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# Comparative Study of Residential Roof Truss Construction Methods: Prefabrication and Built Onsite

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## ABSTRACT

*This paper reports a comparative study of two types of residential roof truss method (prefabrication method and built onsite method) in Malaysia. The first light and easy frame trusses were constructed on site using nailed plywood gusset plates. These trusses presented acceptable spans but demanded considerable time to build. In the 1950's the metal connector plate changed the truss industry by allowing efficient prefabrication of short and long span trusses. With the growing demand for affordable housing, increasing construction costs and sensitive concern for energy-efficiency, contractors and builders across Malaysia have recently begun to re-examine their options for the delivery of housing. Both prefabricated roof truss methods and onsite roof truss construction method are used currently. From these two methods, many macroeconomic factors and regulatory factors like speed of construction and use advanced technology have been cited as reasons for this; little attention has been paid to the nature of the residential construction industry, its operational structures and the ability of the product itself to accommodate the contractor's needs and preferences. From these two methods, the site observation, interview and questionnaire data are been analysed from the characteristic factors that involve in roof truss construction. All the parties that involve in construction industry like roof truss manufacturers, contractors and consultants are being interviewed and asked about the roof truss methods. Finally the result that been generated is show that the prefabricated method is the most popular method and give many advantages to Malaysian construction industry.*

**Keywords:** *comparative study, onsite, prefabrication, roof truss construction method*

## Introduction

The purpose of a roof truss is to support the roof which keeps the elements such as rain, snow and wind out and to support the loads from piping, water tank and ceiling. While performing these functions, they must also support the roofs and their own weight. There are two basic terminology used for trusses in residential construction which are pitched (triangular) truss and parallel chord (flat) truss. Pitched or flat, they are only limited to the load arrangements and the support locations. Flat trusses also known as parallel chord trusses that are an alternative to conventional floor joist systems and are a competitive option to open web joint systems. (www.truss-frame.com 2007) Parallel chord floor trusses may be designed with varying chord and web arrangements and bearing support details. Roof trusses come in all shapes, material and sizes to suit almost every single design of residential roof. This trend has resulted in a growing interest in prefabricated building system including roof truss methods. The

different roof truss methods will be considered in this study to know where the suitable method and give benefit to Malaysian Construction Industry. The advantages and disadvantages will be studied in order to propose the better solution for the benefit of the clients and the contractors.

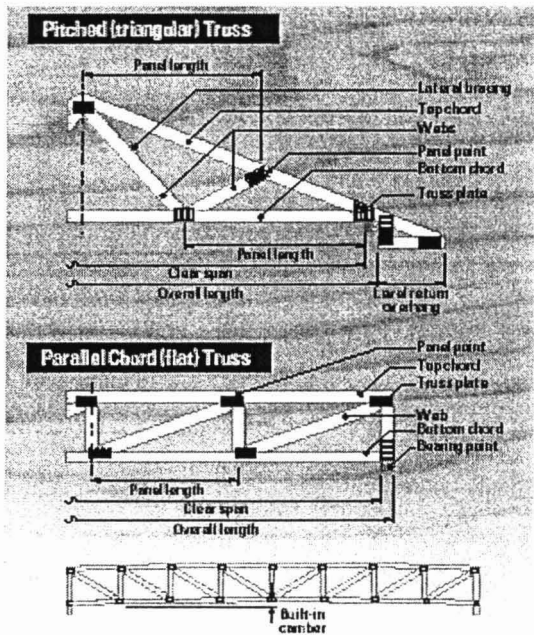


Figure 1: Some Basic Terminology used for Roof Trusses (source: [www.truss-frame.com](http://www.truss-frame.com) 2007)

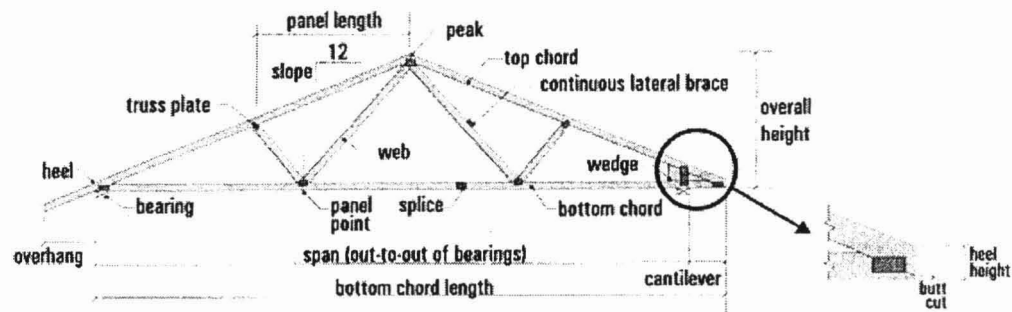


Figure 2: Parts of a Roof Truss (source: [www.arttruss.com](http://www.arttruss.com) 2007)

The goal of this study was to determine if any one method have the potential to lead and provide better productivity and give benefit in the Malaysian construction activity. The practical phase of the study was accomplished by interviewing local and regional contractors and manufacturers about their actual methods of construction used for resi-

dential construction work. These both methods were then analyzed to determine the contribution of the systems to the contractor's productivity.

