering
07-5531606
013-7257737

To my beloved wife, my son,

All my family members,

My course-mates and friends.

..THANK YOU FOR EVERYTHING..

Special thank to my supervisors,

And everyone who had involved

in this study.

..MAY GOD BLESS ALL OF YOU..

Thank you

ACKNOWLEDGEMENT

Alhamdulillah, all the successful things come from Allah. The greatest gratefulness to Allah for His delight for the author to finished this magnificent study.

Firstly, a sincere gratitude is accredited to the supervisor, Associate Professor Dr. Abdul Kadir Marsono for his passionate assistance, guidance and concern throughout this study. A lot of knowledge and experience has been shared especially on a new skills and technology in construction practice. With his invaluable advice and excellent guidance, the author has successfully completed his Masters Project. It is really good deed and exciting opportunity to work with such a dedicated supervisor.

Also special thank to Dr. Masine Md Tap for their ideas and helps on simulation expertise. Above and beyond, the author would like to thank all parties that have been so kindly in giving invaluable information and data to the author. Simultaneously, the author wishes to express his sincere gratitude to all who have helped directly or indirectly in his Masters Project research work.

Last but not least, special appreciate is addressed to all family members especially beloved wife for moral supports, motivation and concerns.

ABSTRACT

Industrialised Building System (IBS) is a construction method that offers economisation of design, site work and materials, provides shorter construction time, saving in labour, better quality control, immunity to weather changes and the most importantly, the cost factor. It has been proven successful in some countries such as Finland, Denmark, Netherlands, Singapore, England and the United States (CIDB, 1998). In our country Malaysia, the shorter construction time offered by IBS may seems to be the solution for the housing demand in Malaysia. The aim of this study is to determine the process flow of housing construction that are applying Industrialized Building System (IBS) components for its main structure. For that purpose, sequence process of installation activities for construction of IBS houses has been identified. Witness 2001 simulation software has been applied to model a construction of 300 IBS houses. The most achievable completion time has been examined and at the same time optimum resources for the construction has been identified during the simulation analysis. It is hoped that the widespread understanding on the Industrialised Building System (IBS) can further help to develop and promote IBS as an innovative construction method in Malaysia.

ABSTRAK

Sistem bangunan berindustri atau *Industrialised Building System* (IBS) merupakan satu kaedah pembinaan yang menawarkan rekabentuk, kerja-kerja tapak dan bahan-bahan pembinaan yang ekonomi, membekalkan tempoh pembinaan yang lebih singkat, menjimatkan dari segi tenaga kerja, menawarkan kualiti yang lebih baik, fleksibel dengan cuaca, dan yang paling penting adalah dari segi faktor kos pembinaan keseluruhannya. Penggunaan IBS telah terbukti amat berjaya di beberapa buah negara seperti Finland, Denmark, Belanda, Singapura England dan Amerika Syarikat (CIDB, 1998). Di negara kita Malaysia, kelebihan IBS yang menawarkan tempoh pembinaan yang lebih singkat seolah-olah menjadi penyelesaian kepada permintaan rumah yang semakin meningkat. Matlamat utama kajian ini adalah untuk mendapatkan suatu senarai proses kerja bagi membina 300 rumah teres dua tingkat yang mengaplikasikan komponen IBS untuk struktur utamanya. Untuk tujuan itu, susunan aktiviti-aktiviti yang lengkap dalam pemasangan komponen IBS telah diperolehi. Dengan menggunakan perisian simulasi *Witness 2001*, masa pembinaan yang terbaik yang mampu dicapai telah dikaji dan pada masa yang sama penggunaan sumber yang paling optimum untuk kerja pembinaan telah dikenalpasti. Diharapkan dengan bertambahnya pemahaman tentang pengaplikasian IBS, secara tidak langsung ia akan membantu dalam membangunkan dan mempromosikan IBS sebagai satu kaedah pembinaan yang sangat inovatif.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.0 Introduction

In the 7th Malaysia Plan, Malaysia planned to construct about 800,000 units of houses for its population which is 585,000 units or 73.1 per cent were planned for low and low medium cost houses. Nevertheless, the achievements are somewhat disappointing with only 20 per cent completed houses in this category despite numerous incentives and promotions to encourage housing developers to invest in such housing category (Kadir *et al.*, 2006). In the 8th Malaysia Plan, almost another 800,000 units of houses are planned to build but the result still unsatisfactory.

With the announcement of the 9th Malaysia Plan, the country continues to embark on the development of affordable and sustainable low and medium cost housing. However, the country is facing a difficult task to accomplish the target of 600,000 to 800,000 houses during this period because the conventional building system currently being practiced by the construction industry is unable to cope with the huge demand (Kadir *et al.*, 2006).

In essence, the demand for construction labour usage varies as the project progresses from structural work including basement construction, architectural and finishing work and mechanical and electrical (M&E) work. Furthermore, the proportion of foreign to local workers also differs considerably through these stages because of different skills required to accomplish the task. Currently, we can see that our country's construction industry is still very comfortably using labour intensive and low technology methods of construction. The intensive use of foreign unskilled workers and low technology equipment and out-of-dated construction methods, has eventually caused low productivity and efficiency of work at construction site (Tay, 2006). As a result this has lead to unproductive practices and initially contributes to the late delivery of work.

The highly dependency on unskilled and cheap foreign workers has definitely contributed to low productivity of work, because although they may be cheap, but they are not efficient and cause high wastage. The quality of work has also been terribly affected due to unskilled working method. After completion defects, structural failures and design inadequacies are some of the tell-tale sign of the current construction scenario in our country. According to CIDB (2000), complaints made by consumers through national media and to the authorities are some of the numerous indications of low quality of work. At the end, these will lead to decreased quality of life in uncomfortable and unfriendly environments.

Therefore, according to those problems, the industry must find an alternative solution such as the industrialised building system (IBS) which has a lot of advantages in term of productivity, indoor quality, durability and cost. The introduction of the Industrialised Building System (IBS) with the promise of improving productivity rate, lowering construction costs and meeting the growing demand for affordable housing is indeed welcoming news to the country's construction industry (Richard, 2005). In other word, the awareness of current trends and latest construction technology and innovation is essential in order to survive in the competitive market.

1.1 Problems Statement

Although the long-introduced Industrialised Building System (IBS) has promised to solve and improved the current construction method and scenario in our country, but the IBS method has been low in gaining popularity, partly due to lack of awareness and coordination among the relevant parties. Currently, the level of usage of IBS method is very low as compared to the conventional methods in building construction (CIDB, 2005). In spite of its many benefits, the different perceptions among the construction players and practitioners towards its application in construction industry has led to the low usage of IBS components in the construction industry.

Dulaimi (1995) believe that considerable research efforts have been directed toward the “hardware elements” of the IBS technology which are concerned with the structure itself (the strength of the concrete and steel, the share forces, the bending moment of the structure members, etc) but to date, the “software elements” of the IBS, which are concerned with the data and information available on the system, users, clients, establishment of manufacturing and assembly layout and process, and allocation or resources and material, have received little attention. Therefore, there is a dire need to overcome the shortage in the “software elements” of the building system research (Badir, Kadir, and Hashim, 2002).

1.2 The Objective of the Study

The aim of this study is to determine the process flow of housing construction that are applying Industrialized Building System (IBS) components for its main structure. Accordingly, there are three specific objectives towards the main goal:

(i) To identify the detail sequence activities of housing construction using IBS construction method.

(ii) To examine the most achievable completion time for IBS housing construction by using simulation software.

(iii) To determine the optimum resource utilization such as tools, machineries and labours in IBS construction by using simulation software.

1.3 Scope of the Study

The scope of work is mainly focused on the installation of IBS components including footings, beams, slabs, columns, walls, toilets, stairs, roofs and fences. It is required for the construction of 300 units of double storey house. The installation process that will be highlighted in this study is starting from transporting IBS components to the site, lifting and delivery, assembly process, fixing and adjusting IBS components until finish the whole structure. Some assumptions that have been made in this study are the installation will not be interrupted due to any delay, machine breakdown, lack of labours and insufficient supply of IBS components from the supplier.

1.4 Significance of the Study

The study is attempted to propose a better alternative method for housing construction. As the construction industry now is facing the challenges of four aspects of time, cost, quality and safety, besides the demands of hundred thousands houses development in Ninth Malaysia Plan, it is vital to have a systematic system or method to be used in this industry. Therefore IBS used in double storey houses has been introduced.

Other than that, this study will be used as a guideline model for the developer or the contractor of IBS projects in the future to construct houses using IBS components with detail information especially on time and resources usage. Besides, this study will show them on how to manage IBS construction method at site by considering the best sequence process whereby it will offer the optimum resources utilization with minimum construction time. Finally the idea gathered and simulation model produced from this study may help all parties involved in IBS construction to prevent unnecessary problems.

Yet, it is hoped that the widespread understanding on the Industrialised Building System (IBS) can further help to develop and promote IBS as an innovative construction method in Malaysia.

1.5 Methodology of the Study

This study consists of five stages towards the final aim as shown in figure 1.1. As far as the title of research is concerned, the main goal together with the objectives of this study has been identified as discussed in previous topic. Then the scope and limitation has been determined to concentrate on the aim of the study. Literature review has been taken place after all preliminaries stage has completed. The purpose of this stage is to strengthen the background knowledge of this study and moreover to achieve some of the objectives fixed in the early stage.

The climax of this study is on the collecting data and the discussion of findings stage. Detail description of procedures to collect data, findings and discussions has been made in chapter 3. Construction simulation approach has been used in this study to replicate the IBS construction of housing in real-time virtual modes. A final finding is to determine the optimum resources utilization in IBS construction by using simulation software. The study ended with conclusion and some recommendations to further develop the result of this research.

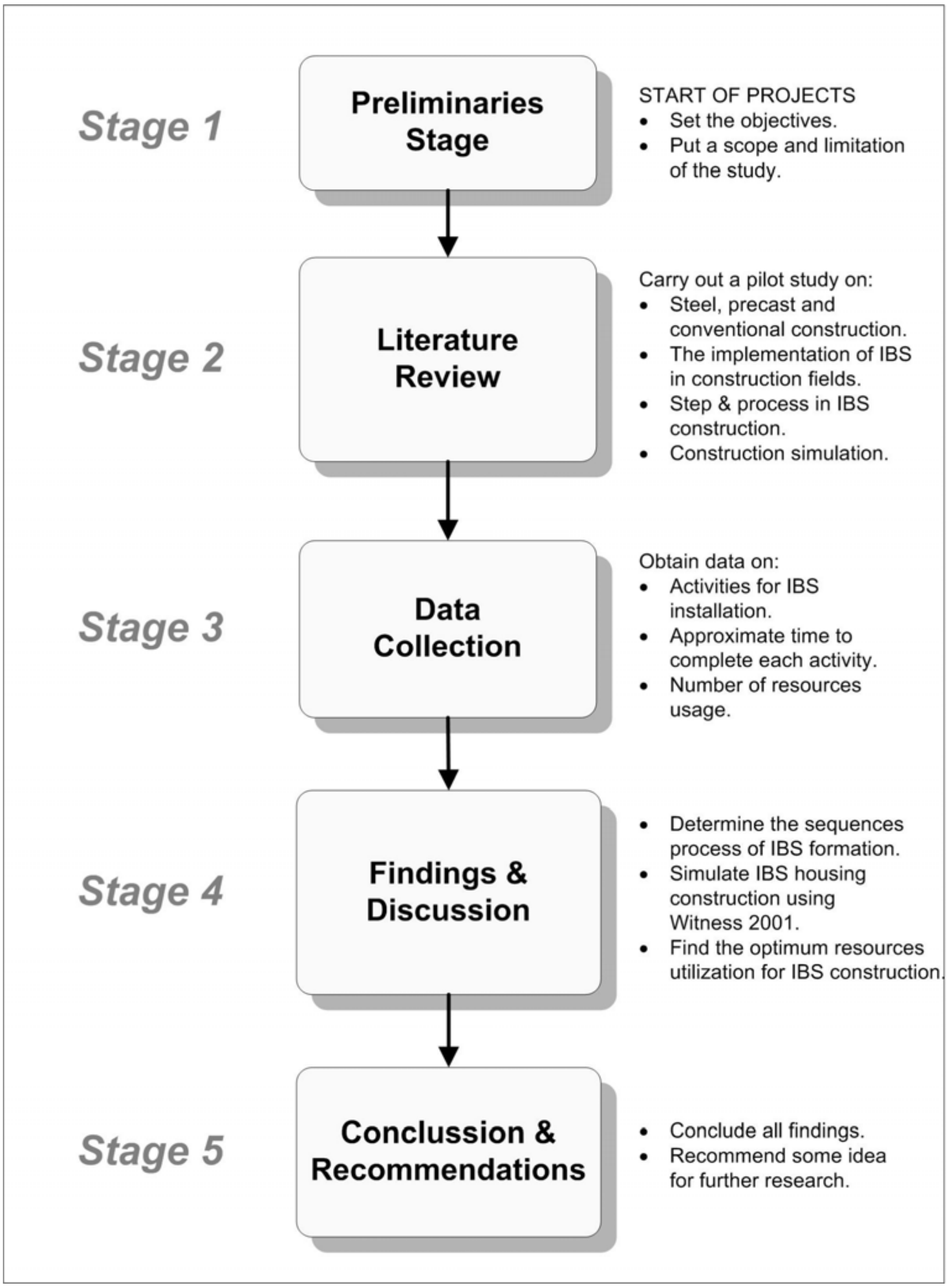


Figure 1.1: Methodology of the study

1.6 Summary

First chapter was explained to introduce and elaborate the background of this study for further understanding on the problems that has been solved. Such that issue on the long-introduced of Industrialised Building System (IBS) still has been low in attaining popularity in construction industry, partly due to lack of awareness and coordination among the relevant parties. By considering the demands of housing development and the need for construction industry to make changes, the introduction of the Industrialised Building System (IBS) with the promise of improving productivity rate, lowering construction costs and meeting the growing demand for affordable housing is definitely welcoming news to the industry. This study is prepared to provide some information of IBS technology that can be implemented by all parties in construction project. With the extensive knowledge on the Industrialised Building System (IBS) may further expand and promote IBS as an innovative construction method in Malaysia, at the same time prevent all the barriers to the adoption of IBS technology in construction Industry.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Literature review on the background information for this study is to discuss as many as theoretical issues to strengthen the final findings. This chapter highlights the subject on Industrialised Building System (IBS) itself, its importance and contribution to the construction industry. It also elaborates the sequence of IBS construction according to the observation of conventional, precast and steel constructions. This chapter also review on the concepts of Modular Coordination (MC), Just-In-Time principles, the sequences of structural formation process of IBS components at site, simulation construction overview and will emphasize on the simulation of housing construction in Malaysia that utilising IBS method. At the same time, this chapter presents on the literature information that will later illustrate the research methodology that has been carried out in the following chapter.

2.1 Industrialised Building System (IBS)

According to Warszawski (1999), building system is defined as a set of interrelated elements that act together to enable the designated performance of a building. "Industrialised system" means to build on-site with elements or components produced by series in plants (Badir, Kadir, and Hashim, 2002). Industrialised Building System (IBS) is one of the improved building systems that are being introduced to achieve the target of faster completion with mass production of the building elements in places out of its final location in a building.

Rollet (1986) also defined the word industrialising as to build on site with elements or components produced by series in plants. An industrialised organisation of building means that these components can be assembled together even though they are produced on different plants as they have then to be compatible. Another definition given by Trikha (1999), expounded that Industrialised Building System (IBS) is a system in which concrete components, prefabricated at site or in factory are assembled to form the structure with minimum in-situ construction. Esa and Nuruddin (1998) also defined that an IBS is a continuum beginning from utilising craftsmen for every aspect of construction to a system that make use of manufacturing production in order to minimise resource wastage and enhance value for end users.

In short, Industrialised Building System (IBS) is a construction method that offers economisation of design, site work and materials, provides shorter construction time, saving in labour, better quality control, immunity to weather changes and the most importantly, the cost factor. It has been proven successful in some countries, namely Finland, Denmark, Netherlands, Singapore, England and the United States (CIDB, 1998). In our country Malaysia, the shorter construction time offered by IBS seems to be the panacea for the housing demand in Malaysia. It is hoped that the widespread understanding on the Industrialised Building System (IBS) can further help to develop and promote IBS as an innovative construction method in Malaysia.

Nevertheless, it requires that the creativity to be created and implemented at all stages of development plan to assembly to achieve successful IBS implementation.

2.2 Typical Classification of IBS

In general, there are various Industrialised Building Systems (IBS) used throughout the world, and they can be classified into several major categories (Junid, 1986). From the structural classification, there are three IBS main groups identified as being used in this country. The typical classifications are as follows:

(i) Frame or post and beam system
(ii) Panel system
(iii) Box system

Figure 2.1 shows the concept of the system as classified above. In the evaluation of the systems, various parameters such as the industrialised process used, the transportation and erection problems, architectural features and the social-economic problems must be considered.

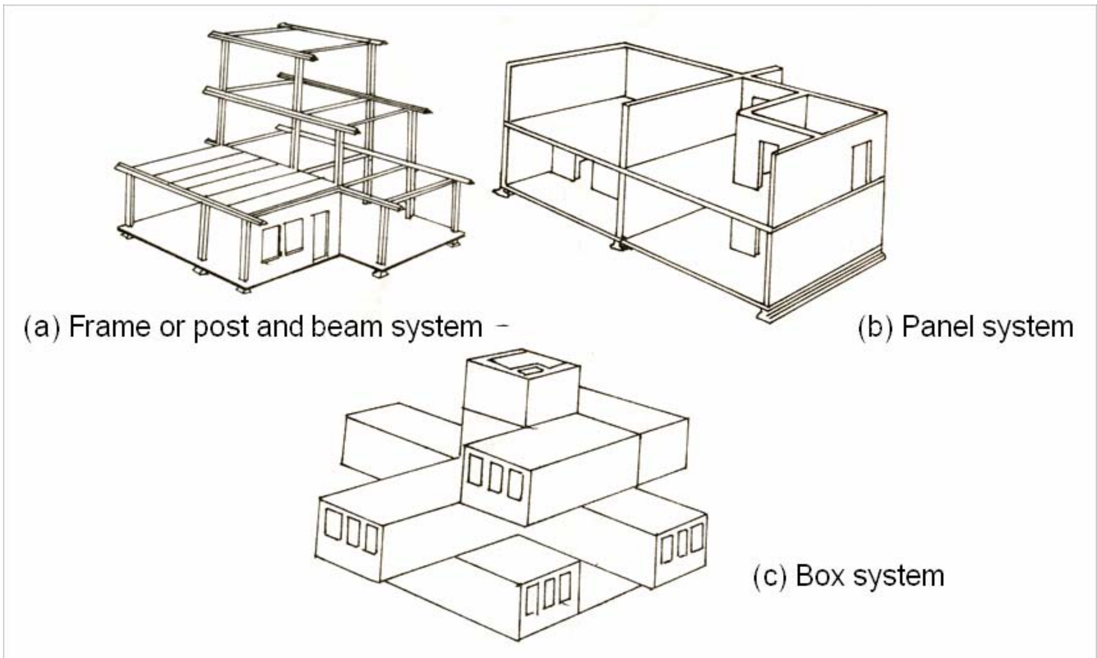


Figure 2.1: Classifications of Industrialised Building Systems (IBS)

However, Majzub (1977) commented that the relative weight of components should be used as a basis for building classification. The factor of weight has a huge impact on the transportability of the components and also has influence on the production method of the components and their erection method on site. This classification by weight can help to distinguish between various basic materials used in the production of the components, which by itself help to determine the characteristics of the studied system. Table 2.1 shows the building system classification according to relative weight of component.

Table 2.1: Building system classification according to structural system

No	General System	System	Production Material
1	Frame system	Light weight frame	Wood, light gage metals
		Medium light weight frame	Metal, reinforced plastics, laminated wood
		Heavy weight frame	Heavy steel, concrete
2	Panel system	Light and medium weight panel	Wood frame, metal frame and composite materials
		Heavy weight panel (factory produced)	Concrete
		Heavy weight panel (tilt up-produced on site)	Concrete
3	Box system (modules)	Medium weight box (mobile)	Wood frame, light gage metal, composite
		Medium weight box (sectional)	Wood frame, light gage metal, composite
		Heavy weight box (factory produced)	Concrete
		Heavy box (tunnel produced on site)	Concrete

2.2.1 The Frame System

Frame system may be defined as those structures that carry the loads through their beams and girders to column and finally to the footing or pilecap. Junid (1986) also stated that, in such a system, the skeletal structures will help to reduce the number and sizes of load carrying members. Their important feature is the capacity to transfer heavy loads over large spans. Therefore, it is used in the construction of bridges, parking lots, warehouses, industrial buildings and sport facilities.

Typical systems of linear components for industrial buildings are composed of structural frames, spaced at equal distances whereby it creates modular linear frame that can be repeated at a desired number of times. Figure 2.2 shows the example of industrial hall using frame system.

Figure 2.2: Industrial Hall using Steel Frame System

2.2.2 Panel System

The second system is panel system which also known as planar system. Panel system may be defined as those structures that carry the load through large floor and wall panels (Junid, 1986). This system probably would be the most widely used prefabricated system which employed planar or panel-shaped elements for floor slabs, vertical supports, partitions and exterior wall. Concrete panel systems are extensively used in Europe for high rise building for ease of construction purpose. In Malaysia, this system is popularly used in high rise flats and low rise buildings.

Unlike frame system that mainly employed as structural framing, panel systems also fulfil interior and exterior space enclosure functions. They may be prefabricated with a considerable amount of finish with a considerable amount of finishing work such as exterior finish, thermal insulation, electrical conduits and fixtures, plumbing and window frames. Therefore, panel system will significantly reduce the content and amount of skilled workers onsite. Hence, this system is widely used in residential buildings, offices, schools, hotels and similar buildings with moderate loads and large amount of finish works. Figure 2.2 shows the application of panel system in industrial housing.

According to Junid (1986), panel system may be defined as those structures that carry the load through large floor and wall panels. The panels can be made in various forms and materials and are normally prefabricated at factory. Depending on the scale of projects, some panels may be fabricated at site for easy transportation. Concrete panel systems are extensively used in Europe for high rise building for ease of construction purpose. In Malaysia, this system is slowly gaining popularity in terms of high rise flats and low rise buildings. Other panel systems available are as such wood, plastic, light weight metal and ferrocement materials.

2.2.3 Box System

According to Junid (1986), box system may be defined as those systems that use three-dimensional modules (or boxes) for fabrication of habitat units. Box system is useful and preferable because of its compatibility with a high degree of finish in the factory and its lateral resistance (Bruggeling and Huyghe, 1991). The main features of this system are in the internal stability as it can withstand load from various directions.

The box system components can be either cast in box-like moulds or assembled it in the plant from panel form elements. The components may contain a large amount of finishing works such as wall and floor finishing, electrical wiring and fixtures, kitchen cupboard, plumbing pipes and windows. This will definitely speed up the construction time at site. In the case of high rise construction, the degree of factory prefabrication is reduced for economic reasons of avoiding doubling of wall, ceilings and floors. Depending on how it is used, the boxes can be made to be load bearing or only support its own weight. The boxes can be produced in monolithic form such as concrete boxes or be made in various sections joined together in the factory. Figure 2.3 show the assembling of box units into position onsite.