Not surprisingly, contractors choose one specific type of construction to build a majority of their projects. They use either prefabrication or onsite roof truss system because they are comfortable with them and confident in them, they know they work and they believe that they are an efficient means of producing a residential house. The actual building methods used by contractors/builders are somewhat determined by several factors including project type, company size and structure and area of the country.

This is no surprise, due to the many advantages of using prefabrication truss method. This engineering approach eliminates guesswork, provides a more uniform roof appearance and speeds the construction process. Using prefabricated roof truss method will cut down on time and labour costs on the job site (Avi Friedman et al. 1997). Houses and buildings can be enclosed more quickly and thus avoid weather related problems. There is thus a need to study and determine the advantages and disadvantages nor using the prefabrication or onsite construction methods. Otherwise to know how this both method can give more economic to our economy status.

## **Objective and Scope**

The objective of this paper is to study and compare the different roof trusses used in Malaysia and to determine the most suitable methods in the residential housing construction in the Malaysian construction industry. An analysis on the different truss method covering aspect like quality, cost, environment, time taken and high buildability score shall be carried out. From the study we can also determine all the advantages and disadvantages of these both methods and approach. Better in time, better in construction and make the profit.

Based on scopes of study, the questionnaires are being made to get all information about prefabricated roof trusses method with onsite roof trusses method. The questionnaire will be passing for all parties that involve in construction and also involve in roof trusses (manufacturers, consultants and contractors). Besides that, these studies have to make some interview and site observation with the trusses manufacturing and contractor.

## **Literature Review**

### **Prefabrication Roof Trusses**

The assembly of units, panels or components under factory-controlled conditions yields a higher quality product which generally results in more energy-efficient homes. Due to the quick and efficient assembly which takes place onsite, the effect of poor weather conditions, is reduced as is the potential for damage due to inadequate material storage and vandalism. Clean-up time and material costs are also reduced due to less wastage, construction management and trade coordination can be simplified and the need for large teams of skilled onsite labor for multiple-unit construction is substantially lowered. The depressed economic climate in recent years has given contractors an incentive to look into new markets and explore alternative construction methods. This trend has resulted in a growing interest in prefabricated roof trusses systems, particularly panelized construction.

### **Onsite Construction Roof Trusses Method**

This method is being used widely in Malaysia and all the work is constructing on the site. This method must have the quality and expertise in construction work. The carpenters/builders have the relationship with the contractor to get the quality and follow the dimension and accuracy to the building or houses. Built Onsite method can be classified also into two categories either by using timber or steel structure (S. Abdol Chini and Kavita Gupta 1996). All the construction way and process same like prefabrication but all the part of build will apply totally at site.

### **Construction Industry Development Board Malaysia (CIDB) Strategies**

The Malaysian construction industry is undergoing a transitional change from an industry employing conventional technologies to a more efficient, systematic and mechanized industry employing the latest computer programme and communication technologies. There is thus a need to improve productivity in the construction industry and will necessitate the use of new materials and new construction techniques that can also increase in mechanization and automation, offsite manufacturing of large components, improved management techniques, better selection and delivery of materials and a more efficient organization of operations on site and in short better constructability (CIDB 2005).

The CIDB on Industrialized Building Systems (IBS) aims development of the strategic plan to chart the IBS vision, mission and action plans in the country. The vision of the IBS strategic plan is to make sure the industrialized Building Systems shall create world class built environment. The missions of IBS are to promote sustainable construction, to penetrate the global market, to employ K-driven technology, to enhance construction standards and quality and also to develop human-friendly built environment (CIDB 2005).

Important Industrialized Building System (IBS) issues shall include:

- i. Move towards zero defects in construction
- ii. Promotion of modularization and standardization in the industry
- iii. Increase in Research and Development (R&D) and enhancement of best practice guidelines
- iv. Integration of roles in the industry
- v. Development of a vision for the construction industry in the new millennium that is technology-led and supported by a highly skilled, well-rewarded and confident workforce. (CIDB 2005)

Finally, the residential roof trusses construction method also the part of the construction activity in Malaysia and must be consider by following CIDB strategies especially for IBS.

### **Methodology**

A survey of prefabrication method by questionnaire is conducted to examine the characteristics of the products and to determine their weaknesses in acquiring the result acceptance by the average. Several factors pertaining to quality and cost estimates are analysed and compared to onsite construction method. The target groups were split



into three categories to respond to the questionnaire is manufacturer, contractor and consultancy. There have 4 section in the questionnaire are section one for respondent's information, section two for roof trusses information, section three for comparison between this two methods and in section four is for comments and recommendation of roof truss method. In a section two is all questions in open close question method and in the section three just ticks/ picks according to ranking that provided.