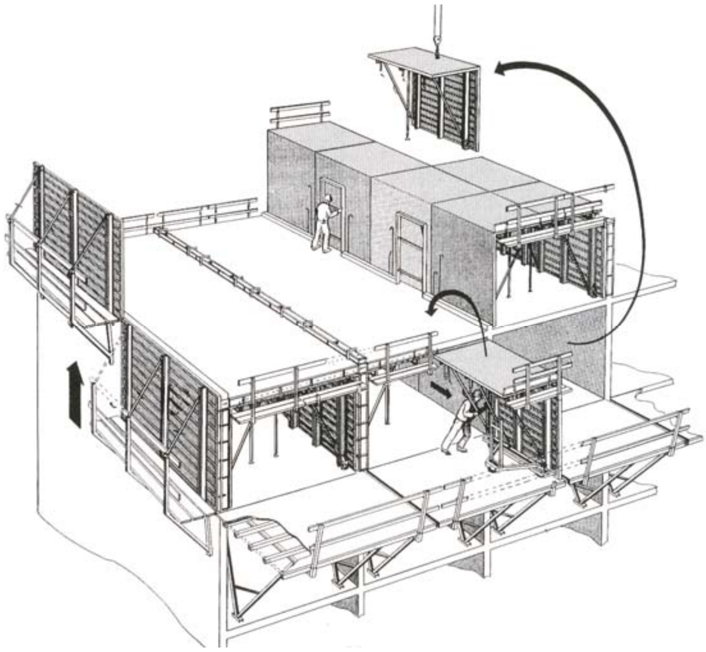


Figure 2.3: Arrangement of box units into position onsite

2.3 Classification for Types of IBS Used in Malaysia

The Industrialised Building Systems (IBS) is a construction process that utilizes techniques, products, components, or building systems which involve prefabricated components and on-site installation. According to CIDB (2003), from the structural classification, there are five IBS main groups identified as being used in this country, and these are:

(i) Precast concrete framing, panel and box systems

This system includes precast concrete columns, beams, slabs, walls, “3-D” components (eg: balconies, staircases, toilets, lift chambers, refuse chambers), lightweight precast concrete, as well as permanent concrete formworks.

(ii) Steel formwork systems

This system includes tunnel forms, tilt-up systems, beams and columns moulding forms, and permanent steel formworks.

(iii) Steel framing system

This system covers steel trusses, columns beams and portal frame systems.

(iv) Prefabricated timber framing systems

This system prefabricated timber trusses beams and columns.

(v) Blockwork systems

This system includes interlocking concrete masonry units (CMU) and lightweight concrete blocks.

2.4 Benefits of IBS Component

Most of the industry players fail to realize that IBS offers better alternative to the traditional and labour intensive in-situ construction. The main benefits offered by the usage of IBS elements are:

2.4.1 High Quality and Aesthetical Value of Products

IBS products are manufactured in a casting area where critical factors including temperature, mix design and stripping time can be closely checked and controlled; and this will ensure that the quality of IBS products are better than cast-in-situ concrete. A huge sum of money will be saved by not having to do rectification works. Also due to factory-controlled prefabrication environment, many combinations of colours and textures can be applied easily to the architectural or structural pieces. A vast range of sizes and shapes of IBS components can be produced, providing a great deal of flexibility and offer fresher looks to the structures.

2.4.2 Cleaner and Safer Construction Site

Usage of IBS elements eliminates or greatly reduces conventional formworks and props. IBS construction also lessens the problem of site wastages and the related environmental problems. The prefabricated products also provide a safe working platform for workers to work on. Workers and materials are also greatly reduced at the construction sites. Also, as elements are produced in the plant and mostly designed to be repetitive, minimal wastage will be experienced at both factory and construction sites.

2.4.3 Faster Construction

IBS construction will save valuable time and helps to reduce the risk of project delay and possible monetary losses. IBS design and production of elements can be started while the construction site is under survey or earthworks. Production are also unaffected by weather conditions due to preliminary work such as the controlled environment on casting area. Also, the usage of large IBS panels will reduce the time taken to complete the structural works. Therefore, other trades such as painting and electrical wiring can begin work sooner.

2.4.4 Greater Unobstructed Span

The usage of prestressed precast solutions such as the Hollow Core slabs and Double-T beams offer greater unobstructed span than the conventional reinforced concrete elements. With having the lesser beams and columns in any structure, it will provide flexible working space. It is very ideal for the construction of places of worship, warehouses, halls, car parks, shops and offices.

2.4.5 Lower Total Construction Costs of Ownership

All of the above simplify the construction processes and increase productivity, quality and safety. As a result, the total costs of construction are reduced.

2.5 Modular Coordination

The introduction of MC in the industry is to improve productivity and quality in building construction as well as to act as a tool towards rationalisation and industrialisation of the building industry. The decision to replace the existing imperial system of weights and measures in Malaysia with the metric system in 1972 provides a unique opportunity for technological advancement and rationalization in the building industry.

The program for change to the metric from 1972 to 1982, however, faced with much difficulty due to the complexity and fragmented nature of the building industry. A coherent system of coordinating dimensions in the building process is crucially needed to facilitate the communication at all levels in the building industry. The approval of the recommendation for the introduction of modular coordination in building in Malaysia by the Government in April 1986 constitutes a positive step to streamline the industry towards proper metrication in building planning, design, construction and manufacturing of building materials and building components. The proper characteristics of MC are:

(i) The basic module is small in terms odd size in order to provide design flexibility, yet large enough to promote simplification in the components' variation in sizes.
(ii) Industry friendly features that not only cater for manufacturing but also the transportation and assembly requirements.
(iii) Ergonomically designed to promote efficiency.
(iv) Internationally accepted to support international market.

The introduction of modular coordination in the industry not only provides dimensional basis for the coordination of dimensions and of those buildings incorporating them, but also it acts as a tool towards rationalization and industrialization of the building industry. Modular Coordination is essentially based on:

(i) The use of modules (basic module and multi-modules)
(ii) A reference system to define coordinating spaces and zones for building elements and for the components which form them.
(iii) Rules for locating building elements within the reference system.
(iv) Rules for sizing building components in order to determine their work sizes.
(v) Rules for defining preferred sizes for building components and coordinating dimensions for buildings.

The use of Modular Coordination as a dimensional basis for the building industry will pave the way for the creation of open design principles and rules which combine freedom in architectural planning and flexibility in the choice of construction method. It offers designers the possibility of incorporating standardized modular components in building projects effectively due to the following advantages:

(i) Dimensional coordination for simplification and clarification of the building process. It provides a common language for the building industry players, thus creating better coordination and cooperation between various parties.
(ii) Limitation of variants in dimensions of components, reducing design time especially with the use of standardized modular components.
(iii) Standardisation of building components, thus reducing manufacturing and installation costs.
(iv) Prefabrication of standardized components to minimize wastage of materials, manpower and construction time.
(v) Industrialisation of the building process through the increased usage of modern technologies such as Computer Aided Design and Drafting and Computer Aided Manufacturing.

Modular Coordination is a concept for coordinating dimension and space for which buildings and components are dimensioned and positioned in basic units or modules. According to CIDB (2005) *IBS Digest October – December 2005 Issue,* MS 1064 introduces a certain geometric discipline using practical approaches which relate to set-up coordination and measurement of components and spaces in the building design.

MC has been introduced in Malaysia since 1986, but has not been widely implemented in the building industry. The main factors limiting the uses of MC in building industries is lack of knowledge on MC concept and it requires precision dimensioning, proper planning and not by mentioning the production of IBS components.

The principal objective of implementing MC is to improve productivity through the reduction of wastages in the production, installation process, to improve quality in the construction industry and to encourage an open system. With Open System approach, building components could combine in a variety of individual building projects while ensuring the architect freedom in their designs.

MC is an important factor in application of Industrialised Building System IBS by way of standardization of components and dimensions such as reduce time of production and installation of components, achieving repeatability and able to construct building at lower cost.

2.6 Just-In-Time Philosophy

Just-in-time (JIT) is originated from manufacturing industry. It is known as a philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity (Ahmad, 2005). It also has been described as an approach with the objective of producing the right part in the right place at the right time or “just in time”. The just-in-time philosophy has the potential for managing the movement of precast concrete components from the prefabrication yard to the construction site. Besides, it is also can be used for the logistics management to help raise productivity levels.

JIT should improve profits and return on investment by reducing inventory levels, increasing the inventory turnover rate, reducing variability, improving product quality, reducing production and delivery lead times, and reducing other costs such as those associated with machine setup and equipment breakdown. There are altogether six key principles to illustrate the JIT philosophy. These six principles include elimination of waste, total quality control, supplier relations: single sourcing, Kanban or pull system, the uninterrupted work flow and top management commitment and employee involvement.

In the aspect of elimination of waste, waste is regarded as anything that does not add value to the final product. Waste results from any activity that adds cost without adding value, such as the unnecessary moving of materials, the accumulation of excess inventory, or the use of faulty production methods that create products requiring subsequent rework will be eliminated in JIT. Therefore, excess inventory is regarded as waste since it does not add any value to the final product. By stockpiling inventory, it does not bring any benefit. It will just tie down the capital and takes up space. Besides, it also incurs storage cost which includes insurance and security cost. There are also risk of obsolescence and risk damage during the storage time. In this case, JIT concept calls for buffer stocks or zero inventories.

Other than that, the JIT philosophy also emphasis on the total quality control concept for a smooth and just-in-time execution of the work processes. It is because the rejection of materials due to the poor quality of the products will indirectly affect the whole production workflow and schedule. Total quality control is the practice of building quality into the process and not identifying quality by inspection (Richard *et. al.*, 2001). Besides, it also refers to the theory of employees assuming responsibility for the quality of their own work. In the JIT philosophy only good quality product from the production operations will be accepted. If all product are good, then no “just-in-case” extra inventory is needed. Hence, it can help to achieve high quality and high productivity.

The manufacturing sector is one of the well-developed sectors, whereas the output process is given full attention. According to Ahmad (2005), the success of JIT can be clearly seen only in the manufacturing sector. This can be done, due to the closed and controlled surrounding environment, assisted by the usage of full automation and mechanical instruments. At the same time, the manufacturing of uniform components in a continuous on-going process has helped to increase the efficiency of operational and big scale project economy.

In reality by looking to the construction sector especially on the conventional methods, most of the works are carried out at site. Therefore, construction process and labour work will be severely affected by the weather. If the current situation persists, the construction work will continue to depend on continuous labour force and the production rate will remain at its lowest. Thus the implementation of JIT principle in the construction sector through the introduction of precast elements is hoped to achieve such success rate that has been long tasted in the manufacturing sector. In this situation, the work process will be done in a controlled and closed environment. The site will only be the installation place, whereas the components produced from the factory will be delivered to the site and ready for installation.

The use of precast elements can help control the usage of formworks, reinforcements and concrete in order to prevent wastage. Proper monitoring and control and the quality assurance of raw materials and the steel moulds can ensure the production of high quality products. In this case, prefabrication can meet the demand of lean production. Figure 2.4 shows the JIT principle in the construction industry scenario.

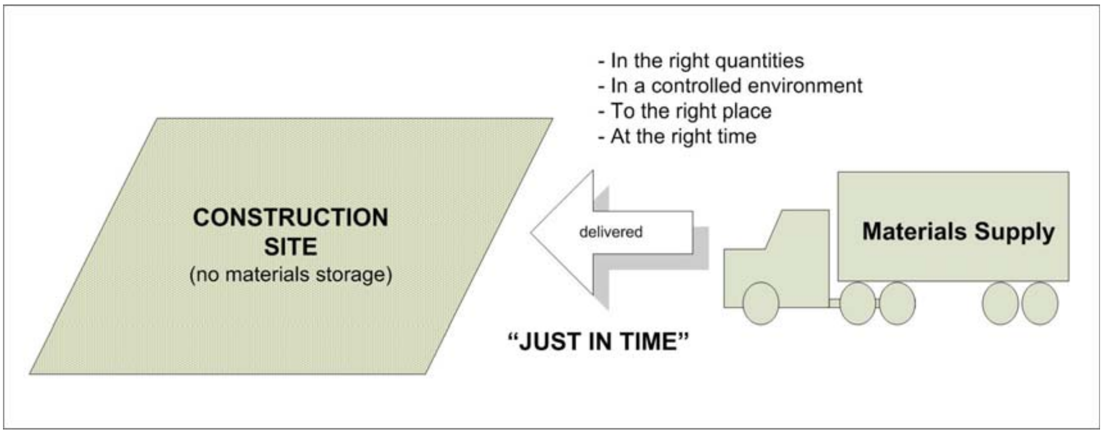


Figure 2.4: Principle of Just In Time.

In the construction sector, it needs a big space for the storage of materials at site, and this will only reduce the capital budget. The need to prepare a large storage area will not only waste money in allocating a large area for storage purposes, but if the materials are not properly kept at site, it will affect the quality of the materials greatly. Therefore, the implementation of JIT principle can save cost associated with storage, since the materials will be delivered to the site in the right quantities and in a controlled environment, to ensure that the quality of the components are guaranteed.

Since the materials will be delivered to the right place at the right time, this will also reduce cost associated with storage of materials at site.

In this context, it can clearly see that the JIT principle has a good potential in developing precast concrete components into eliminating the problem associated with storage of materials at site, and also the heavy traffic problem at site. It is hoped that the JIT principle can be fully implemented in the construction industry in our country, so that the productivity and efficiency of work at site can be improved to a greater height.

2.7 The Selection of an Industrialised System

Before selecting an industrialized system, there are a few aspects to be considered such as economics, marketing, technology, management, physical performance and architectural design. In the aspect of economics, it requires the selection of the most profitable method, suitable location and size of the prefabrication plant. Hence, the forecasting of the demand is required in order to determine the size of the prefabrication plant.

In addition, marketing includes advertising, sales engineering and advertising contracting for projects. As for the technology, it involves the selection of materials, and production technique. It is vital in the selection of the materials, which will determine the quality of the production. Besides, connecting, jointing and finishing techniques needed also to be taken into account.

Management is always the most important aspect in the industrialised building systems. Planning and coordination production, transportation, erection and quality control are depending on the good management skill. Another aspect need to be considered is the physical performance which includes strength, stability, fire resistance, thermal and acoustic requirements, maintainability and insulation. Moreover, architectural design is also important in the considering of implementing an industrialized system. It involves aesthetics, functionality, versatility and flexibility.

2.8 Barriers to the Adoption of IBS in Malaysia

IBS is not new in the Malaysian construction industry, particularly the usage of steel structures and precast concrete for the construction of bridges, drains and other infrastructure projects. Nevertheless, the usage of IBS in the Malaysian building industry is still very low if compared to the conventional methods. According to Ng (2006), the construction industry has been slow in adoption of IBS due to several reasons:

(i) Wide swings in houses demand, high interest rate and cheap labour cost, make it difficult to justify large capital investment. Contractors prefer to use labour intensive conventional building system because it is far easier to lay off workers during slack period.

(ii) Fully prefabricated construction system requires high construction precision. Malaysian labour forces still lack of skilled workers. Many of foreign skilled workers had left the country after the widespread crackdown on illegal foreign workers in recent years. The new batches of foreign workers do not possess the required skill and have to be retrained.

(iii) The construction industry is so fragmented, diverse and involves many parties. Consensus is required in the use of IBS during planning stage. However, the owners, contractors and engineers still lack of scientific information about the economic benefits of IBS.

(iv) Lack of research and development in the area of novel building system that uses local materials. Majorities of IBS in Malaysia are imported from developed countries, thus driving up the construction cost. Engineering degrees in local universities seldom teach about the design and construction of IBS.

(v) The economic benefits of IBS are not well documented in Malaysia. Past experiences indicated IBS is more expensive due to fierce competition from conventional building system. Furthermore, there is an abundance of cheap foreign workers in Malaysia.

(vi) The use of IBS in developed countries is so successful due to high quality and high productivity. But, in Malaysia, the scenario different, most projects constructed with IBS were low quality and high construction cost.

(vii) Lack of incentive and promotion from government in the use of IBS. Many architects and engineers still unaware of the basic element of IBS such as modular coordination (MC).

2.9 Government and CIDB Initiative

The usage of IBS in building is still low in our country. From a survey conducted by Construction Industry Development Board (CIDB) Malaysia, the usage level of IBS in the local construction industry stands at only 15% (IBS Survey, 2003). The early efforts of the Government to encourage the use of IBS in the construction sector has yet to garner a good response and this sector is still practicing conventional construction methods that have proven time and again to be wasteful, dangerous and messy.

The industry needs one fundamental plan that involves all the important aspects in this evolution process. In this respect, the IBS Roadmap 2003-2010 is formulated as a reference for all parties in implementing all programs towards the modernization of the Malaysian construction sector. IBS Roadmap 2003-2010 is to ensure that its programs are implemented to meet the total industrialisation of

Malaysia's construction industry by the year 2010. Figure 2.5 simply illustrates the improvement of IBS industries in the future.

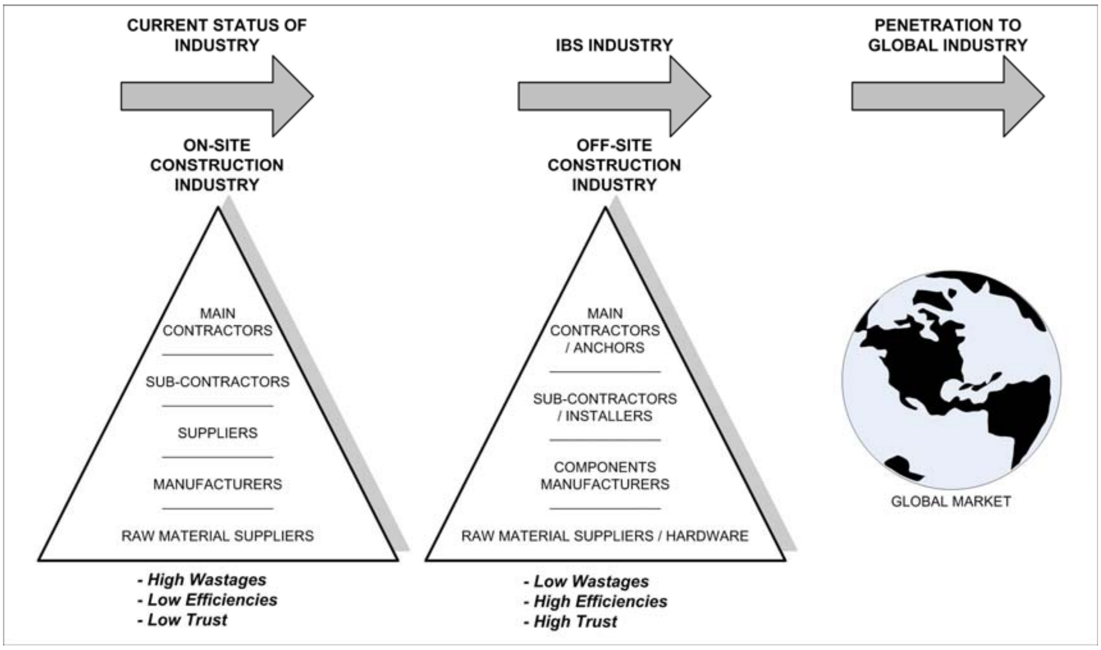


Figure 2.5: Improvement of IBS Industry in the future

The Malaysian Government is also currently very active in promoting the usage of prefabricated materials, particularly IBS components. In 7th, 8th and 9th Malaysia Plan, increment of budget for the IBS sector can be seen dramatically offered. The Public Works Department (JKR), CIDB as well as the Ministry of Housing and Local Government are among the leaders in championing its usage in the construction industry. JKR has also produced a new set of drawings utilizing IBS Close System components for its standard quarters. More houses, hostels, schools, colleges and low cost houses are also now being designed and constructed using IBS elements.

It is hoped that more clients, designers and contractors in the local construction industry heed to government's call for the industrialisation of the construction sector and choose for precast or IBS construction as an alternative to the in-situ method. The commitment and cooperation between the government and private sector are crucial in ensuring the success of the program. Figure 2.6 clearly shows how benefit IBS implementation to all practitioners in IBS construction industry. There are a lot of job opportunities coming in if IBS industries are fully launched. Therefore, in order to survive in the era of globalization, it is important for local players in construction industry change their perception and begin to use new techniques to produce better quality, productivity and safety in construction.

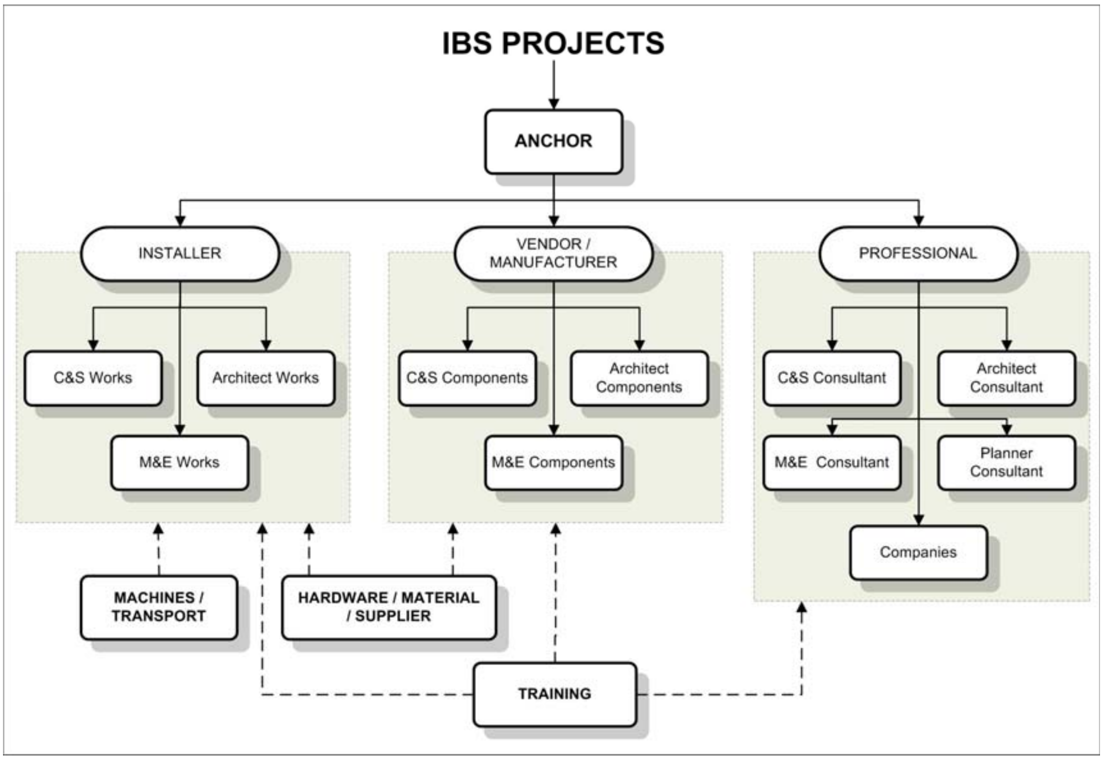


Figure 2.6: Parties involved in implementing IBS construction

The Government is determined to ensure that every Malaysian will have access to affordable homes. During the period 1971-2003, the Government constructed 490,000 units of low-cost houses while the private sector constructed 509,000 units for low-income families. The Government intends to provide an additional 100,000 units of affordable homes to be implemented through the industrialized building system. The usage of IBS components in Government building projects will be increased from 30 percent currently to 50 percent commencing from year 2005. According to the Prime Minister, housing developers who utilize IBS components exceeding 50 percent will be given full exemption on levy imposed by CIDB (IBS Digest, 2005).

2.10 Industrialized Building Systems versus Conventional System

The study has been done by Badir, Kadir, and Hashim (2002) in order to determine the advantages and disadvantages of using IBS method. Compared with the conventional method, IBS have lesser cost and higher speed of construction. In terms of the total number of labour force required in the current IBS, it is far lower than those required in the conventional method of construction. In terms of usage of heavy equipment, the IBS construction requires less use of heavy equipment than that required for the conventional method of construction. This is due to the fact that most of the IBS are of formwork, sandwich panel, block panel, and steel frame. These systems do not require use of heavy equipment. The precast panel is the only system that needs the use of heavy equipment during erection.

In terms of quality of the building, the IBS construction was found to be capable of producing units of higher quality than what the conventional construction method could achieve (CIDB, 2005). However, the IBS need a much higher initial capital investment than does a conventional system. This is because factories or production facilities must be constructed and because of the high cost of training labour. Table 2.2 simply shows the percentage of response when the IBS method was compared with conventional method.

The IBS construction activities are highly capital intensive. This is the main disadvantage of the IBS. The heavily mechanized approach has displeased a substantial number of the labour force from the building construction industry. In some IBS there is a tremendous need for expert labour at the construction site. Therefore, extra costs are needed to train the semiskilled labour force for highly skilled jobs. On the other hand, the savings in labor cost and the savings in material cost are also the major advantages of the Malaysian IBS. The control in using materials, such as steel, sand, and timber, will result in substantial savings on the overall cost of the project.

Table 2.2: Comparing IBS with Conventional System Factors
(Badir, Kadir, and Hashim, 2002)

	Answering percentage of respondents (with reference to conventional system)		
Factors	More (%)	Less (%)	Same (%)
Cost of construction	5	86	9
Cost of transportation	20	50	30
Speed of construction	77	23	—
Save in raw material	55	27	18
Total number of laborers	5	86	9
Unskilled	41	50	9
Skilled	14	86	—
Expert	14	63	23
Initial capital investment	57	10	33
Flexibility of design	59	9	32
Heavy equipment	24	48	28
Ease of erection	68	32	—
Quality of building	95	—	5

2.11 Conventional Construction Method

According to Bannet and Grice (1985), for the conventional construction approach, it is based on the rigid separation of design and construction. The design team prepares detailed drawings, specification and often Bill of Quantity. The tender documents are prepared and the contract will be awarded to the winning bid from the contractors. The contractor will then manage the construction projects by using subcontractors.

Conventional construction method involves construction work being carried out at site. It involves site preparation by fellow contactors before the laying of the footings. The foundation is then built on the footings, to extend above the level of the ground. The building is actually made on the foundation. Usually a floor is laid on the foundation. Beams will then be constructed, followed by the construction of columns and slabs. Where it is necessary, staircases will be constructed, before eventually roof beams are constructed, followed closely by the construction of roof trusses. When the roof is to be framed on the site, the top sill plate is nailed on top of the wall sections. Cutting and nailing each piece of wood one at a time takes a lot of time. Not only must each piece be cut but each piece must be carried up the ladder to the right place.

Water proof roofing materials will be placed to ensure the roof is water proof before roof tiles are placed in position. Brick walls will be constructed where necessary, with allocations for the placement of doors and window panels. Painting and aesthetic decoration on walls and floor slabs will follow up and the end product will be a complete on-site building. Figure 2.7 summarizes the sequence activities in conventional construction method.

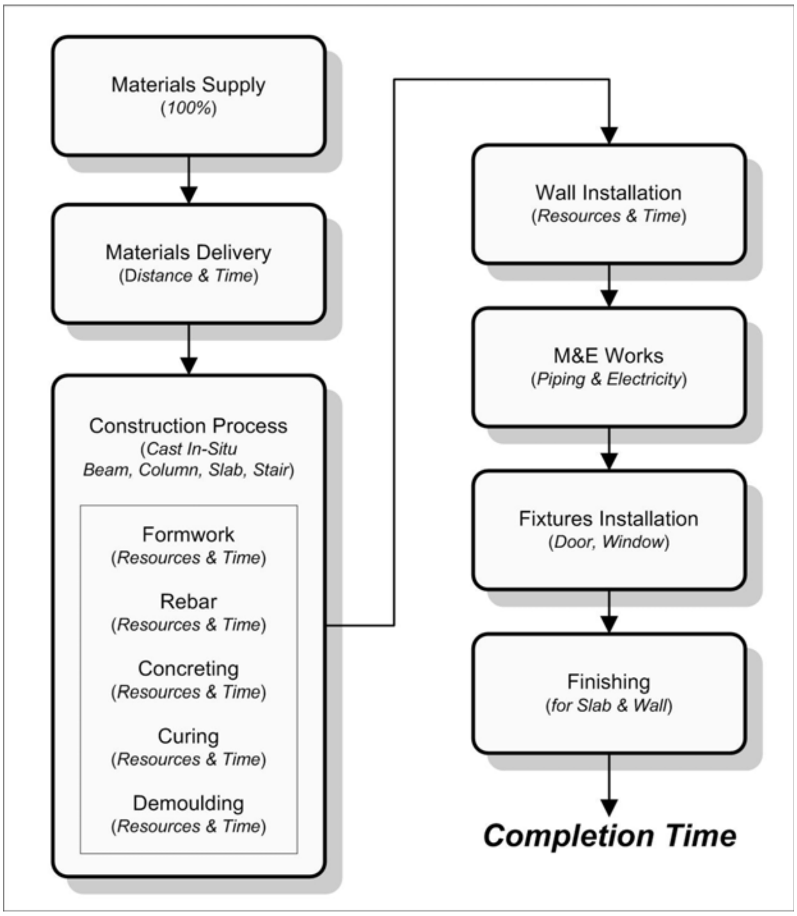


Figure 2.7: Sequence activities of conventional construction method

Certainly, with so much on-going works happening on site, many skilled and unskilled labourers are needed to carry out the works on site. Formworks have to be constructed to specified dimensions and concrete casting will be done when all the formworks and reinforcements have been properly laid on site. Weather is a common factor that affects the working schedule on site, and often, material wastage is a problem faced by contractors.

Conventional construction method requires proper planning and scheduling to ensure that the work is within the progress schedule. Due to many uncertainty and risk of wastage at site, close watch on the cost of the construction project is essential to minimise any risk of increase in the construction cost of the entire project.

2.12 Precast Construction

The construction of precast concrete should start with very tough planning and scheduling. Schedule is one of the major reasons why precast construction is employed. Hence a high emphasis is placed on commitment of a specific schedule when a project is awarded. Sequence of construction may be dictated by several factors including client' requirements, physical constraints of site especially on access, commercial advantages and to a lesser extend technical requirements.

After specifically determine the size and pattern of precast components that will be used, it will be ordered from pilot plant. Delivery of precast components is a factor to be considered during the design stage of precast components. The size, shape, weight, route, site access, commercial aspects, etc all contribute it. In Malaysia, the most common mode of transport is by trucks or trailers, and to a lesser extent by rail or by barge. Usually, for very large components especially for infrastructure projects casting is carried out near the site. Most of the components are laid horizontally for delivery although some components maybe required to be delivered in a near vertical position. Special frames during transportation will be required to avoid damages, toppling, etc.

At site, considerations such as temporary accesses, condition of accesses, turning circle for trailers, capacity of culverts, and temporary parking add on to the factors to be considered at the planning stage. Temporary stability of a part of a precast building is of significant importance and pre-determined before commencement of installation works. On site, it is not recommended to store the precast elements for long durations or in large quantities. This will eliminate the possibilities of damages, double handling and site safety concerns. However they may be situations when this becomes a necessity. If it so inevitable, some of the considerations are:

(i) ground conditions able to carry self weight of stack,
(ii) earth movements due to other works,
(iii) accessibility of transportation,
(iv) lifting capacity of cranes hoist,
(v) special racking if required, and
(vi) safety aspects such as stability of stack, toppling etc.

When it comes to the construction of precast concrete, it is more simplicity compare to conventional. Precast components will be delivered to the site, whether to the storage area or to the installation place. Usually the deliveries process is transported by heavy trucks because the components have a quite heavy self-weight. After reach construction site, the component will be unloaded by crane whereby the capability of crane is depending on components' weight. Some workers are needed to assist the installation component process in order to hoist, adjust and fix it into the right places. The vital point to be alert in precast construction will be the connection between components. The concept of good precast construction is when the whole structure of precast building may react as one united component as far as conventional product is resulted. Finally, the construction will end up with finishing and usually finishing method will be same as conventional by installing door, window, tiles, mechanical and electrical tools, etc.

2.13 Steel Construction

Steel construction is not too far different with precast construction. The components of steel structure are ordered from pilot plant with certain specifications. Before that, it is also need a good plan and schedule. Planning is one of the major reasons why steel construction is employed. Without a good planning, problems will occur during construction process especially on components installation. Hence a high emphasis is placed on commitment of a specific planning when a project is awarded. Design of steel structure must be recognize in detail including connection type, bolt size, welding strength, etc.

Once it is principally determine the size and design of steel components that will be used, it will be ordered from pilot plant. Delivery of precast components is a factor to be considered during the design stage of precast components. The size, shape, weight, route, site access, commercial aspects, etc all contribute it. In Malaysia, the most common mode of transport is by trucks or trailers, and to a lesser extent by rail or by barge. Usually, for very large components especially for infrastructure projects casting is carried out near the site. Most of the components are laid horizontally for delivery although some components maybe required to be delivered in a near vertical position. Special frames during transportation will be required to avoid damages, toppling, etc.

In construction of steel structure, honestly it is also more ease compare to the conventional approach. Steel components will be delivered to the site, whether to the storage area or to the installation place. After reaching construction site, the component will be unloaded by crane with certain capabilities. More workers are needed to install the component in order to hoist, adjust and fix it into the right places. The workers are professional or skilled people because it involves bolting and welding the connection. Not a lot of welders know how to weld professionally and generally the welder will have a license for welding purposes.

Finally, the construction will end up with finishing and usually finishing method will be same as conventional by installing door, window, tiles, mechanical and electrical tools, etc. Steel finishing is not too similar to precast finishing because in steel structure, there is a need to protect steel surface from fire or any other damager. Therefore the final product between steel structure and precast structure in term of interface, it will be some differences. Most of the time, steel and precast are combined together to have simplicity in construction, speed of overall completion time, cost economization, smart interface, etc.

2.14 Sequence of Construction for IBS Method

IBS method is different from the conventional construction method. Known for its benefits in terms of shorter construction time, saving in labour, material saving, better quality control, immunity to weather changes and the cost factor, IBS method illustrates a different approach to the construction method commonly used. It offers an alternative to the existing conventional building system.

Among one of the most important characteristics of IBS method is IBS components are prefabricated offsite. According to Chew and Michael (1986), prefabrication system of construction means breaking a whole housing unit into different components such as the floors, walls, columns, beams, roofs, etc. and having these components separately prefabricated or manufactured in modules or standard dimensions in a factory. Figure 2.8 show sequence of activities of IBS construction method.

Figure 2.8: Sequence of activities for IBS construction method

IBS method emphasizes on prefabrication concept. Firstly, the design stage is carried out where the IBS components are designed according to specifications. Then, the components are prefabricated at factory, where components of IBS are manufactured according to specified dimensions and specifications. Quality-controlled and highly aesthetic end products through the processes of controlled pre-fabrication and simplified installations has maintained and ensured the quality of work in the construction industry.

The IBS components are then transported to the site from the factory for assembling process. At site, the IBS components are assembled accordingly with the assistance of a crane. The reduction of construction waste with the usage of the standardized components and less in-site works provides a cleaner site due to lesser construction waste. Finally, the final unit of the building is finally assembled and ready for occupation.

IBS method offers a new concept in terms of speed of construction, and it clearly shows many other benefits as compared to the conventional construction method. According to Chew and Michael (1986), IBS also consists of two types of prefabricated systems in the market, namely; fully prefabricated system and partially prefabricated system.

Fully prefabricated system is referring to the components produced in the factory and later transported to the site for erection. Fully prefabricated system consists of three categories, namely; panel system, frame system and box system. Further description and explanation of the above-mentioned systems has been clarified in the sub-section before.

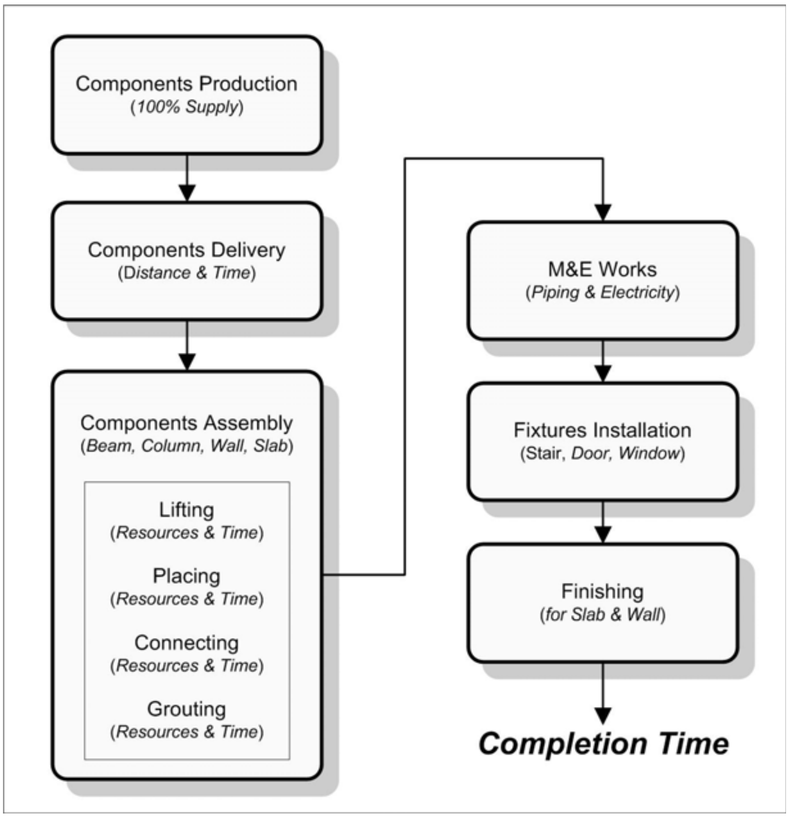


Figure 2.9: Sequences process of IBS components installation

Partially prefabricated system is a type of system in construction where certain elements that can be standardized are prefabricated in the factory, whereas other components are cast in-situ. In this construction method, certain elements as such wall panels, slab panels and staircase are considered as precast components, while the columns, beams and the foundations are usually cast in-situ due to ease and speed of construction. According to Chew and Michael (1986), this system usually give more rigid construction and better water tightness characteristic, which are normally a big problem with the usage of panel system and frame system.

2.15 Modelling and Simulation in Construction

Simulation has been recognized as one of the most powerful tools that help decision makers in manufacturing and other industries to solve difficult and complex problems for design, control or improvement of systems. The benefits from using simulation include reduced costs, improved quality and productivity, and shortened time-to-market. In spite of its power and benefits, the technology is still underutilized in many applications. The main reasons are:

(i) Simulation modelling is a time-consuming and knowledge intensive process requiring not only the knowledge from application domain, but also from the simulation and implementation domain (Arons, 1999). This cross-domain communication has caused great amount of difficulties in simulation modelling, and the cost for training and skill development is very high.

(ii) Most simulation models developed with the current technology are customized “rigid” models that cannot be reused or easily adapted to other even similar problems.

(iii) With the current technology, simulation modelling is still an ad-hoc process, for instance a craft rather than a science. The modelling quality and efficiency depend largely on the skill and experience of human modellers (Mclean, 2001). The loss of “intellectual capital” due to a high turnover rate and continuous retirement of experienced employees has further worsened the problem.

On the other hand, the construction phase of a civil engineering facility is a complex enterprise characterized by a set of tasks or activities with complex relationships. The progress of these activities is heavily influenced by an environment that is described by stochastic phenomena such as changing weather conditions, equipment breakdowns, etc (Carson, 2004). Hence, the planning, scheduling, and control of the various activities and resources of a construction project are among the most challenging tasks faced by a professional construction manager (Barrie and Paulson 1992).

Tools and techniques to analyze, plan, and control the construction processes must be utilized. Over the last two decades, research and advancements in the area of modeling and analysis of construction processes have demonstrated the usefulness of computer simulation in this role. Modeling is an important step for understanding and improving a process' performance (Kartam *et al.,* 1997). One of the more widespread construction modelling or simulation tools is CYCLONE, developed by D. W. Halpin in 1977.

2.16 Simulation Worldviews

Simulation modeling software usually takes one of three worldviews which are event scheduling, process interaction, or activity scanning. As their names suggest, each puts its main focus on the events, the processes, or the activities in a simulation, respectively.

When following an event scheduling perspective, a model developer must define the model logic and system state changes that occur whenever any event occurs. A process is a sequence of events, activities and other time delays associated with one entity as it flows through a system. For example, a customer process at a bank consists of an arrival event to the lobby, perhaps joining and waiting in a queue of delay, a service time by a teller, and finally a service completion event. In terms of concepts discussed earlier, the service time is an activity and the teller is a resource.

Simulation software based on the process interaction perspective, or worldview, provide a way for a user to define a process for each entity in the system. Activity scanning provides a way to define model logic by focusing on activities from the point of view of a resource, defining resource state changes depending on various events. For example, in the bank, the teller serves one customer until completion and then looks at the queue. If the queue is not empty, the teller "takes" the first entity out of the queue, changes its own state to "busy" and begins a new service activity. If the queue is empty, the teller changes its own state to idle.

Simulation is most useful in the following situations (Carson, 2004):

(i) There is no simple analytic model, spreadsheet model or "back of the envelope" calculation that is sufficiently accurate to analyze the situation.
(ii) The real system is regularized; that is, it is not chaotic and out of control.
(iii) System components can be defined and characterized and their interaction defined.
(iv) The real system has some level of complexity, interaction or interdependence between various components, or pure size that makes it difficult to grasp in its entirety. In particular, it is difficult or impossible to predict the effect of proposed changes.
(v) For designing a new system, considering major changes in physical layout or operating rules in an existing system, or being faced with new and different demand.
(vi) In considering a large investment in a new or existing system and it represents a system modification of a type for which someone has little or no experience and hence faces considerable risk.
(vii) Someone need a tool where all the people involved can agree on a set of assumptions, and then see both statistically and with animation the results and effects of those assumptions. That is, the simulation process as well as the simulation model can be used to get all members of a team onto a more common understanding.
(viii) Simulation with animation is an excellent training and educational device, for managers, supervisors, engineers and labour. In fact, in systems of large physical scale, the simulation animation may be the only way in which most participants can visualize how their work contributes to overall system success or creates problems for others.

2.17 The Advantages and Disadvantages of Simulation

Simulation allows experimentation with a model of a system. Without a model, it will either experiment with a real system that probably causing major disruptions or proceed without such experimentation and analysis at some potential risk. Simulation allows the identification of problems, bottlenecks and design shortfalls before building or modifying a system. It allows comparison of many alternative designs and rules of operation. Evaluation and comparisons can take place before committing resources and investment to a project.

Simulation allows studying the dynamics of a system, how it changes over time and how subsystems and components interact. A simulation model provides about the only method to study new or non-existent complex dynamic systems for which analytic or static (spreadsheet) models provide at best a low fidelity model with correspondingly low accuracy.

In contrast, often simulations are time consuming, data is not available or costly to obtain, and the time available before decisions must be made is not sufficient for a reliable study. In some companies, an early success with simulation has evolved into simulation becoming a “checklist” item on every project whether it is justified or not for the project at hand. In some situations, the animations and other visual displays, combined with the time pressure present on all projects, may mislead decision makers into premature conclusions based on insufficient evidence.

In addition, inexperienced simulation analysts, or those too focused on the simulation software and technology may add too much detail to a model and spend too much time in model development, resulting in the original goals and project timelines being forgotten. This often leads management to conclude that simulation, while a promising and interesting technology, is too costly and time consuming for most projects.

A good simulation model provides not only numerical measures of system performance, but provides insight into system performance. Insight comes from a tacit understanding of system behaviour, an understanding that can be developed by intelligent use of animation and other visual aids, and an intelligent set of valid experiments together with a good statistical analysis.

2.18 Witness 2001 Software

Witness 2001 is Lanner Group's simulation software package. It is the culmination of more than a decade of development. That experience has led them to evolve a visual, interactive and interpretative approach to simulation. The program indeed has the ability to support multiple analyses by allowing rapid changes to the model's logic and data. In addition, Witness 2001 is capable of handling large and complex systems such as a manufacturing facility. Using this simulation tool could generate the following benefits:

(i) Better visual interaction and display during the simulation runs.
(ii) Appropriate constructs to model the tasks, resources, flow of information.
(iii) Eliminates the need to use programming language to create models.
(iv) Easy to use and make modifications to the model.
(v) Easy to add detail such as breakdowns, or any other interruptions at certain steps.
(vi) Easy to perform optimization such as minimize cost, minimize lead time or maximize benefits.
(vii) Easy to obtain statistics such as lead time, throughput, resource utilization, task efficiency.
(viii) Easy to assign resources to study resource optimization.

Witness 2001 is world wide used. One example, it is actively used by Air France as a support tool for the purchase of baggage handling logistics services. The simulation models developed using this tool has resulted in the establishment of more effective resource solutions than those proposed by service providers. The efficiencies obtained are primarily financial, yielding a saving of several million Euros per year. They also have an organizational dimension in that the service providers are now committed to a constructive process to improve their overall performance.

In Witness 2001 designer tools, the most commonly used discrete elements are ‘parts’, ‘buffers’ and ‘machines’. They are displayed as dynamic icons and represent tangible entities in the real-life situation under study. ‘Parts’ flow through the model and can represent, for example, people moving through a supermarket, products moving through a production line, or calls in a telephone exchange. ‘Butters’ are places where parts are held, such as people in a queue, parts awaiting an operation on a factory floor, or the space containing aircraft waiting to land. ‘Machines’ represent anything that takes parts from somewhere, processes them and sends them to their next destination, for example a supermarket checkout or a machine tool. Logical elements represent control and information aspects of the model and include attributes, variables, distributions and functions.

There are three steps to build a model in the program as shown in Figure 2.10. Whatever the model’ requirements, the principles behind the process are simple to understand and implement. Three steps are defined, displayed and detailed. ‘Define’ is for defining the major elements that make up the simulation model. ‘Display’ is for displaying each of the elements in order to build up a pictorial representation of the facility layout. Finally ‘Details’ for specifying the characteristics of the elements have been used in the model. For example specify the timings and routing of parts as they move through the model.

After the elements are defined, displayed and detailed, the model can be run immediately and any logical errors can be located and corrected at this stage. The model can then be modified by adding, changing or deleting items, and then be run again to assess the impact of these changes. The simulation can be run in different modes, from step by step with full screen display to a 'hatched' time in the future with no screen display. The element flow shows the movement of parts through the model.

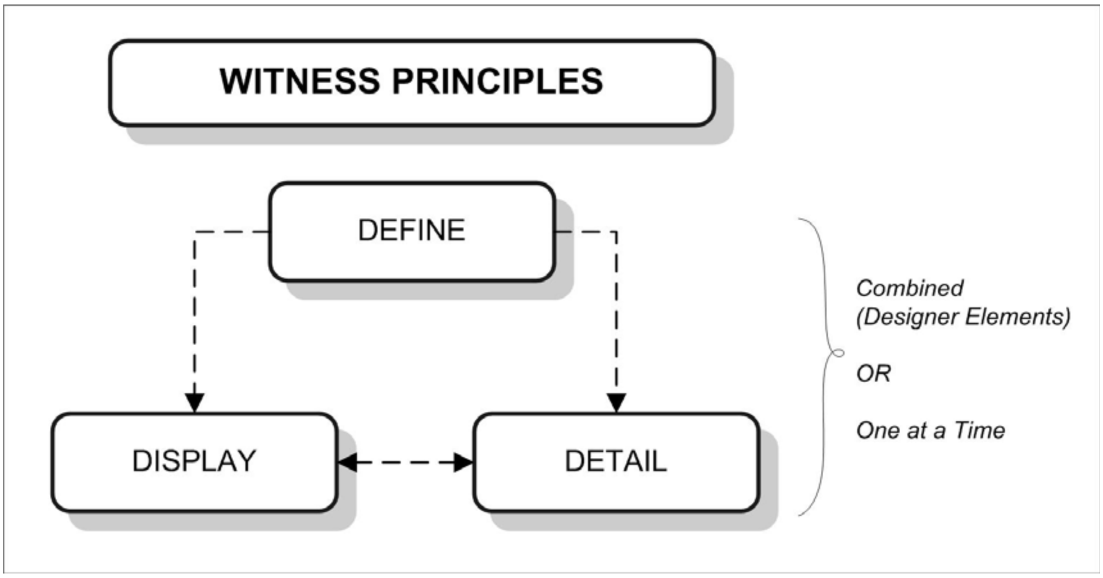


Figure 2.10: Model building steps in Witness 2001.

Last but not least, statistical reports are also generated automatically. These reports can be used to help choose between alternative modelling scenarios. Standard reports comprise a collection of statistics for an element and can be exported in several formats. There are many Witness 2001 features which aid analysis, including standard report tables and graphs which list the basic mathematical behaviours of all elements in the model automatically. Designer can also create time series, pie charts, histograms and customised report tables and expressions in Witness 2001 for the purpose of optimization, understanding, new production line design, construction simulation analysis, etc.

2.19 Summary

Literature review obtained a lot of information background for this study especially on the IBS construction in recent construction industry. There are advantages and disadvantages, opportunities and barriers in implementing IBS technology. Compare to the conventional, IBS offer better construction process especially on the productivity, time, cost, quality, and other extra benefit on the safety, simplicity, clean site, constructability and so on. Malaysian Government is currently very active in promoting the usage of prefabricated materials, particularly IBS components. The Public Works Department (JKR) and CIDB as well as the Ministry of Housing and Local Government, are among the leaders in supporting the usage of IBS in construction industry. Pilot study on the sequences process of IBS construction and conventional method has been done and the result publicized that IBS present more simplicity on the erection process. With the application of Just-In-Time concept, the installation of IBS components will be very effective in term of time and resources used. In this chapter, some information of the first finding to identify the sequences process of IBS construction on double storey house has been achieved.

CHAPTER 3

METHODOLOGY

3.0 Introduction

The research methodology in this chapter serves as a guide to the author in achieving the objectives and scopes of the study. This chapter further discuss in detail about research procedures, from how the data is collected until how it is processed and analysed to achieve the objectives and scopes of the study. Generally there are various methods of study. Nevertheless the best and suitable method should be chosen in order to ensure that the study can be conducted in an appropriate and efficiently approach. Simultaneously, a systematic methodology also may help in preventing unnecessary mistakes that may occur in the study.

3.1 Research Design

Figure 3.1 shows the methodology of the study towards the main goal and objectives. At least there are five major stages have been completed in this study, which are preliminaries stage, literature review, data collection, findings and discussion, and finally will end up with conclusion and recommendations.

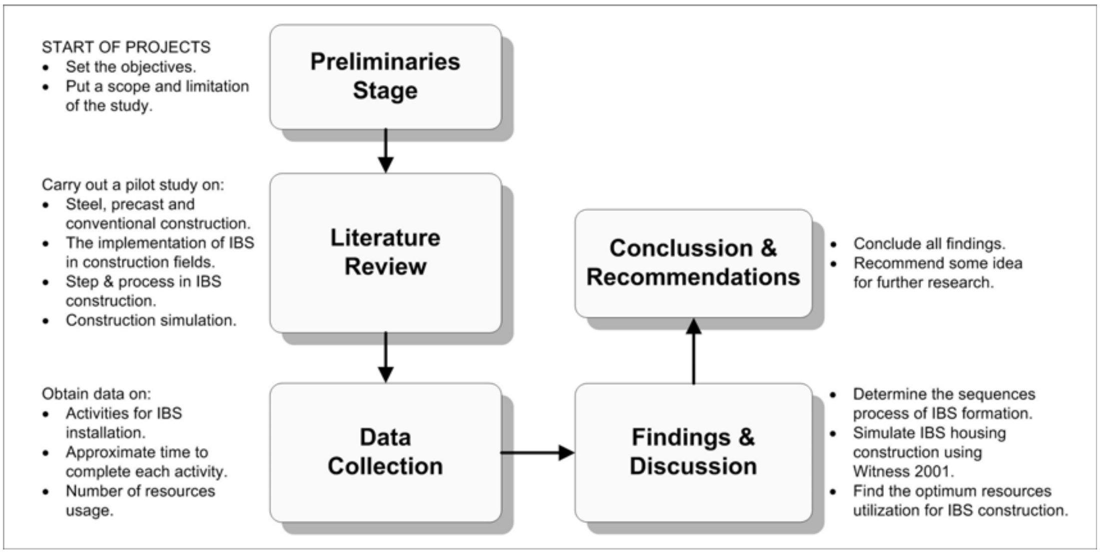


Figure 3.1: Methodology of the study

In the early stage, it involved the identification and further understanding of the research topic, which consists of problem statement, research objectives and scope of studies. In this study, the title of research has been decided first followed by the main goal of doing that study. Detail objectives in order to achieve the aim have been determined presently together with scope and limitations to focus the study with appropriate target. Preliminaries stage is important to establish the beginning structure of the research.

Subsequently literature review has been done on several references from electronic journals, books, magazines and articles, to further enhance understanding on the research topic. Based on the objectives and scopes of the study, this research has been focussed on the means to solve and to achieve the objectives of this study. Pilot study has been conducted on the process of conventional construction method, steel construction method, precast construction method, the application of IBS in construction industry, sequence steps of IBS installation, and a few on construction simulations.

Stage three and four was the climax of this research. It involved a lot of discussion and argument and has been discussed in another sub-topic afterwards. The main objective in the third stage is to identify time and resources used in IBS construction method while the forth stage focus more on modelling and simulation of the IBS construction to determine the optimum resources utilization with appropriate time.

In the final stage, conclusions and recommendations will be drawn out based on the results of the analysis obtained. Final checking will be carried out at this stage to improve the quality of the research study and also to improve the gap in the study conducted.

3.2 Data Collection

The third stage involved data collection. The data collection was emphasized on the construction sequence of IBS components to follow conventional construction method. This means that, the sequence of construction and erection of IBS components at site should follow the sequence of conventional construction method. It has been done by conducting a pilot study on several construction sites of double storey housing that applied conventional method for their project. Simultaneously, some survey for steel construction and precast construction method also has been done to revise the sequences process of components installation at site because some of IBS construction method should be almost the same with both of them.

Data collection also involved the details of the proposed lifting system at site, with the capacity of cranes required, its working radius and its working productivity while handling the installation of precast and steel components at site. Site studies for the lifting system have also been carried out at several sites utilizing IBS method in its construction project. Further study which includes interview session with the supplier of the crane equipments for major construction projects in the country has also been carried out. On the other hand, it also engaged the determination of time of each activity in the proposed IBS method. For this purpose, it involved site studies on several construction sites implementing IBS method in the construction process either steel structures or precast concrete. At the same time, interviews have been conducted with several precasters, main contractors and precast specialist sub-contractors in obtaining the data for the time used of each activity for the IBS method.

In this context of study, the focus of study is particularly to emphasize on the installation of IBS components at site. In other words, this study is mainly focussed on assembly time and resources used for the IBS components installation. Therefore, other factors such as production of IBS components at factory, transportation to site location, labour supply and availability of IBS components has to be maintained constant with no defect.

The study was conducted to analyse how long does it takes to assemble each components at site in producing the entire 300 IBS double storey houses. Figure 3.2 illustrates the model of proposed double storey house using IBS components. Recently, this model of IBS house is still does not exist in current construction, thus it needs some tools to represent or replicate the construction process so that some analysis can be done in order to study the system. For that reason, simulation software was used in this study to emulate the real system.

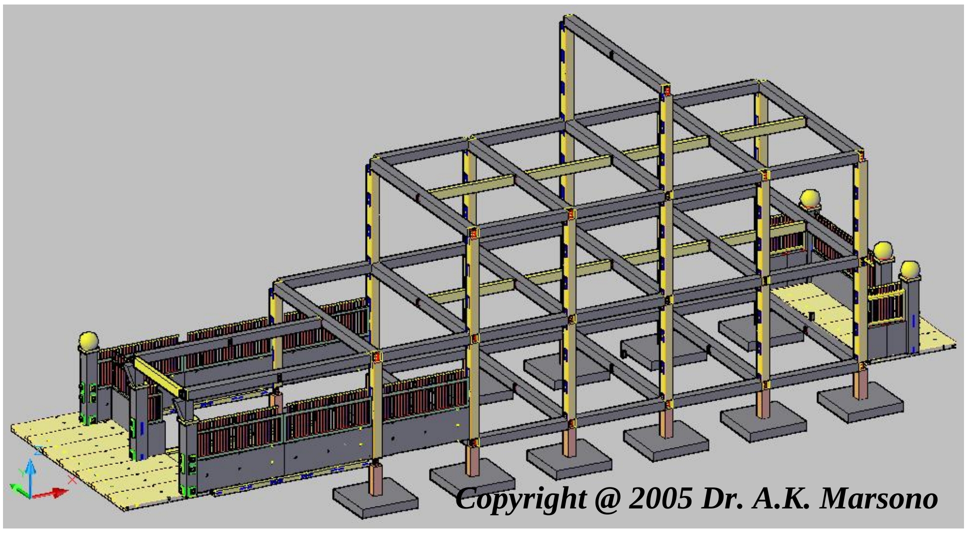


Figure 3.2: A structure model of double storey house using IBS components

3.3 Modelling and Simulation

With the collected data, a model then has been created using simulation software. In this study, Witness 2001 simulation software was used to simulate the IBS construction process by considering time and resources as parameter. Witness 2001 is one of the simulation software that has a very interactive and friendly user interface as the example shown in Figure 3.3. As literature discussed in Chapter 2, Witness 2001 is commonly used in analyzing a process of manufacturing products. As far as construction simulation was concern, the main objective is to find out the optimum resources utilization in IBS construction method by restricting the minimum time that the system may achieve. Therefore, time and resources are the main concern in the simulation. Time means the overall time needed to complete the installation of IBS components while resources means the machinery and labour needed in erecting the components in a stipulated time.

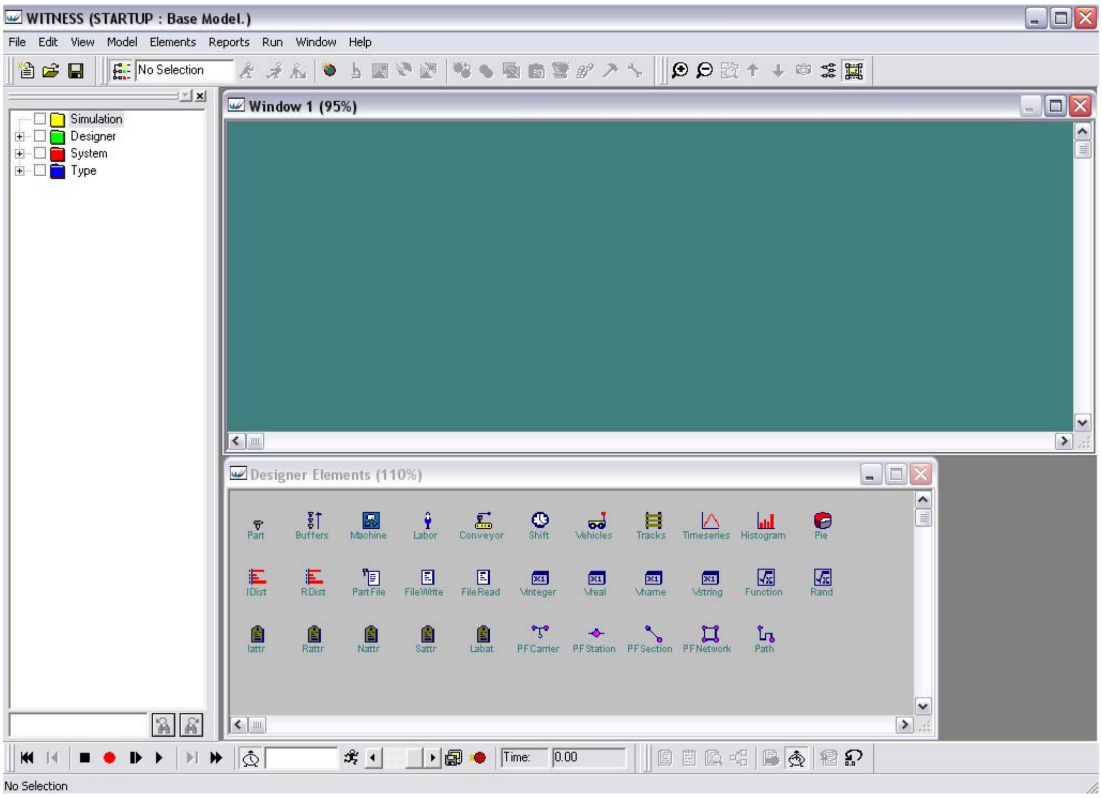


Figure 3.3: Example of simulation case using Witness 2001

In order to setup simulation process, there were some steps have been followed as shown in Figure 3.4. A model of house that applying IBS components was first been proposed. In this case, the model was prepared by other researchers and it was assumed that in term of structure capabilities, there will be no argument. With the proposed of IBS double story model house as shown previously, the study specifically determined the number of IBS components such as footing, beam, column, stair, slab, roof, and wall that might be used for the main structure.

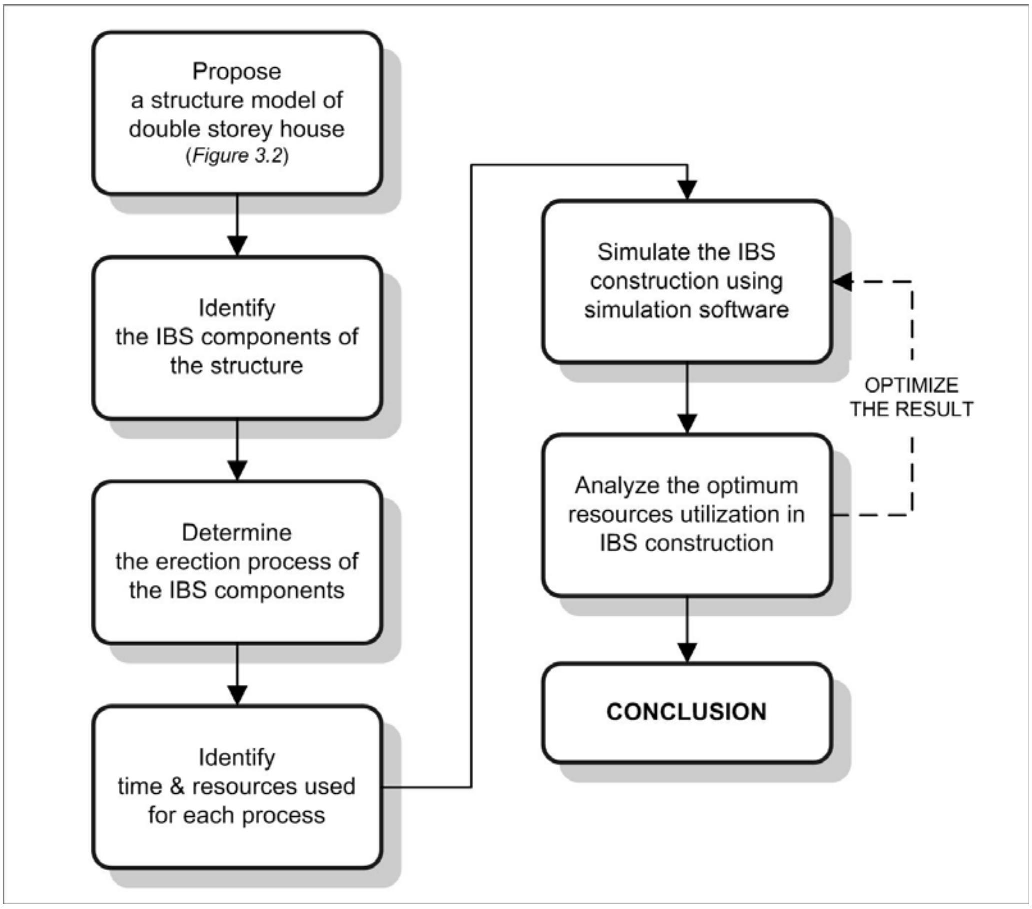


Figure 3.4: Steps in developing simulation process

Again the scope of study is limited to focus just on the construction process for double storey IBS house including only the main structure itself. Besides main structure means it including the footing, ground beam, ground slab, first floor column, wall, first floor beam, first floor slab, second floor column, roof beam, roof segment and other components such as toilet, stair etc. This is important scope in order to simplify the study so that the aim of this study can be clearly defined.

With the strong background of literature review, detail sequence of the construction process for IBS method has been established. Simultaneously, with collected data of time and resources utilization in third stage, together with detailing of IBS erection process, simulation can be done in easier way. Again the objectives have been referred consistently in order to achieve the final findings according to the target. In simulation analysis part, the aim is to get the optimum resources used in IBS construction, therefore the simulation have to repeat for several times to get the most optimum number of resources. However, the weakness in simulation process using Witness 2001, optimization could be achieved only by using approximation but it is still proper compare to the manual try and error analysis. A brief explanation on simulation analysis and the results have been presented in Chapter 5.

3.4 Summary

Methodology has been design parallel towards the main goal of this study which is to determine the process flow of housing construction that are applying Industrialized Building System (IBS) components for its main structure. In general, the study started with pilot study on IBS approach in construction industry. Then a model of IBS double storey house has been proposed. Afterwards the process and all parameters that will be used especially on time and resources utilization in IBS construction have been determined. It is related to the first findings to identify the detail sequence activities of housing construction using IBS construction method. A real time construction using simulation software has been developed to approximately plan and control the IBS construction in virtual manner. The most achievable completion time and the optimum resources that might be utilized in IBS construction has been identified and that are the second and third findings whereby with the result, the implementation of IBS housing construction in the real form can be applied.

CHAPTER 4

DATA COLLECTION

4.0 Introduction

Data collection’ topic involved a great deal of data gathered from site survey, interview and pilot study on previous research. Data input from site observation has been discussed first in order to give some background knowledge on the data collection for the subsequent topics. Site observation including conventional house construction, precast and steel construction for buildings. Afterwards, IBS housing construction has been proposed in the subjects of site layout plan, types and quantity of IBS components and the circumstances on IBS construction including supply and demand, crane capabilities, working hour, resources requirement and so on. This has been followed by the finding on the first objective whereby it is to identify the detail sequence activities of housing construction using IBS construction method.

4.1 Site Observation

On site observation, there are several site that has been observe and some engineers has been interviewed in order to obtain full data to proposed IBS housing construction for this study. The site observation report has been presented in a division so that it can clearly define where the data has been founded and then applied to the new proposed IBS housing construction.

4.1.1 Conventional Construction

Conventional construction method involves construction work being carried out at site. It involves site preparation by fellow contactors before the laying of the footings. The foundation is then built on the footings, to extend above the level of the ground. The building is actually made on the foundation. Usually a floor is laid on the foundation. Beams will then be constructed, followed by the construction of columns and slabs. Where it is necessary, staircases will be constructed, before eventually roof beams are constructed, followed closely by the construction of roof trusses. When the roof is to be framed on the site, the top sill plate is nailed on top of the wall sections. Cutting and nailing each piece of wood one at a time takes a lot of time. Not only must each piece be cut but each piece must be carried up the ladder to the right place.

Water proof roofing materials will be placed to ensure the roof is water proof before roof tiles are placed in position. Brick walls will be constructed where necessary, with allocations for the placement of doors and window panels. Painting and aesthetic decoration on walls and floor slabs will follow up and the end product will be a complete on-site building.

Crane factor is the most important in housing construction. The engineer should know how many cranes must be utilized in order to obtain optimum resources. Crane is also important in IBS construction besides all the activities in IBS construction are using crane. Housing construction is differ than tall building construction where it use tower crane to install the components. So it is economic in term of cost of crane. Therefore, there is a dire need to focus on analysis of crane factor in the study.

4.1.2 Steel and Precast Construction

Steel and precast constructions are two methods that are almost similar to each other. The components of steel or precast structure are ordered from pilot plant with certain specifications. Before that, it is also need a good plan and schedule. Planning is one of the major reasons why steel construction is employed. Without a good planning, problems will occur during construction process especially on components installation. Hence a high emphasis is placed on commitment of a specific planning when a project is awarded. Design of steel structure must be recognize in detail including connection type, bolt size, welding strength, etc.

Once it is principally determine the size and design of components that will be used, it will be ordered from pilot plant. Delivery of components is a factor to be considered during the design stage of components. The size, shape, weight, route, site access, commercial aspects, etc all contribute it. In Malaysia, the most common mode of transport is by trucks or trailers, and to a lesser extent by rail or by barge.

In construction of steel structure, honestly it is also more ease compare to the conventional approach. Components will be delivered to the site, whether to the storage area or to the installation place. After reaching construction site, the components will be unloaded by crane with certain capabilities. More workers are needed to install the component in order to hoist, adjust and fix it into the right places. The workers are professional or skilled people because it involves bolting and welding the connection. Finally, the construction will end up with finishing and usually finishing method will be same as conventional by installing door, window, tiles, mechanical and electrical tools, etc. Steel finishing is not too similar to precast finishing because in steel structure, there is a need to protect steel surface from fire or any other damager. Therefore the final product between steel structure and precast structure in term of interface, it will be some differences.

4.2 Proposed IBS Construction

For this point of study, the IBS house that has been used is currently new and different from the other IBS closed system applied nowadays. Therefore, before the data analysis and discussion has been done, there is a need to elaborate the proposed IBS housing construction for this study. The explanations are on the subject of site layout plan, types and quantity of IBS components and the circumstances on IBS construction including supply and demand, crane capabilities, working hour, resources requirement and so on.

4.2.1 Site Layout Plan

Site plan for this study was set up as shown in Figure 4.1. The total house to be completed was 300 houses where it is presented in a uniform distribution with 15 houses per row in 20 rows. The position of the houses is organized without according to any existing plan but anyhow it is arranged in order to simplify the next simulation modelling work.

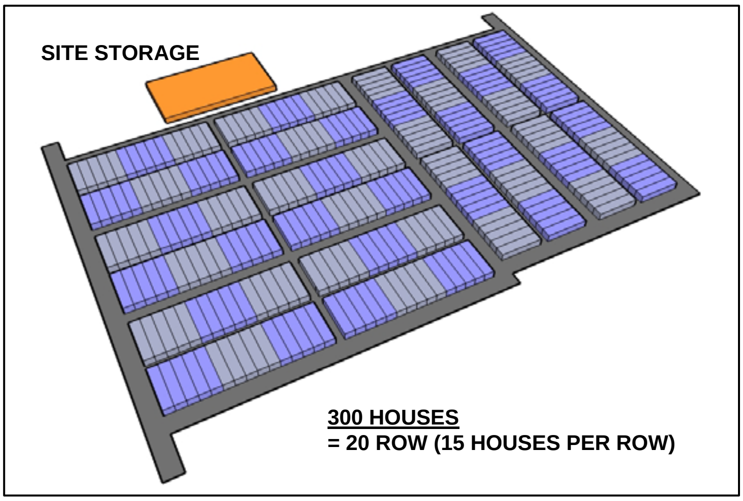


Figure 4.1: Site Plan for IBS Housing

4.2.2 IBS Components

IBS Component for housing includes several types: footing, beam, column, slab, wall, roof, stair, toilet, etc. In this study, the types and numbers of IBS component that have been used for simulation analysis were identified from IBS house model as publicized in Figure 4.2. The model has been prepared by other researcher in AutoCAD format. From there, the analysis on the type and the number of IBS components utilized can be determined. It was summarized as shown in Table 4.1. Then the model has been adjusted to make a double storey terrace house of 15 units. Another calculation has been done in order to get the number of components used in 15 IBS houses. Finally it has been multiple by 20 rows for the purpose to obtain final number of components of 300 IBS houses. This data has been further used in simulation analysis as described in Chapter 5.

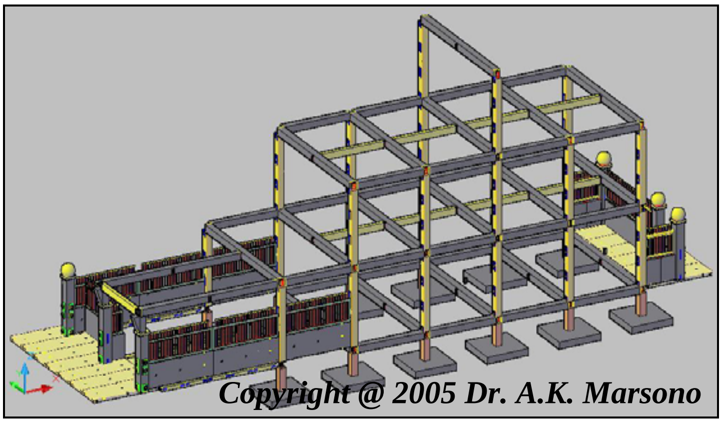


Figure 4.2: House Model using IBS Components

Table 4.1: The Types and Number of IBS

Types of Component	No. of House		
	1	15	300
Footing	12	96	1920
Beam	77	889	17780
Slab	69	1035	20700
Column	28	238	4760
Toilet	3	45	900
Stair	1	15	300
Wall_1	48	384	7680
Wall_2	28	420	8400
Roof	5	75	1500
Fence	20	230	4600

4.2.3 Supply of Components

As far as components supply was concerned, it was estimated that all components were delivered to the site sufficiently in term of amount and correct time. As shown in site plan, there is a storage area for components to be located while waiting for placement. For the purpose of simulation analysis, all transportation time between component plant to the site and from storage to the crane were excluded. The reason was to avoid complex simulation analysis where the actual focus of analysis was on the installation components itself.

4.2.4 Resources Requirement

Observation was conducted on several construction sites for resources consumption during installation process and it was reported that for every component, there are a number of resources used such as workers, crane, surveyors and tools for bolting and grouting. In term of this research, it was decided to occupy six types of resources which are Crane, Instructor, Surveyor, Grouter, Labour1 who involve in lifting component and Labour2 for installation process as shown in Table 4.2. The selection of this type of resources is made from site observation input and expert's interview.

Table 4.2: Type and Task for Selected Resources

Types of Resources	Task
Crane	Hoist and deliver components for installation process
Instructor	Giving instruction to the crane operator
Surveyor	To give instruction to the workers in order to adjust the components installation
Grouter	As a tool for grouting purposes
Labour1	Assist the hoisting work
Labour2	Install the components to the places

4.2.5 Working Time

Working time must be set up before running the simulation. Hence, this study fixed the time for work as 60 minutes in an hour, seven hours in a day and 6 days in a week without concerned any public holidays. Working hour is from 8.00 a.m. until 5.00 p.m. with 2 hours of total break, this means seven hours effective time per day. In short, it was calculated that one week will be equal to 2520 minutes and this equivalent was used for simulation analysis.

4.2.6 Crane Constraint

Crane analysis was conducted to determine required number of crane or number of movement should be implemented. One row of houses content 15 houses and it was assumed that the most effective working radius for crane is within five houses. Therefore one row needs at least three numbers of crane or three movements for the same crane. From site observation, crane movement together with setup time will take approximately between 15 minutes and 25 minutes. Figure 4.3 shows on crane capabilities and how working radius was calculated.

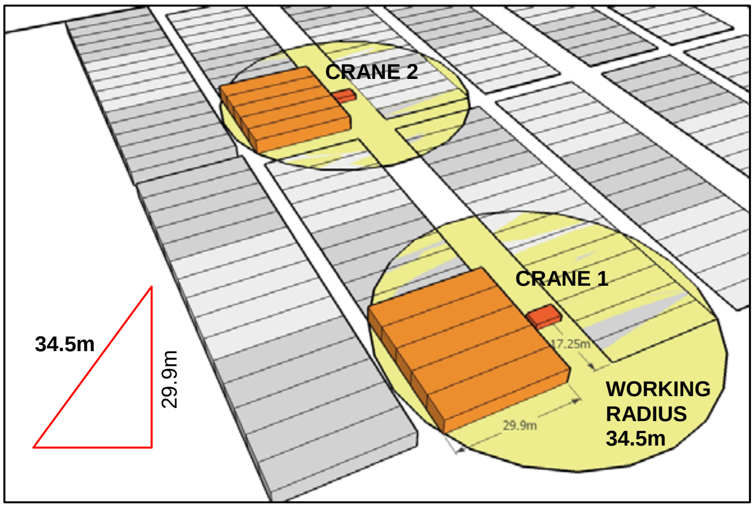


Figure 4.3: Working Radius for Cranes

4.2.7 Installation Process

In installation process, there were three types of data should be obtained: sequence of activities, time required and resources involved. Sequence of activities was identified from the IBS house model and information from experts. Time requirement and resources utilization for each activity was collected from site study by using stopwatch and information from engineer. However, because of the difference IBS components installation process, some of the activities have been assumed. Table 2 shows the complete installation process for each IBS components with time and resources usage. This finding related to the first objective of this study.

4.3 Process Flow of IBS Housing Construction

IBS housing construction involves a lot of installation IBS components. There just a little focus on in-situ construction where it engages raw materials to be placed. Therefore the process flow in IBS construction will be more systematic compare to existence construction method. From site observation, there are some tips on IBS construction method that is almost similar to the steel and precast construction. Moreover, the sequences in constructing a number of houses still follow to the conventional approach. This is because there are plenty of the best management approaches in conventional system that can not be argue. This study was attempted to examine the application of IBS components in order to replace existing conventional structure using conventional cast in-situ method.

In Chapter 2, literature on sequence of IBS construction has been concluded as shown in Figure 4.4. From basic information on common step of IBS construction sequences, process flow on how to construct IBS houses using the same approach, but different in IBS components. The different of those components will be on size, weight and connection. This is because the components that will be used are from the other researcher input. So the factor that has been considered in order to design the process flow of IBS housing construction were the weight, size and connection of the components.

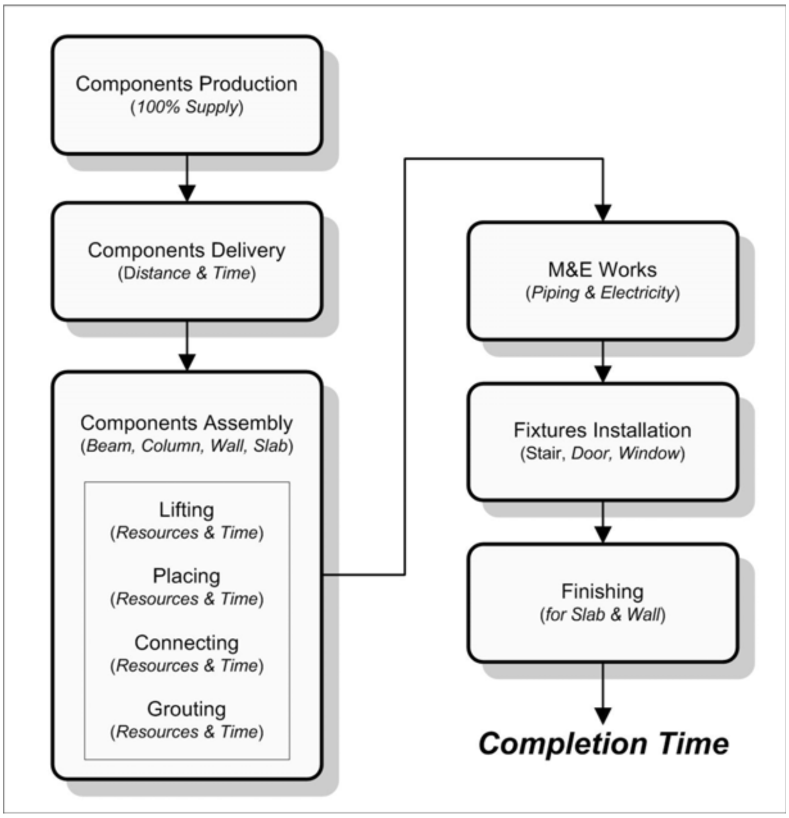


Figure 4.4: Sequences of IBS Construction Activities

According to the model of IBS house in Figure 4.2, the connection of IBS components will be similar with steel components connection. They use a bolt connection but in term of IBS, there is some grouting after the bolt is fixed. In term of size, it could be similar to precast components where they use precast concrete that was created in a factory. But the weight is different with existing precast concrete because they usually fabricated in a large size and using hard concrete. For this model, the components are lighter and smaller. As far as all the factors have been considered, final decision on process flow has been design as shown in Table 4.3. Simultaneously, the time taken for installing the components also has been identified by considering all those factors. Resources utilization for each activities has been find out by site observation. Final finding for the first objective is as presented in Table 4.3.

Table 4.3: Installation Process for each IBS Components

COMPONENTS	PROCESS	TIME	RESOUCES
Footing	Hoist & Deliver	00:30	1C,1I,1L1
	Adjust & Affix	06:00	1C,1I,2L2,1S
	Backfill	02:00	2L2
GF Beam	Hoist & Deliver	00:30	1C,1I,1L1
	Adjust & Affix	05:00	1C,1I,2L2
GF Slab	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	03:00	1C,1I,2L2
GF Toilet	Hoist & Deliver	02:00	1C,1I,2L1
	Adjust & Affix	08:00	1C,1I,4L2
	Rebar & Grout Slab	05:00	2L2,1G
GF Column	Hoist & Deliver	01:00	1C,1I,2L1
	Adjust & Affix	07:00	1C,1I,2L2,1S
	Grout Connection	01:30	2L2,1G
GF Wall 1	Hoist & Deliver	00:30	1C,1I,1L1
	Adjust & Affix	05:00	1C,1I,2L2
GF Wall 2	Hoist & Deliver	01:00	1C,1I,2L1
	Adjust & Affix	07:00	1C,1I,3L2
1F Beam	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	05:30	1C,1I,2L2
Stair	Hoist & Deliver	02:00	1C,1I,3L1
	Adjust & Affix	12:00	1C,1I,5L2
1F Slab	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	03:00	1C,1I,2L2
1F Toilet	Hoist & Deliver	02:30	1C,1I,2L1
	Adjust & Affix	10:00	1C,1I,4L2
	Rebar & Grout Slab	03:30	2L2,1G
1F Column	Hoist & Deliver	01:00	1C,1I,2L1
	Adjust & Affix	07:30	1C,1I,2L2,1S
	Grout Connection	02:00	2L2,1G
1F Wall 1	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	05:30	1C,1I,2L2
1F Wall 2	Hoist & Deliver	01:30	1C,1I,2L1
	Adjust & Affix	07:30	1C,1I,3L2
Roof Beam	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	05:30	1C,1I,2L2
Roof	Hoist & Deliver	02:00	1C,1I,3L1
	Adjust & Affix	12:00	1C,1I,5L2
Ext Beam	Hoist & Deliver	00:30	1C,1I,1L1
	Adjust & Affix	02:00	1C,1I,1L2
Ext Slab	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	03:00	1C,1I,2L2
Ext Wall & Fence	Hoist & Deliver	01:00	1C,1I,1L1
	Adjust & Affix	04:00	1C,1I,2L2

(RESOURCES: C = crane, L1 = labor1, L2 = labor2, I = instructor, S = Surveyor, G = grouter)

4.4 Summary

This topic presents a complete data collection before further study on simulation modelling is carried out. Three types of construction: conventional, precast and steel, has been observed on several construction sites. Moreover several data has been obtained by interviewing engineers or experts and from previous related research. Consequently, preliminaries data on proposed IBS construction has been recognized in term of site layout, components supply, general working time, resources usage and constraint. Finally the first objective has been successfully achieved by providing complete process flow of IBS housing construction together with time taken and resources utilized. This process was summarised from the whole data gathered and has been reviewed by experts. From there, this study has been expanded into simulation modelling on IBS housing construction.

CHAPTER 5

SIMULATION ANALYSIS AND DISCUSSION

5.0 Introduction

In this topic, detail explanation on simulation modelling and analysis has been clarified. It concerned about preliminaries stage of modelling on how data gathered in Chapter 4 have been effectively converted into a simulation modelling. Then a brief description on simulation analysis conducted in the study and comprehensive discussion has been presented. As far as simulation analysis is concerned, this chapter highlighted a topic on simulation elements: part, buffers, machine, labour, vehicles and tracks, another topic on simulation modelling starting from one house model to 300 houses model and its description, and finally on simulation analysis that included the findings for objectives two and three in this study. At the end, the final aim for this study to determine the process flow of housing construction that are applying Industrialized Building System (IBS) components for its main structure has been obviously presented.

5.1 Simulation Elements

This study employed Witness 2001 simulation software for simulation purposes. With the background literature on this software information that has been described in Chapter 2, it is extremely effective to be applied in order to simulate the construction of IBS housing. Nevertheless, Witness 2001 generally used in manufacturing simulation process. Therefore in order to apply a system of construction process, there are several vital points to be altered as to ensure an effective relation between the system model and the real construction process. Firstly, after setting up a complete process flow of IBS housing construction as prepared in Chapter 4, it has been converted into a replication of manufacturing process by using Witness 2001 simulation elements: Part, Buffers, Machine, Labour, Vehicles and Tracks, as shown in Figure 5.1. The conversion needs a deep and clear understanding of sequences process for the system and knowledge on how to use Witness 2001.

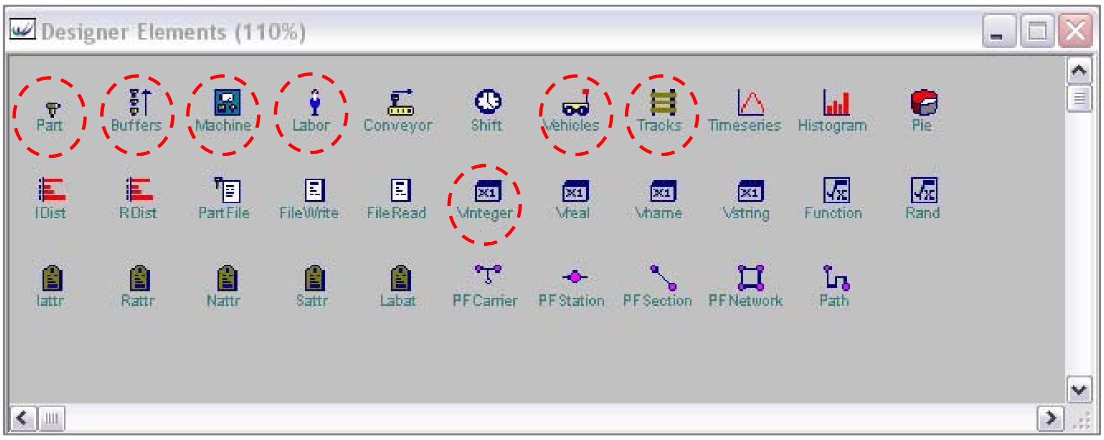


Figure 5.1 : Designer Elements in Witness 2001

5.1.1 Part

In general, parts or entities are used to represent those discrete items that move around the model. They can be used to represent small electronic components, large oil tanks, or anything in between. Parts also have been used to represent calls in a telephone exchange, process path and other types of information flow. In term of simulation for IBS housing construction, parts have been used to show all IBS components utilized in that construction such as footing, beam, slab, column, wall, stair, roof, fence and toilet.

Witness 2001 creates parts and introduces them into the simulation at the time and place dictated by the model. Parts can be handled singly; they can combine into one; one can split into several; or a group can be batched together. Parts can change into other parts as they progress through the model. For this study, parts was simply used as one rigid item from start until finish the whole system without any change, split or batch into a group. The total numbers of each part or IBS component were referred to Table 4.1 as previously presented. According to that table, there are ten types of IBS component used in construction and each of them has different number. For simulation purposes, all the information must carefully applied and should be checked frequently.

Figure 5.2 illustrates on parts element and the detail of its character. When detailing parts, it needs to decide whether they are passive, active or active with profiles. If parts are passive, it means they are always available. Elements in simulation model can pull them from an infinite supply location at any point in time. On the other hand, if parts are active, they arrive into the model following a specific pre-determined inter-arrival time and lot size. For that case, IBS components in this simulation model were set as passive parts and have been pulled to the model from infinite supply location. This is because this study had set an assumption that the supply of IBS components will be 100% sufficient with no delay, defect or any interruption.

The attachment or path of IBS components in that model were quite simple starting with the components were pulled into the system from infinite location, reached component plant where logically the components was created. Travelled to the site storage by using vehicles or trucks, and finally forwarded to the installation places where it needs some resources or labours to erect the components. The vital point here is the supply and demand of IBS components can be assumed as nil time involved because to circumvent any interruption in simulation process due to supply and demand, whereby the model actually focus on the erection process of all IBS components until it finish becoming 300 IBS houses.

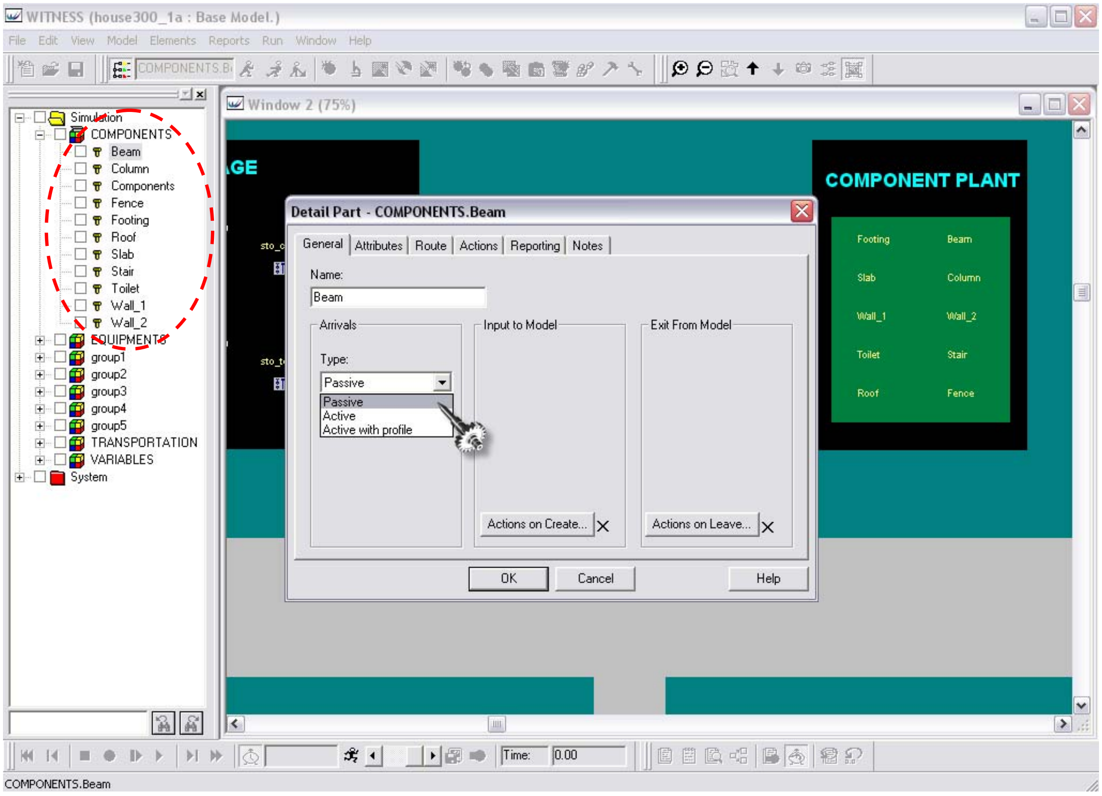


Figure 5.2: The detail of Parts (IBS Components)

5.1.2 Buffers

In Witness simulation, buffers or queues store parts. They do not actively pull parts in. parts are pulled out by some other elements or they are pushed out by a buffer exit rule. In this situation, buffers are mostly used in site storage. It contains 10 buffers for particular IBS components: Footing, Beam, Slab, Column, Wall_1, Wall_2, Stair, Roof, Fence and Toilet. Buffers in site storage are used to store the IBS components that reached site. At the same time, it calculates the number of components that entered site and the maximum number of components that has been stored in the buffers. Figure 5.3 shows how buffers are used to calculate the number of components that reached site. As far as no limitation in a supply of components, the capacity of buffers is set to be capable to keep the maximum number of IBS components that entered the site.

On the other hand, buffers are also used in the segment of housing construction. Almost all machines or activities in this system consist of buffer that functioned as storage and calculating tools. It is important to have buffer in each activity because of two reasons: first is to reconfirm that the components are pass trough the activities by checking the increment of the number in buffers, second is to verify the total number enter and go out from the system must be in the same amount.

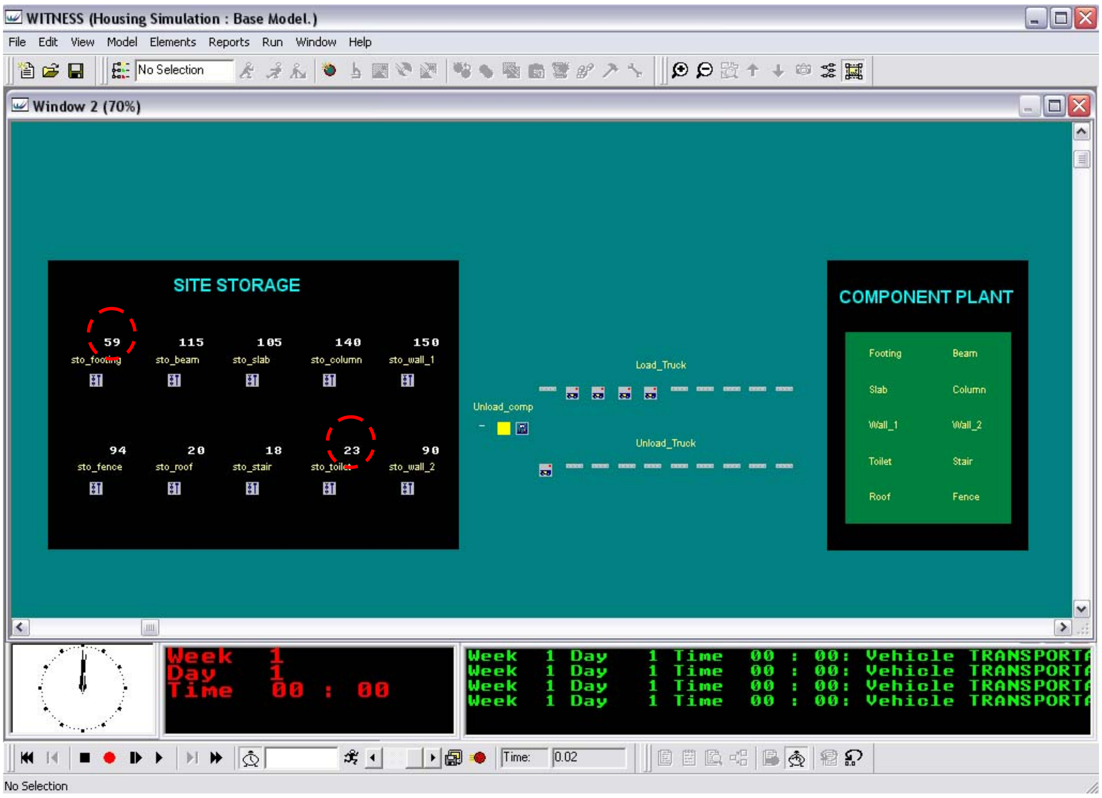


Figure 5.3: Utilizing Buffers in Site Storage

5.1.3 Machine

Machines are considered as the important element in simulation process. They are physical elements that operate on a part, often changing it in some way. Machines in usual manner, take time to process parts, changing from one state to another as time advances. In simulation of IBS construction model, machines are used as activities or process that usually run in construction work. With the information resulted in Chapter 4 on the sequence activities to construct IBS houses as shown in Table 4.3, each of them will be considered as machines to process IBS components which is to fix and adjust the components on a case by case basis, until complete all IBS houses.

While considering the detail of machine elements, Figure 5.4 shows on how information was transformed from Table 4.3 to Witness simulation software. One of the activities for examples footing, has three or more sub-activities involved such as hoist and deliver, adjust and affix, backfill, etc. Witness 2001 allowed users to make multiple cycles in one machine. Thus in this case, multiple cycles were occupied and each sub-activity has been declared with different cycle time, labour usage and logic rules. That is mean a machine will become as activity while the multiple cycles will represent as sub-activities.

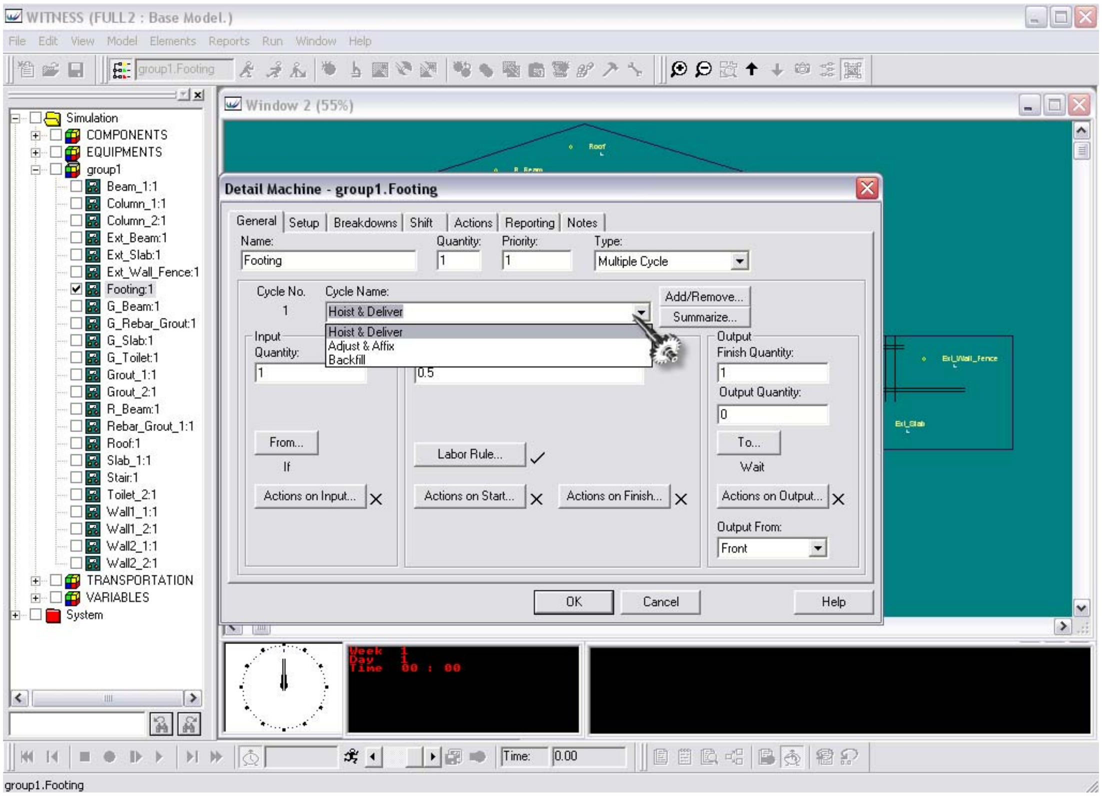


Figure 5.4: Cycle Detail for Machines Element

One by one activity according to the sequences has been transferred into a simulation model. All detail of each machine has been stated in the model. In order to make the machine follow the right sequences, some logic rules for action on start, action on finish, input rule, output rule, labour rule, etc. Figure 5.5 basically shows on how logic rules were declared in simulation model. It is done by using machine' detail window.

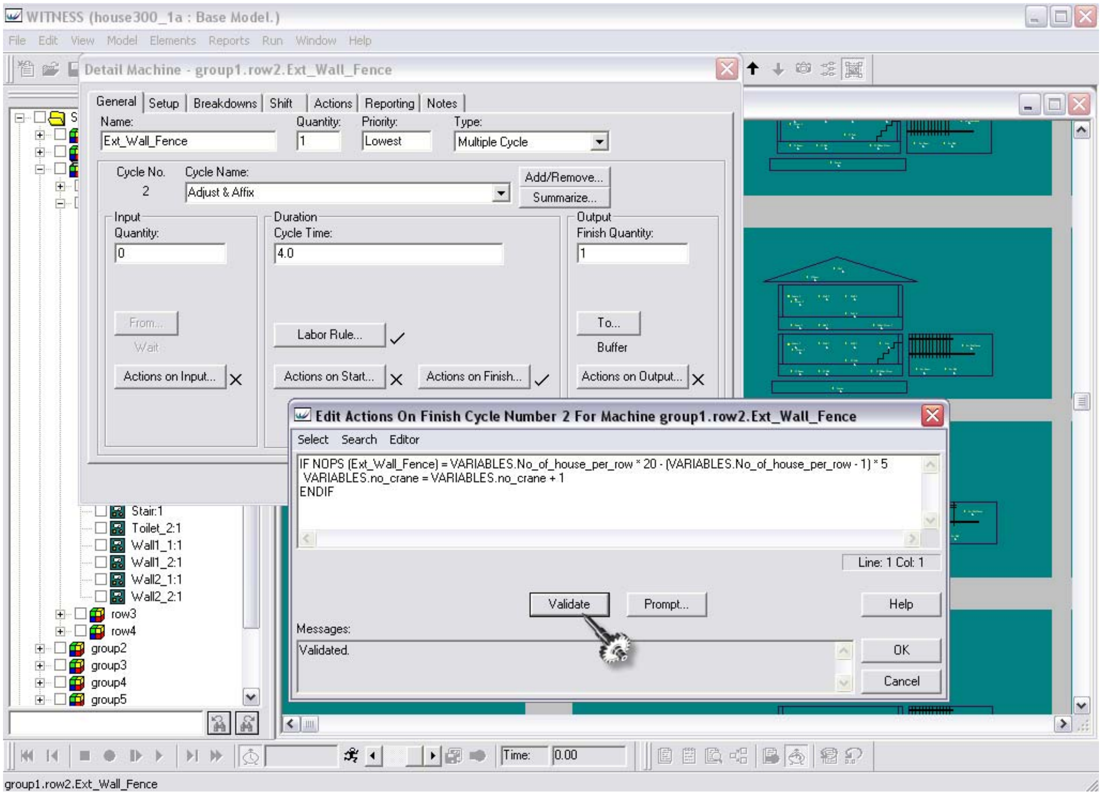


Figure 5.5: Statement of Action on Finish for Machines Element

The cycle of machine activities was easily recognized. First, the machine will wait for a sign to start and the sign was set using 'If and Else' statement. The rule is simple whereby the first machine will be started when simulation start running. The second machine will be started when the first machine finish all cycles. It will follow the rule until finish all activities. The machine starts operation by pulling a component one by one from buffer in site storage. While the operation was ready to begin, labour rule will be applied where it takes some of free labours or resources to operate the components. Before that, action on start will be implemented in order to reduce the number of cranes for the purpose to inform that the crane is on running. After that, when the machine is already finished its job, the number of crane will be increase back. All rules that has been explained previously, has been applied to all machines. Some of the example of logic rules is:

LABOUR RULE

```
EQUIPMENTS.Crane#1 AND EQUIPMENTS.Instructor#1 AND
EQUIPMENTS.Labor_1#1
```

INPUT RULE

```
IF NOPS (Footing) < VARIABLES.No_of_house_per_row * 12 -
(VARIABLES.No_of_house_per_row - 1) * 6 AND VARIABLES.no_crane >= 0
    PULL from COMPONENTS.Footing out of TRANSPORTATION.sto_footing
ELSE
    Wait
ENDIF
```

ACTION ON START

```
IF NOPS (Footing) < 1
    VARIABLES.no_crane = VARIABLES.no_crane - 1
ENDIF
```

ACTION ON FINISH

```
IF NOPS (Ext_Wall_Fence) = VARIABLES.No_of_house_per_row * 20 –
(VARIABLES.No_of_house_per_row - 1) * 5
    VARIABLES.no_crane = VARIABLES.no_crane + 1
ENDIF
```

5.1.4 Labour

Labours in manufacturing process are considered as operator for conducting machines. While in construction, labours are workers who constructing building and other construction works. Basically in simulation, labours recognized as resource that may need to be present for an operation or task to take place. More often than not, the employed of labours always associated with machines because machines need a number of resources to run some task. In this case of study, labours were created and assigned to several construction activities. Figure 5.6 simply demonstrates the participation of labours in simulation model and the detailing of resources in order to set quantity, name of labour, shift, allowance and other character that should be hold by labours.

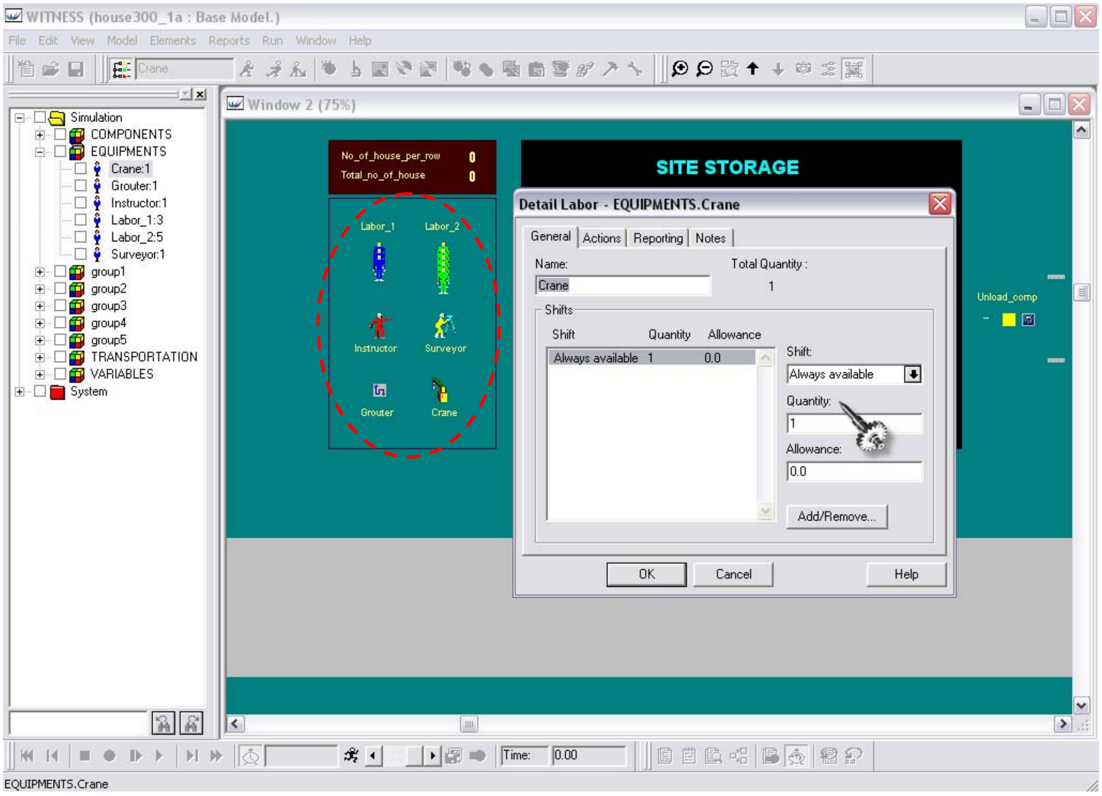


Figure 5.6: Detail of Labour Elements in Witness 2001

Labours are not just workers or people. They can be tool, machine, crane, a group of workers, etc. Therefore in this simulation study, there were six types of labours used in the model which are Crane, Instructor, Surveyor, Grouter as a tool, Labour1 who involve in lifting component and Labour2 for installation process, as mentioned earlier in Chapter 4. In detail of labours, all of them have been set to the maximum number required to perform any task. This mean, there would be no ‘lack of workers’ problem occur during construction process. However in some cases of analysis, limitation in the quantity of labours that utilized in the system must be happened to determine the optimum number of resources that should be used to complete overall project within the most achievable completion time. Other detailing such as shift and allowance has not been considered.

5.1.5 Vehicles and Tracks

Vehicles are created to perform transportation task. They involve carrying, delivering, loading and unloading IBS components from one place to another. On the other hand, tracks in Witness simulation are presented to guide the movement of vehicles so that they can go from one to another place with exact path. For that reason, vehicles and tracks are used in IBS construction simulation as transportation to deliver IBS components from component plant to storage site. Trucks reached pilot plant to load components, delivered the components to storage site using path, unload the components at storage site and keep them into a buffer and finally went back to the component plant using another path as shown in Figure 5.7.

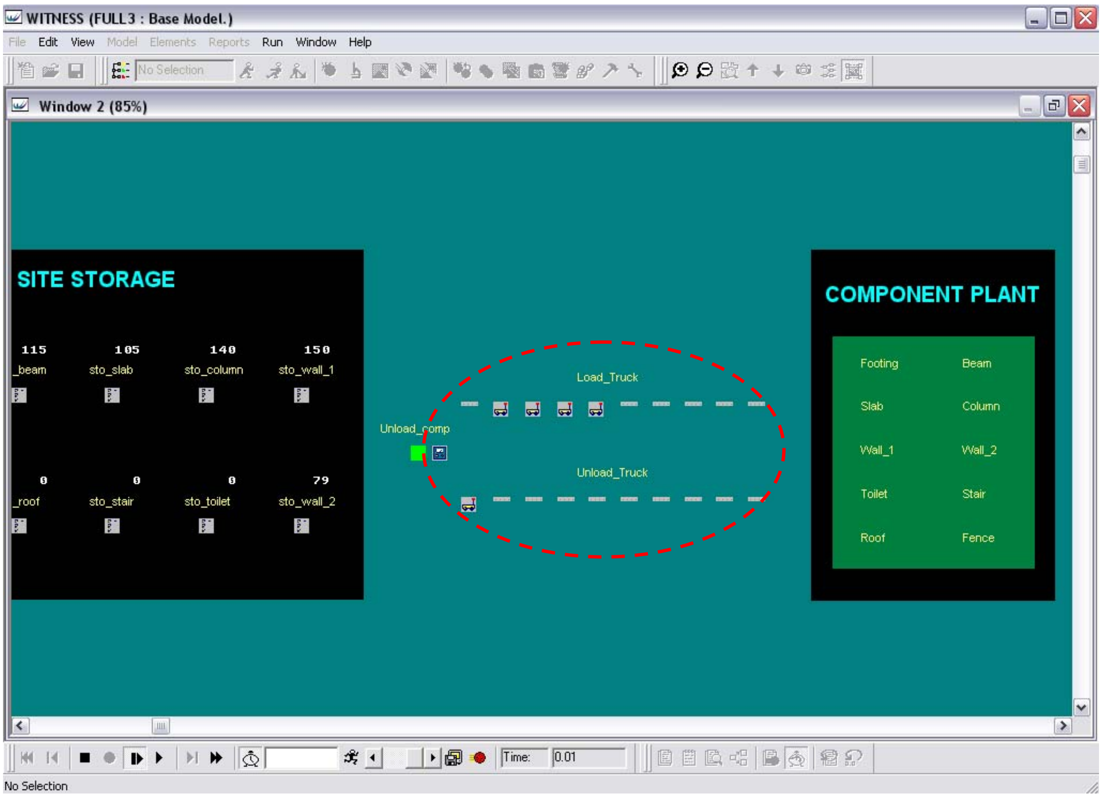


Figure 5.7: The Function of Vehicles and Tracks in the Model

There is some logic rules are applied to the elements in order to create a character of vehicles according to real character. The main point is to ensure that the number of components store in buffers at storage site should never be nil as far as no interruption due to insufficient components supply are allowed. This means the vehicles must, in all the time, deliver sufficient components to the site without lacking. Therefore in order to overcome the problem, the minimum number of components in buffers was set as ten to avoid any disturbance during construction. As a result, logic rule for loading components was stated as:

```
IF NPARTS (sto_footing) < 10
    PULL from COMPONENTS.Footing out of WORLD
ELSE IF NPARTS (sto_beam) < 10
    PULL from COMPONENTS.Beam out of WORLD
ELSE IF NPARTS (sto_slab) < 10
    PULL from COMPONENTS.Slab out of WORLD
ELSE IF NPARTS (sto_column) < 10
    PULL from COMPONENTS.Column out of WORLD
ELSE IF NPARTS (sto_wall_1) < 10
    PULL from COMPONENTS.Wall_1 out of WORLD
ELSEIF NPARTS (sto_wall_2) < 10
    PULL from COMPONENTS.Wall_2 out of WORLD
ELSE IF NPARTS (sto_toilet) < 10
    PULL from COMPONENTS.Toilet out of WORLD
ELSEIF NPARTS (sto_stair) < 10
    PULL from COMPONENTS.Stair out of WORLD
ELSEIF NPARTS (sto_roof) < 10
    PULL from COMPONENTS.Roof out of WORLD
ELSE IF NPARTS (sto_fence) < 10
    PULL from COMPONENTS.Fence out of WORLD
ENDIF
```

The truck loaded components and delivered to the storage site before went back to the pilot plant using different track. At storage area, in order to unload the components to the particular buffer, there is a rule applied which is:

```
PUSH COMPONENTS.Footing to sto_footing, COMPONENTS.Beam to sto_beam,
    COMPONENTS.Slab to sto_slab, COMPONENTS.Toilet to sto_toilet,
    COMPONENTS.Column to sto_column, COMPONENTS.Wall_1 to sto_wall_1,
    COMPONENTS.Wall_2 to sto_wall_2, COMPONENTS.Stair to sto_stair,
    COMPONENTS.Roof to sto_roof, COMPONENTS.Fence to sto_fence
```

5.1.6 Vinteger

Vinteger stand for ‘Variables Integer’ element in Witness 2001. In general, most data can be stored in Witness using the element’ details such as cycle time, breakdown data, part quantities, etc. However it is often useful to store data in variables. Variables are most useful when the data to be stored or used does not relate to individual parts or cannot be used directly in the element' details. In this simulation model, variables was used in order to set the number of houses per row, the number of IBS components and the number of crane utilized. The reason is because in analysis part, the number of those subjects has been frequently changed. Initialize action tool that was set up before the model start to process, were the place for declaration all variables as illustrated in Figure 5.8. While simulation was running, all the information has been grabbed by the system and affected the final results.

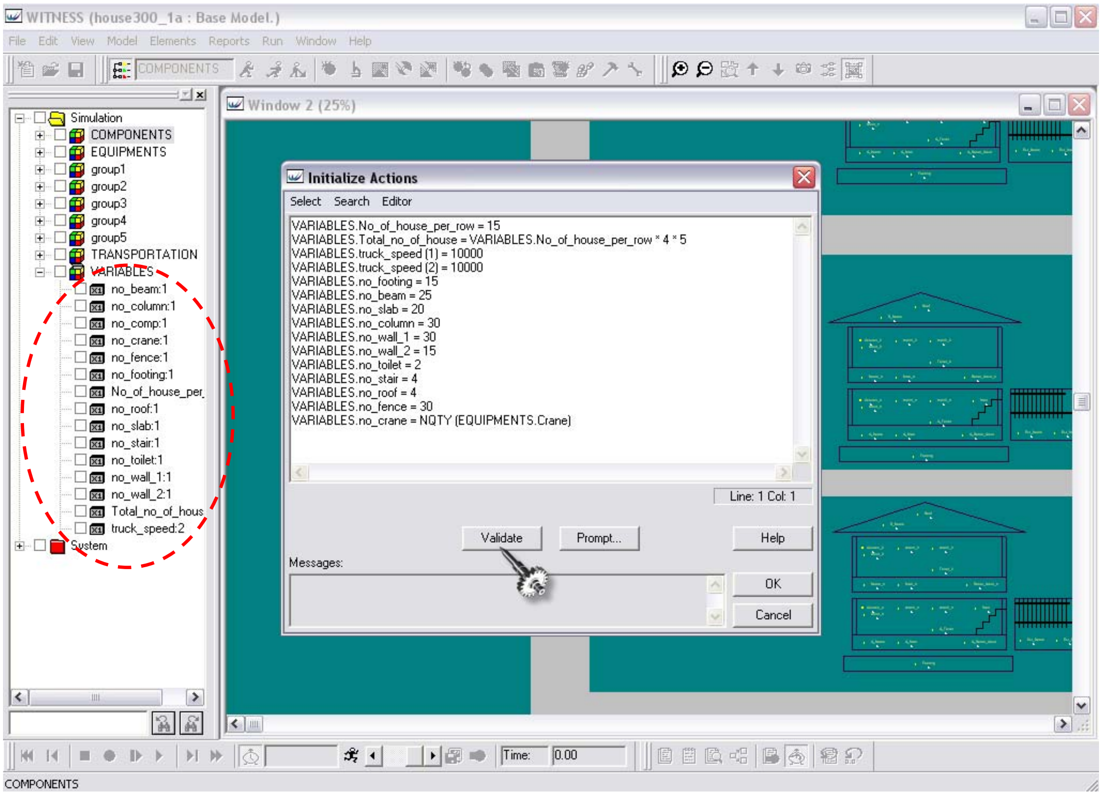


Figure 5.8: Initialize Action for Variables Declaration

5.2 Simulation Modelling

A designer element in Witness is such a basic formula to perform the real simulation model. People use it to develop a large system that consist a lot of elements seems like what has been done in this study. There were more than hundred of machine elements employed in the IBS housing construction simulation. Therefore the difficulties in simulation modelling was to make sure all elements are running followed the rules and sequences until it finish to the end. For that reason, simulation model was done step by step beginning with one model of house, then it goes to the 15 houses to represent a row of houses, applying next step for 2 rows which consist of 30 houses, then it goes to 60 houses, 120 houses, 180 houses, 240 houses and finally reached the maximum number of houses which is 300 houses or 20 rows of IBS houses.

5.2.1 One House Model

For the first step, one house model has been built by applying all sequences activities in constructing one IBS house. All rules for every element in simulation model have been declared. The total number of components has been set according to the information stated in Table 4.1. While the simulation is running, a detailed check has been done in order to verify the sequence of activities follow the order, the number of component that has been processed is exact and the utilization of resources is work out.

Generally in simulation modelling, the complete model will be verified with real data on site to make sure the model is applicable in order to represent the real system. In this case of study, there were no existing real data to compare for validating process, thus according to Lanner Group (2000), a model can also be validated by verifying the result with experts in that background. Hence the study refers to the simulation experts and IBS practitioners in order to authenticate the system. Figure 5.9 shows a complete model of one IBS house after it finish simulating to construct the house. From the figure, final number of components that has been processed by a machine is clearly stated. The result to complete one IBS house is approximately about 1824.00 minutes (4.34 days of 7 hours/working days). Also there is a tool of statistical analysis prepared by Witness 2001 can be used in order to further examine the results.

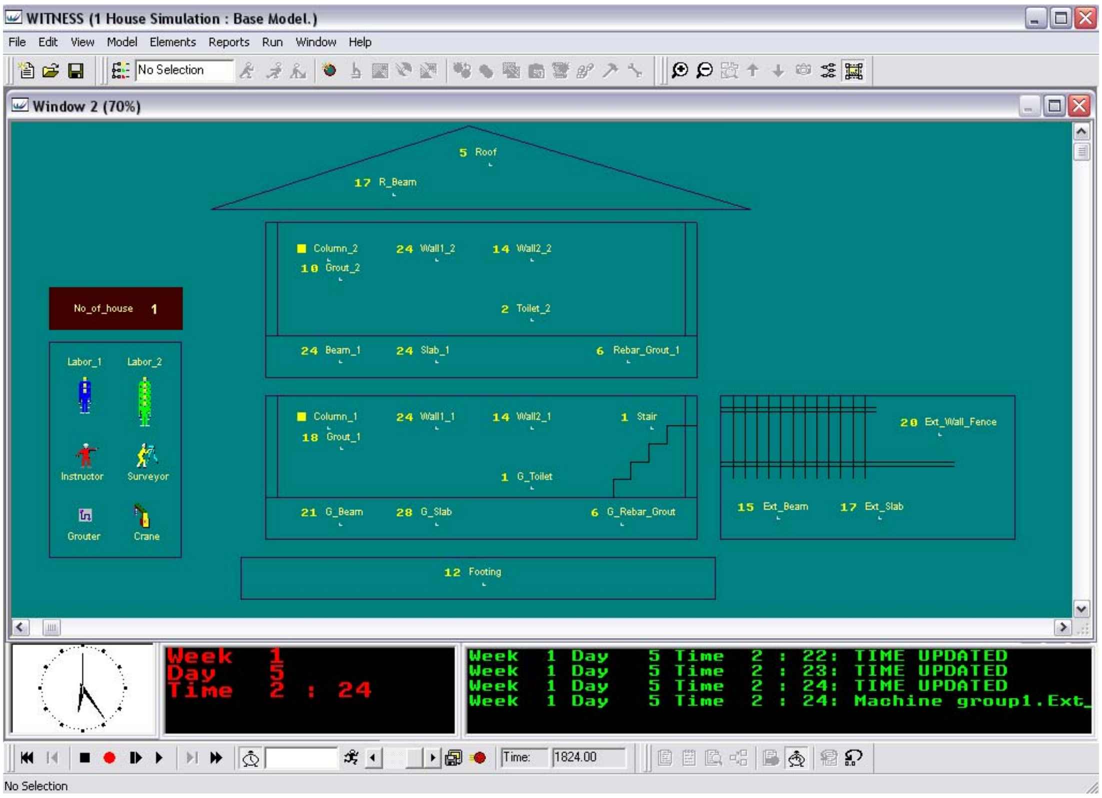


Figure 5.9: A Model of One IBS House

5.2.1.1 Definition of Resources Group

For the purpose to simplify the analysis, another term in simulation modelling has been defined. A group of resources has been set as rigid combination number of each type of resources. This was called a resources group. It is defined by using statistical tool in Witness 2001 whereby it detects on the percentage of utilized resources during construction progress. It s done on a model of one IBS house and keep it run to the end. From there, a statistic on labours progress has been examined and the result shows only one crane, one instructor, one surveyor, one grouter, three labour1 and five labour2 has been utilized while the system was running. This means, those labours are only the need resources to construct one IBS house. Therefore this study attempts to put that combination of labours as a group of resources.

5.2.2 15 Houses Model

Once the model of one house was completed and all preliminaries study has been conducted to that model, another 15 IBS houses model has been developed. 15 houses will represent one row of houses as describe in Chapter 4. The model was developed by upgrading the existing one model of IBS house. The different only on the total number for the components of IBS as presented in Table 4.1. So the model has been altered to fix a new number of components and obviously the results will be increased as well as the number of components has been enlarged. Figure 5.10 simply shows on the model of 15 IBS houses and the overall running time was stated as 22152.47 minutes (52.7 days of 7 hours/working days). Previously the result for a model of one IBS house was 1824.00 minutes and if multiple by 15 houses, it becomes 27360.00 minutes (65.1 days of 7 hours/working days). Hence it is clearly explained that the analysis of 15 houses can not be done by simply duplicate the result of one house because in the real situation, there are some circumstances that the time can be reduced if it is applied for a bundle of components to operate.

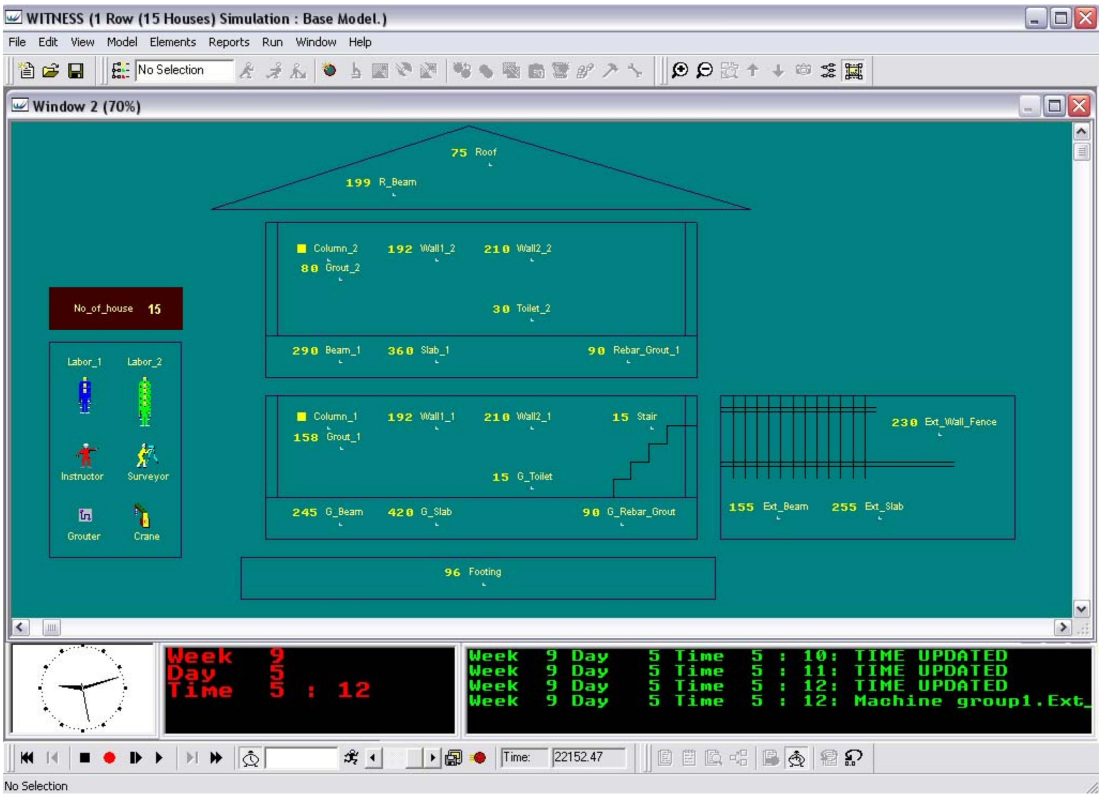


Figure 5.10: A Model of 15 IBS Houses

5.2.2.1 Crane Movements

Basically, 15 houses in one row will take a long distance for a crane to achieve for components installation purposes especially for hoist and deliver work. In Chapter 4, it has been discussed on capabilities of crane during construction of IBS houses where the best approach for a crane is within five houses working radius. In other to move aside to cover another five houses, it takes about 15 to 25 minutes for the movement and set up. Figure 5.11 demonstrates about the setup time for a crane movement that has been assign in machines detail. So that is means, it will take two times of setup time for each activities in order to complete 15 houses. As far as crane movements was concerned, the result stated in Figure 5.11 is actually by considering this factor and so that it became more similar to the real practice.

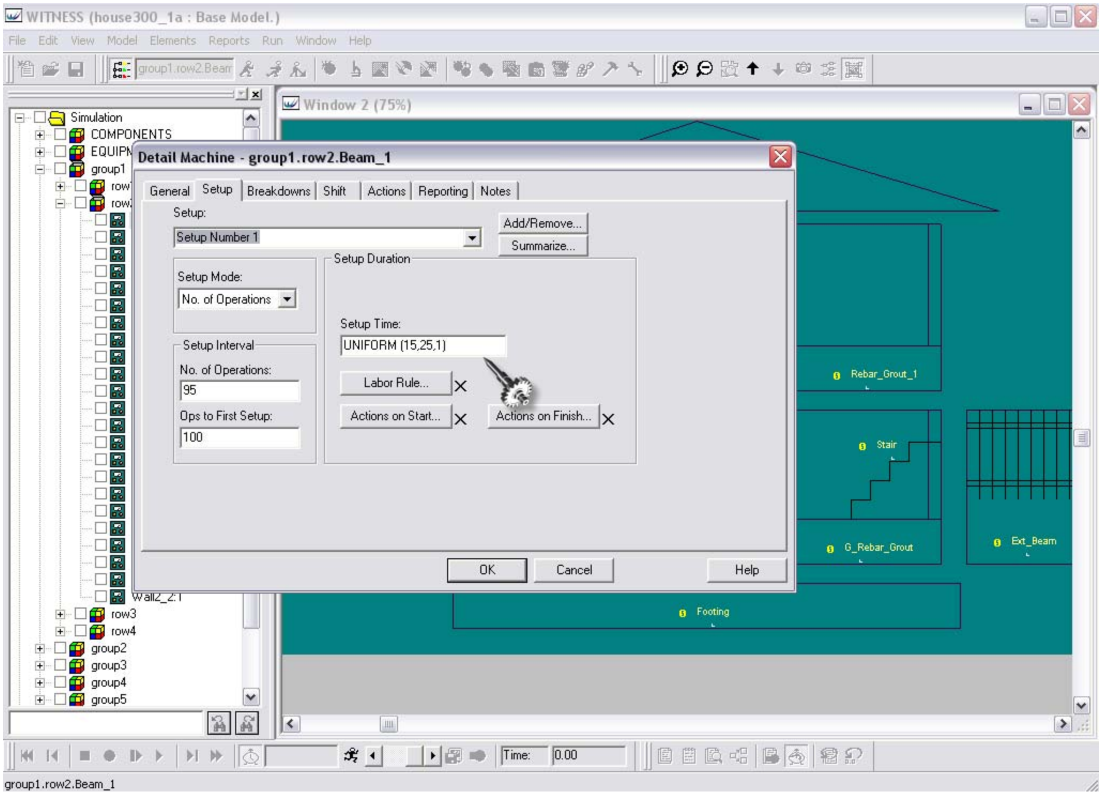


Figure 5.11: Assigning a Setup Time for a Machine

5.2.2.2 Valuation of Progress Percentage

There are a lot of facilities tools organized by Witness 2001. In order to know the overall time for determination of completion time for one IBS house model, there will be one segment in interface of Witness 2001 window that shows running time for that simulation as illustrated in Figure 5.12. The running time will show the real time running whilst the simulation in a progress. After it finish, the time will ended and that will be the final completion time for that particular model.

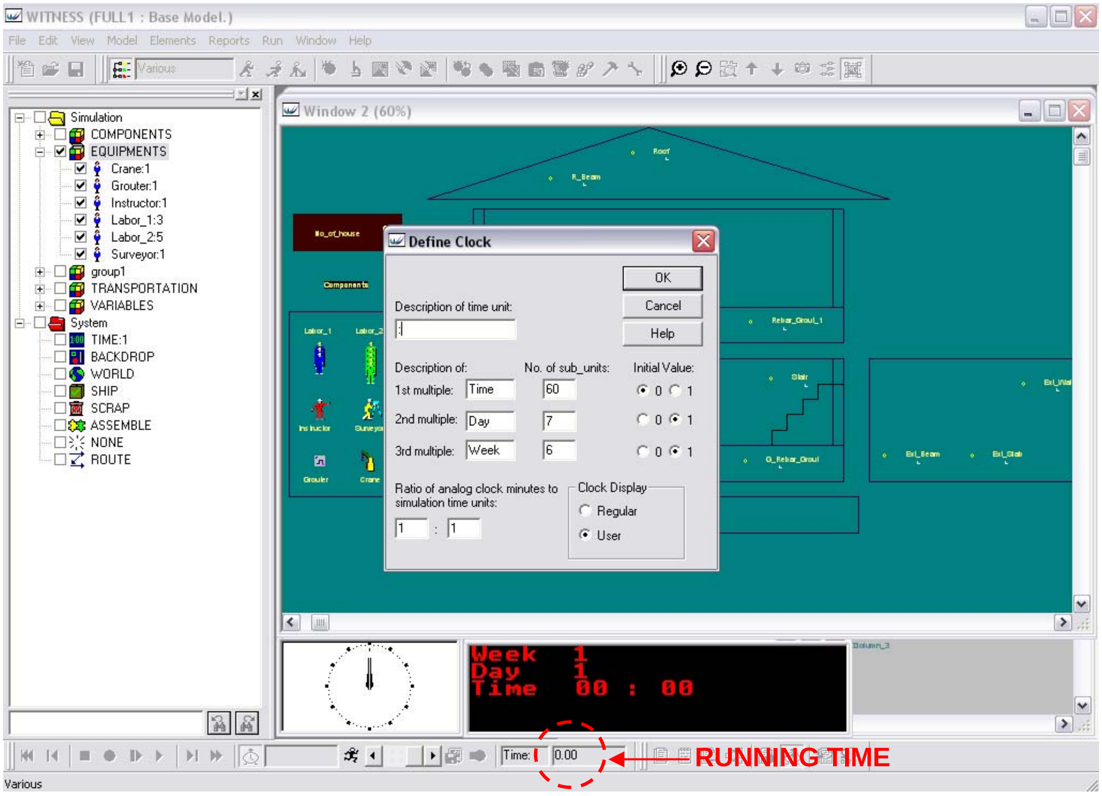


Figure 5.12: Define Clock in Witness 2001

In this simulation study, 'Next Row Start Up' (NRS) percentage has been used to simplify the analysis. NRS explanation has been clearly explained in the next sub-topic. Anyhow, the point is, to implement NRS, the percentage of work progress must first be determined. In order to determine progress percentage, the overall time for finishing one IBS house has been set as 100% progress. Then the time will be divided into certain division so that NRS of 12.5%, 25%, 50%, 75% and 100% can be determined. Table 5.1 describes about progress percentage and the time running.

By knowing the running time for particular progress percentage, simulation model has been run to identify on what activities do the progress percentage represent. This is important to programme the simulation in order to follow progress percentage so that the factor of NRS percentage can be implemented. Also there are some tools to set up clock time. This study fixed the time for work as 60 minutes in an hour, seven hours in a day and 6 days in a week without concerned any holidays.

Table 5.1: Activities and Running Time for Particular Progress Percentage

Progress Percentage	Time Running (minutes)	Activities Involve
12.5%	2769.06	Ground Floor Beam
25%	5538.12	Ground Floor Toilet
50%	11076.24	Stair
75%	16614.36	First Floor Wall2
100%	22152.47	External Wall and Fence

5.2.2.3 Definition of 'Next Row Start Up' (NRS) Percentage

According to Table 5.1, there are at least five progress percentage has been defined. This percentage has been further used to assign 'Next Row Start Up' (NRS) factor as guidance for the next row of IBS house to start constructing. NRS factor was applied only for the whole 300 IBS houses model where it involves about 20 rows. The construction will start with the first row while another row will be waiting for a sign to start. Either 12.5%, 25%, 50%, 75% or 100% of NRS percentage will be assigned to the system and it will be followed to the end of simulation running. The main constraint for a system to keep running was the limitation of resources. A machine or activity can not be run without resources and for that reason, if there was any restraint, the system will be waiting for another machine to complete its task. All this circumstances can be created using logic rules in Witness 2001. A logic rule has been declared to the system so that the process of construction will follow the sequences of NRS percentage. One example of that rules are:

```
IF NOPS (Footing) < VARIABLES.No_of_house_per_row * 12 -
(VARIABLES.No_of_house_per_row - 1) * 6 AND NOPS (group1.row1.G_Rebar_Grout)
>= VARIABLES.No_of_house_per_row * 6 AND VARIABLES.no_crane >= 0
    PULL from COMPONENTS.Footing out of TRANSPORTATION.sto_footing
ELSE
    Wait
ENDIF
```

The rules simply explained that, if the number of rebar and grout activities for the first row is finished, this activity can start pulling components of footing from site storage. This means the operation of second row will start process at the moment that the first row was just finish the rebar and grout activity. So it will continue for the third row to wait for a sign from the second row to finish rebar and grout activity seems like the first one.

5.2.3 300 Houses Model

Afterwards by duplicating 15 houses model, another model of 30, 60, 120, 180, 240 and 300 houses as illustrated in Figure 5.13, were developed to make a detail analysis and to get specific results. The main point to be considered in duplicating the model was the connectivity of each row of houses must clearly define. In that case, NRS percentage has been applied to make a connection between rows so that all 20 rows of houses can be finished. This means, there are five models of 300 IBS houses where each of them take one of different NRS percentages. From there, further analysis has been done to study on achievable completion time and resources optimization analysis. Another factor was on the number of resources especially Crane. In the simulation analysis, there was a crane limitation to be allocated in other to see the impact of that restraint to the final completion time. Therefore some rules are applied as to make sure the number of crane is decreased when each row of houses start to construct and increased back when it finish. The rules are:

<u>ACTION ON START</u>

```
IF NOPS (Footing) < 1
    VARIABLES.no_crane = VARIABLES.no_crane - 1
ENDIF
```

ACTION ON FINISH

IF NOPS (Ext_Wall_Fence) = VARIABLES.No_of_house_per_row * 20 –
(VARIABLES.No_of_house_per_row - 1) * 5
    VARIABLES.no_crane = VARIABLES.no_crane + 1
ENDIF

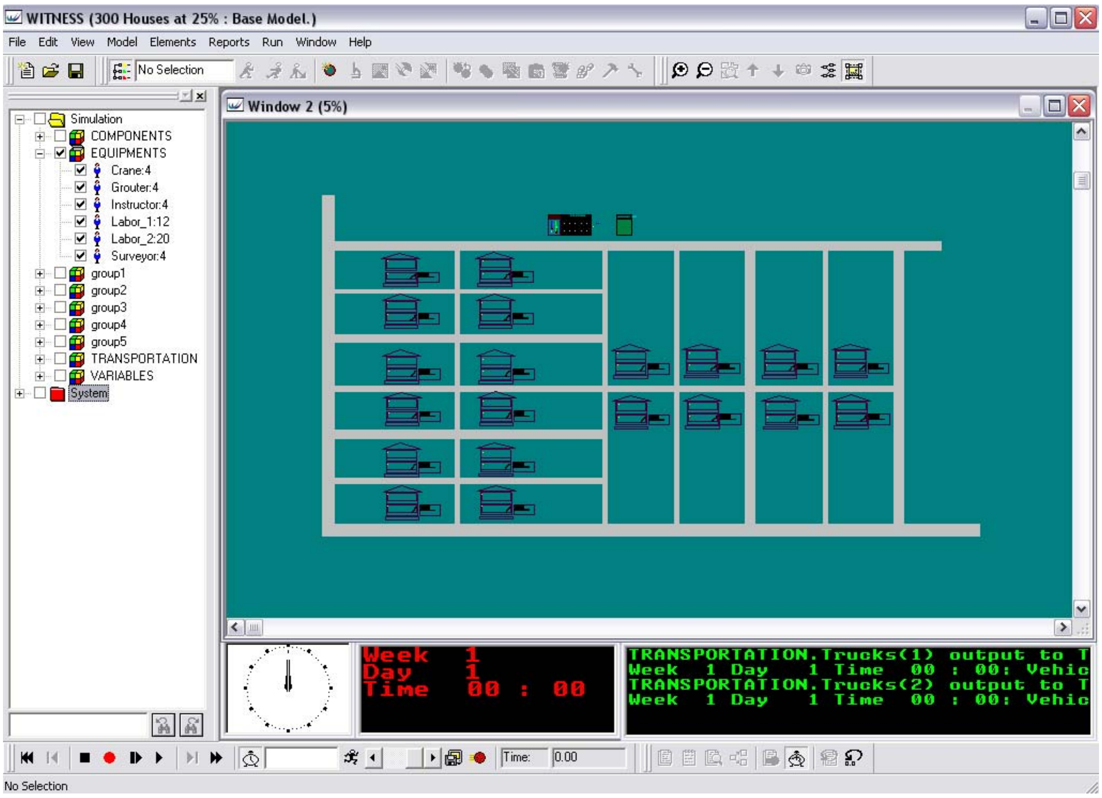


Figure 5.13: A Model of 300 IBS Houses

5.3 Simulation Analysis

Simulation analysis is the most important part in the study whereby it incorporates both findings for second and third objectives. Starting with simulation model of one IBS house as explained before, all data and results were testified to suit the real time of construction. Generally in simulation modelling, the complete model will be verified with real data on site to make sure the model is applicable in order to represent the real system. In this case of study, there were no existing real data to compare for validating process, thus according to Lanner Group (2000), a model can also be validated by verifying the result with experts in that background. Therefore the first model of one IBS house has been reviewed by experts followed by further 15, 30, 60, 120, 180, 240 and finally 300 IBS houses model.

As far as simulation analysis is concerned, there were three types of analysis have been examined: achievable completion time without resources constraint, achievable completion time with resources constraint and analysis of resources optimization. It was related to the second and third objectives to examine the most achievable completion time for IBS housing construction and determine the optimum resource utilization such as tools, machineries and labours in IBS construction by using simulation software.

5.3.1 Achievable Completion Time

The minimum time duration to complete 300 IBS houses has been testified by using Witness 2001 simulation software. By considering the differences in NRS percentage for IBS housing construction, brief comparison and analysis have been done. There were at least five Next Row Start Up (NRS) percentage has been considered in this analysis: 12.5%, 25%, 50%, 75% and 100%. In order to find the most achievable completion time, this first analysis was done without considering resources constraint. The purpose is to simplify the analysis so that the relation between completion time and NRS percentage applied can be clearly examined. Moreover the analysis was done step by step, starting with 30 houses, 60 houses, 120 houses, 180 houses, 240 houses and finally the whole 300 houses to make the analysis more systematic.

A model of 300 IBS houses applying 12.5% of NRS was first been examined. As mentioned before, the real analysis actually has been done step by step. Table5.2 shows a complete result for all analysis for achievable completion time without resources constraint. The result is presented in a week’s unit where one week is equal to 2520 minutes as elaborated evidently in Chapter 4. In general, the overall running time for 12.5% NRS of 30 IBS houses is 9.68 weeks, 60 IBS houses is 11.45 weeks, 120 IBS houses is 15.01 weeks, 180 IBS houses is 18.58 weeks, 240 IBS houses is 22.15 weeks and 300 IBS houses is 25.70 weeks. Afterwards, the analysis goes to the next NRS percentage and the result is presented in Table 5.2. 100% NRS has been set as a default value for NRS and it became a guideline for the results in order to do a comparison. For that reason, a different percentage of each result has been compared to 100% NRS result for the purpose to observe the effectiveness of using different NRS percentages.

Table 5.2: Achievable Completion Time for 300 IBS Housing.

Percentage for the next row to start up	No. of houses completed						
	0	**30**	**60**	**120**	**180**	**240**	**300**
12.5%	0.00	9.68	11.45	15.01	18.58	22.15	25.70
(Time Decreased Percentage)	***0.0%***	***44.3%***	***67.4%***	***78.6%***	***82.4%***	***84.2%***	***85.4%***
25%	0.00	10.62	14.27	21.56	28.87	36.19	43.49
(Time Decreased Percentage)	***0.0%***	***39.6%***	***53.4%***	***79.3%***	***72.6%***	***74.3%***	***75.3%***
50%	0.00	13.11	21.75	39.05	56.35	73.67	90.98
(Time Decreased Percentage)	***0.0%***	***25.4%***	***38.1%***	***44.4%***	***46.6%***	***47.6%***	***48.2%***
75%	0.00	15.54	29.07	56.12	83.16	112.27	141.37
(Time Decreased Percentage)	***0.0%***	***11.5%***	***17.2%***	***20.1%***	***21.1%***	***20.2%***	***19.6%***
100%	0.00	17.57	35.12	70.27	105.42	140.61	175.79
(as benchmark)							

**(in weeks)*

Further study has been done by plotting the results into a line graph. Figure 5.14 shows the performance for each NRS to achieve the best completion time. According to the graph, 12.5% NRS is the fastest approach to complete 300 IBS houses where it takes only 25.70 weeks compare to 25% NRS (43.49 weeks), 50% NRS (90.98 weeks), 75% NRS (141.37 weeks) and 100% NRS (175.79 weeks). The graph also shows the more number of houses applied, the more gap of completion time between each NRS will be resulted. However the different between 12.5% and 25% of NRS has not too far affected. This is probably because of resources utilization factor. Although smaller NRS is applied, if there is a constraint of resources, it might disturb the performance of that particular NRS. For that reason, further analysis has been done in order to implement resources constraint in the system.

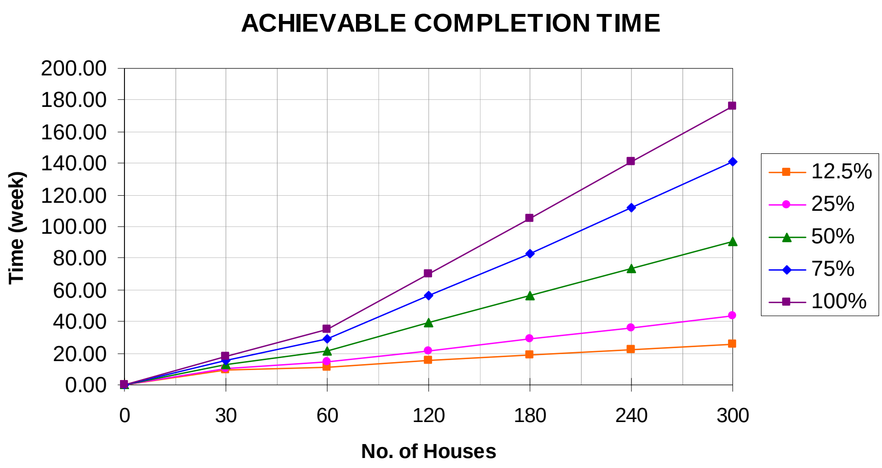


Figure 5.14: Achievable Completion Time for 300 IBS Housing.

5.3.2 Achievable Completion Time (Resource Factor)

In this topic, the resources factor has been applied to the system and the result has been examined. Using the term of 'resources group' as discussed before, the analysis was set the model to have an increment of resources group beginning from one group to ten groups as shown in Table 5.3. The percentage of NRS should be the same. According to the results, a graph as shown in Figure 5.15 has been plotted.

Table 5.3: The Effect of Number of Resources Group on Completion Time

Percentage for the next row to start up	No. of Resources Group (1 GROUP = 1 CRANE, 1 INSTRUCTOR, 1 GROUTER, 1 SURVEYOR, 3 LABOUR1, 5 LABOUR2)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
12.5%	175.79	88.77	62.42	46.63	38.74	34.47	30.83	29.06	27.27	25.70
25%	175.79	89.74	63.34	49.45	43.49	43.49	43.49	43.49	43.49	43.49
50%	175.79	92.23	90.98	90.98	90.98	90.98	90.98	90.98	90.98	90.98
75%	175.79	141.37	141.37	141.37	141.37	141.37	141.37	141.37	141.37	141.37
100%	175.79	175.79	175.79	175.79	175.79	175.79	175.79	175.79	175.79	175.79

**(in weeks)*

Referring to the graph result, the increment of resources group to 100% NRS has result no changes. This is actually because of there is no need on another group of resources as it can be proceed just using one resources group. 75% NRS shows a little bit change on two groups of resources but still constant for the next increment. 50% NRS is also at the same performance. However, 25% NRS shows better result for the first five increment of resources group. There is a dramatic change if five groups of resources are assigned for 25% NRS compare to one group. On the other hand, 12.5% shows a good performance as well as the number of groups is increased. Nevertheless, it is just a little bit better if compare to 25% NRS. It is happens because of resources constraint factor that affected the performance of 12.5% NRS so that the result will be approximately the same. It is believed that the result of 12.5% NRS will becomes more extreme when the group of resources assigned to that system is more than ten.

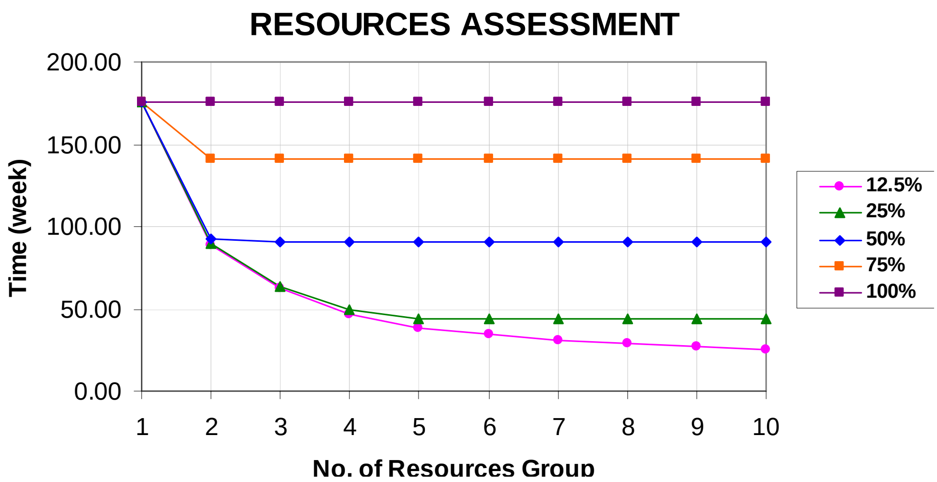


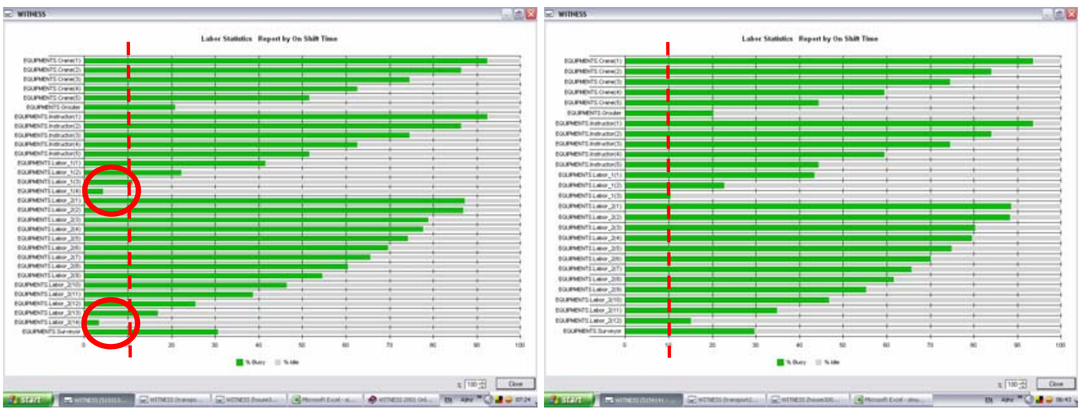
Figure 5.15: The Effect of Number of Resources Utilization on Completion Time

So in this case of study, the 25% NRS has been decided to be the best alternative to be selected in order to construct 300 IBS houses. As far as the most achievable completion time is concerned for the second objective, it can be concluded that the most achievable completion time to complete a construction of 300 IBS houses is 43.49 weeks with the utilization of five resources groups.

5.3.3 Resources Optimization

Resources optimization will be the third findings in this study. From the previous analysis, further analysis is to optimize the number of resources during installation process. After analyze the effect of resources group number, 25% NRS was then tested in various combination number of resources but in fix number of crane together with instructor, in order to optimize the number of each resource.

Witness 2001 offered excellent analysis tools whereby it can describe the contribution of each element (including resources) after running simulation. Figure 5.16 shows how report was produced during simulation analysis. Therefore every trial, simulation report has been examined and reconsidered the number of resources. For this point of study, the minimum percentage for each resource utilized must be above 10%. This is to make sure all resources are worked in fair productivity rate. Table 5.4 simply explains the result on five trials has been made. The final trial has been considered to be the best optimized resources number: five cranes, five instructors, one surveyor, one grouter, three labours1 and twelve labours2, where the contribution of all resources are above 10% and simultaneously the increased time is not too long, almost in two weeks (2.03 weeks).



(a) Before Reconsideration ***(b) After Reconsideration***

Figure 5.16: Optimizing Resources Using Witness 2001 Simulation Report

Table 5.4: Optimizing the Number of Resources

No. of Crane	No. of Trial				
	1	2	3	4	5
No. of crane	5	5	5	5	5
No. of instructor	5	5	5	5	5
No. of surveyor	5	2	2	1	1
No. of grouter	5	2	2	1	1
No. of labour1	12	6	4	3	3
No. of labour2	15	15	14	13	12
Completion time *(in weeks)*	43.49	43.49	44.10	45.12	45.52
(Increased Percentage)	***0.0%***	***0.0%***	***1.4%***	***3.8%***	***4.7%***

5.3.4 Detail Resources Assessment

Last but not least, the selected number of resources that has been optimized was detailed out according to appropriate construction period. In this case, the required number of resources: crane, grouter, instructor, labour1, labour2 and surveyor, per week were recognized as illustrated in Figure 5.17. This result can be used to further optimize the number of resources utilized during construction period by applying shift and overtime.

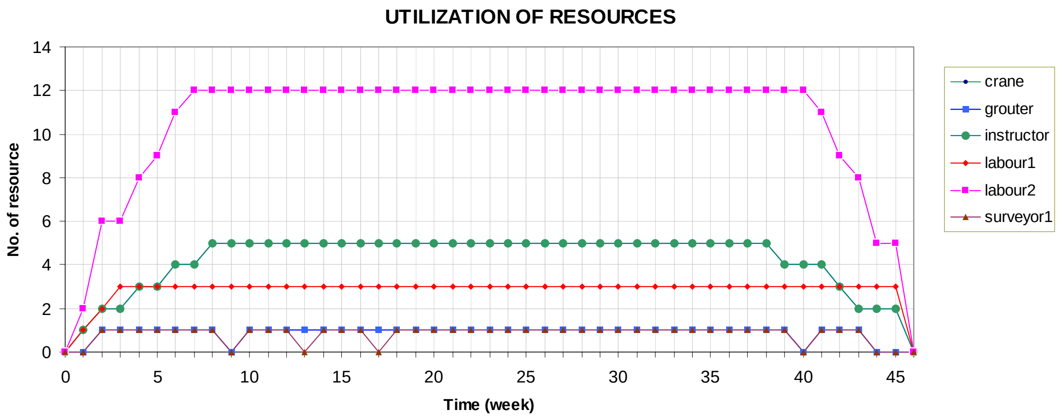


Figure 5.17: Summarize of Resources Utilization per Week

5.4 Summary

Witness 2001 simulation software is a good tool in replicating virtual IBS housing construction as a simulation model. A lot of logic rules applied to the model elements thus it becomes more accurate in order to represent as a real system and yet an analysis can be done through simulation model perfectly. From the discussion in this chapter, two objectives of this study have been clearly defined. The most achievable time and the optimum resource utilization are the most important findings in order to propose new method in constructing double storey house. In general, the factor of ‘Next Row Start Up’ percentage is really affected the completion time of IBS installation for 300 houses. The smaller NRS percentage, the faster completion time will be resulted. However, it is also depend on the crane factor. The smaller NRS percentage, the more number of cranes is needed. The best choice is to optimize the number of overall resources whilst at the same time achieves the fastest completion time that be able to accomplish as what has been done in this simulation analysis.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.0 Introduction

As far as the purpose of this study was concerned, the aim of this study is to determine the process flow of housing construction that applied Industrialized Building System (IBS) components for its main structure whilst the objectives are to identify the detail sequence activities of housing construction using IBS construction method, to examine the most achievable completion time for IBS housing construction by using simulation software and to determine the optimum resource utilization such as tools, machineries and labours in IBS construction by using simulation software. Research methodology as described in chapter 3 has been completely pursued whereby the most challenge part was in simulation modelling application. Simulation for the first place is for the purpose of designing a trial model on non-existing situation. Thus it should be no mistake as far as complex process implemented and a lot of parties involved. For this final chapter, all findings has been reviewed and summarized in proper manner so that relation between results and the aim are clearly observed. Last but not least, as far as time limitation is concern, there are some recommendations for further improvement for this study, at the end of this chapter.

6.1 Findings Review

As mentioned above, there are three objectives to be completed in order to achieve the main goal. Consequently, there are three findings have been accomplished during the research progress as presented in the next sub-topic.

6.1.1 First Finding

The first objective is to identify the detail sequence activities of housing construction using IBS construction method. A comprehensive literature review has provided some figure of IBS construction method for housing. Sequence of housing construction using conventional method is the key point to have an overview of construction process at site. The implementation of steel and precast component in large building is something useful information can be interrelated to the IBS implementation. From there, how IBS components are install during construction has been figure out.

In Chapter 4, the complete sequence process of IBS housing construction has been successfully identified. It is straight forward installation whereby it begins from footings, ground beams, ground slabs, a component of toilet, ground floor columns and walls, first floor beams, a component of stair, first floor slabs, toilets, columns and walls. Then it goes to the roof beams, roof elements and finally the external components such as fence, corridor, etc. With that result, site survey and interview the experts has been carried out to find the time and resources used for each activities listed. A frequent study on the sequence activities, time taken and the resources utilized has been made until the perfect finding on the detail sequence activities of housing construction using IBS construction method has been achieved as presented in Table 4.3.

6.1.2 Second Finding

Second objective is to examine the most achievable completion time for IBS housing construction by using simulation software. To obtain a variety results of completion time for the purpose to do a comparison, ‘Next Row Start Up’ (NRS) percentage has been declared. As explained in Chapter 5, NRS is used as guidance for the next row of houses to start constructing. It will follow step by step until finish all 20 rows of houses. In this study, at least five NRS percentage have been pursued: 12.5%, 25%, 50%, 75% and 100%. Simulation model for 300 IBS houses has been set to consider those NRS percentage and the final result will be the achievable completion time for each different NRS approach.

As a result, without considering crane limitation factor, 12.5% NRS shows the fastest completion time among others. By studying the graph results, it seems the lowest percentage of NRS, the fastest completion time achieved. For that reason, there is some limitation put on a number of crane utilized. Final result shows, 12.5% NRS is still the fastest but by referring to the graph, 25% NRS such be the best choice among others. The reason is because 12.5% NRS acquire a quite lot of resources. By restraining the number of crane, performance of 12.5% NRS has been disturbed. In term of construction progress, it looks like ineffective and not systematic. All the argument has clearly discussed in Chapter 5. Therefore, 25% NRS with 43.49 weeks of completion time will be the most achievable construction period for 300 IBS houses, concurrently it is the finding for second objective.

6.1.3 Third Finding

Third objective and it will be the final finding, is to determine the optimum resource utilization such as tools, machineries and labours in IBS construction by using simulation software. In this scope of study, there are at least six types of resources used in construction process which are Crane, Labour1, Labour2, Grouter, Surveyor and Instructor. By default, one group of resources should contain 1 crane, one instructor, one surveyor, one grouter, three labour1 and five labour2 as discussed previously in Chapter 5. As far as optimum resource utilization is concerned, by analyzing the 25% NRS approach, five cranes, five instructors, one surveyor, one grouter, three labours1 and twelve labours2 will be the optimum resources as it is able to finish the 300 IBS house construction in 45.52 weeks (within a year).

Basically, 300 IBS houses with 25% NRS can be finish in 43.49 weeks if maximum resources applied. But anyhow, by applying full number of resources, logically it seems uneconomic besides some of resources are not in full utilized. Witness 2001 as simulation software is able to detect the percentage of resources utilization in the system while it is running and from there the optimization analysis has been executed. There are at least five trials have been made in order to achieve the most optimum number of resources as presented in Chapter 5. Final trial has been decided to be approved as it gives at least all resources are utilised more than 10% during the construction process. Moreover, the increment of completion time after optimization, shows only 4.7% increased compare to the default result. Therefore, five cranes, five instructors, one surveyor, one grouter, three labours1 and twelve labours2, in order to construct 300 IBS houses in 25% NRS, will be the final finding.

6.2 Overall Conclusion of the Study

The use of IBS components in the construction of houses is proved as alternative ways to reduced construction time. Although this study focus on installation process of IBS components for double storey house, which is only apart of the whole construction cycle, but indirectly it is prove as an option to have faster construction period during construction part.

Nevertheless this study has been identified the activities and process involved during IBS construction with specific time and resources needed. In general, it is quite simple process of components installation using IBS method. From there, achievable completion time has been examined using simulation software whereby it is hardly related to the number of resources used especially crane. Again the reason is because IBS construction depends excessively on facilitation of crane for lifting and installing components. The more crane used, the faster completion time will be achieved.

Using simulation software Witness 2001, the construction of 300 IBS houses with a limitation of five cranes, 43.49 weeks (almost a year) of achievable completion time can be attained and it involved five groups of resources: five cranes, five instructors, five surveyors, five grouters, fifteen labours1 and twenty five labours2. Consequently after optimization of resources, five cranes, five instructors, one surveyor, one grouter, three labours1 and twelve labours2 will be able to finish the 300 IBS house construction in 45.52 weeks (still in a year) with 4.7% of increased time compare to previous result. Completing the main structure of 300 houses in a year is something great if compare to the previous construction results.

With that result, the aim of this study to determine the process of housing construction using Industrialized Building System (IBS) components in detail has been successfully accomplished. In view of the fact that a simulation model of 300 IBS houses is completely prepared and it may assist for the next researcher to do further analysis on IBS housing construction as recommended in the next topic. Yet it is hoped that the widespread understanding on the Industrialised Building System (IBS) can further help to develop and promote IBS as an innovative construction method in Malaysia.

6.3 Recommendations

Last but not least, due to the time constraint in preparing this research, there are still some spaces for further enhancement and perfection of the final findings. As a termination for this research, further improvement and development of this study is possible especially in the following areas:

(i) In this study, the installation of IBS components process for the main structure of double storey houses, there is only one method of sequence considered. It is better to have variety of choice or method in installing the components so that an analysis to obtain the most achievable time can be comparable to each other. So it is suggested to prepare another more method of sequences process for IBS houses.

(ii) For optimization purposes, by using a suitable decision making tools to identify the optimum resources utilization, the analysis will be more efficient. It is suggested to use other optimization software such as Microsoft Excel, Solver, Mathematical Programme, etc..

(iii) It is recommended to include an interruption of some activities such as lacking of workers, trucks breakdown, insufficient crane and other resources, etc. Also, by including some failure for any critical activities.

(iv) As far as result of this study are concerned, it is recommended to further analysis on detail of crane' scheduling and simulation, team of resources' scheduling and simulation and transportation analysis. In order to overcome the constraint of crane, it should be attempted to study on alternative ways to replace the crane with portable lifting machine or by reducing weight of IBS component using lightweight materials.

(v) Finally, the whole process of IBS construction can be further studied by involving more on preliminaries stage, procurement, tender stage, management, earthwork stage, and should be also clearly studied on the finishing works, mechanical and electrical (M&E) component installation, smart interfaces, external works, etc.

REFERENCES

Badir, Y.F., Kadir, M.R.A. and Hashim, A.H. (2002). *Industrialized Building Systems Construction in Malaysia.* Malaysia: Journal of Architectural Engineering, March 2002.

Bannet, J. and Grice, A. (1990). *Procurement Systems for Building, Quantity Surveying Techniques, New Directions*. United Kingdom: (ed P.S Brandon), BSD Professional Books, Oxford.

Chew, Y.L., and Michael (2001). *Construction Technology for Tall Building. 2nd Edition.* Singapore: Singapore University Press and World Scientific Publishing Co. Pte. Ltd.

CIDB (1998). *Report on Colloquium on Industrialised Construction System.* Malaysia: CIDB Malaysia.

CIDB (2000). *Malaysian Construction Industry Technology Foresight Report.* Malaysia: CIDB Malaysia.

CIDB (2000). *Modular Design Guide: 3rd Edition.* Malaysia: CIDB Malaysia.

CIDB (2005). *IBS Digest April – June 2005 Issue.* Malaysia: CIDB Malaysia.

Dulaimi, M. (1995). "*The challenge of innovation in construction*." Building Research and Information, 23(2), 106–109.

Esa, H. and Nuruddin, M.M. (1998). *Policy on Industrialised Building System – Report on Colloquim on Industrialised Construction System.* Kuala Lumpur.

IBS Digest. (Jan-Mar, 2005). Construction Industry Development Board, Malaysia.

Junid, S.M.S. (1986). *Industrialised Building System - Proceedings of a UNESCO/FEISEAP Regional Workshop.* Malaysia: UPM Serdang.

Kadir, M.A., Tap. M.M. and Ng, S.C. (2005). *Simulation of Industrialised Building System Components Production.* Malaysia : UTM Skudai.

Kadir, M.R.A., Lee, W.P., Jaafar, M.S. and Sapuan, S.M. (2006). *Construction performance comparison between conventional and industrialised building systems in Malaysia*. Structural Survey, Volume 24, Number 5 2006.

Lanner Group (2000). “Witness 2000”

Majzub (1977). *Modular Housing Systems Used Around the World.* International Journal of Housing Science, Vol. 1. Malaysia.

Ng, S.C. (2006). *Simulation of Industrialised Building System Components Production.* Malaysia : UTM Skudai.

Richard, R.B. (2005). *Industrialised Building System : Reproduction before automation and robotics.* Canada : Journal of Automation in Constuction.

Rollet, M. (1986). *Modular Coordination in the Building Industry - Proceedings Towards Industrialization in the Building Industry.* France: France Research Centre for Concrete Industries.

Tat, C.W., and Hao, H. (1999). *Precast Planning for Singapore.* Prefabrication Technology Center 4th Anniversary Seminar. Singapore.

Tay, E.M. (2006). *Industrialised Building System Formation Scheduling for Public Buildings.* Malaysia : UTM Skudai.

Trikha, D.N. (1999). *Industrialized Building System - Prospects in Malaysia. In Trikha et al., Proceedings of World Engineering Congress 1999: Industrialised Building Systems and Structural Engineering.* Malaysia: UPM Serdang.

Wang, B.T.H. (1987). *Construction and Development (With Reference to Malaysia).* Malaysia: Pelanduk Publications (M) Sdn. Bhd.

Warszawski, A. (1999). *Industrialized and Automated Building Systems*. London: E & FN Spon.