A number of 20 companies in Malaysia are selected to provide basic information on their products and services. The methods' quality is examined in technical and practical terms, including craftsmanship, technical performance, durability, flexibility and ease of assembly. Then, interviews also are carried out with the manufacturers to determine economic, marketing and practical implications associated with using their product. Cost estimate are also obtained for a specific design. These estimates and analysis are then compared to others using onsite roof truss method. After that, the contractor and the consultant are being also passed the questionnaire for get the detail information of the prefabrication method and onsite method. Then questionnaires are being collected and make analysis for all data. This was accomplished using both contractor input and direct observation of these construction systems.

#### *Questionnaire for contractors and consultants/ architects*

In order to determine which methods of roof trusses construction method for residential houses use and prefer, the following list of questions were put together and presented. A majority of these contractors, consultants are located in the Klang Valley and most of the others are located in Kuala Lumpur and Selangor. These two states were selected based on their population and high rates growth of construction residential houses.

By interviewing these contractors and consultants, a large amount of practical knowledge and real-life data was obtained that cannot be found in any published form. Contractors and consultants were interviewed in two different ways; some of the contractor and consultant were interviewed orally. However, some of these interviews occurred face to face, while others took place over the phone. The second method was for the contractor and consultant to complete the questionnaire on their own idea and then return it to ours. Each question was designed to extract specific information from each contractor/ consultant and company.

#### *Questionnaire for manufacturers*

Manufacturers also were collected data by using the two different methods. The first method was for the manufacturer to complete the questionnaire. The second method was by interviewed the manufacturer and make the site observation. These interviews occurred face to face and by phone. Manufacturer that involve in prefabrication roof trusses method either using steel or timber structure. The entire question was designed to get the detail information about the prefabrication method and to know about process that involved in production of roof truss.

#### *Observation of the Methods*

After each method of roof trusses construction had been identified by the contractors and consultants, there was a period of observation. This observation was made during a visit to a project where the construction methods defined by the contractor were being used. During this onsite visit, the method of construction was closely observed and

documented with notes and photographs. This onsite observation was only conducted for construction project in the Klang Valley area. The method was evaluated based on the speed of production, the ease of construction, the productivity and the efficient. Besides that, the method was evaluated and determined the advantages and disadvantages to the Malaysian aspect.

## Results and Discussion

The results and data from the questionnaire are shown in Table 1 below.

Table 1: Analysis of comparison between prefabrication and built onsite roof truss method mean value

No	Characteristic	Prefab.	On-site
1	Durability	4.61	1.97
2	Strength	4.5	2.01
3	Weight	4.4	1.88
4	Equipment wastage	4.6	1.9
5	Material wastage	4.59	1.93
6	Environmental friendliness	4.61	1.96
7	High buildability expert	4.66	3.71
8	High buildability unskilled	3.89	3.8
9	High buildability sitelabor	4.53	3.69
10	High buildability quality control	4.41	3.56
11	Design strength	4.27	3.66
12	Design tools	4.29	3.73
13	Cost easy	4.64	3.23
14	Cost crantage	4.17	3.29
15	Cost foundation	4.63	1.64
16	Cost easy construct	4.57	1.44
17	Cost labour	4.09	1.5
18	Cost material	4.5	1.46
19	Non combustible	4.5	1.99
20	Dimensional stability	4.2	2.17
21	Speed construction	4.6	2.36
22	Truss safety	4.58	2.23
23	Truss advanced technology	4.58	1.94
24	Truss better appearance	4.6	1.78
25	Truss clean	4.6	1.83

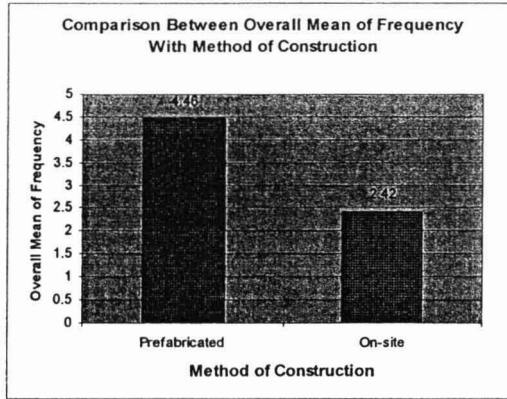


Figure 3: Graph of the comparison between overall mean of frequency versus method of construction

From the questionnaire that has been collected, the result and data were analysed by using a mathematical program or software. The frequencies are showing the total of the respondent that answers the question in five categories either very poor, poor, average, good and very good. The percent and valid percent touch about the percentage of the respondent that select or answer question in order and not in order.

All the data in table result are interpret and display into the graph to show the prefabrication system and built onsite system frequencies. For the prefabrication method the graph show the high frequency are localized at the 4.5 to 5.0 values. The mean and standard deviation for prefabrication roof truss system are 4.4651 and 0.66715 respectively. While the built on-site frequency graph show the high values for frequency are located at the average part about 3.0 value. The mean and standard deviation for built on-site are 2.4272 and 0.81201 respectively. In cost characteristic result, the prefabrication method gets high mean value because the method can easy to handle, can deduct high labor cost and material cost. But in prefabrication method, there have only to consider is transportation and crane cost for installation. The client may save additional money by spending less on labor costs with a speedy completion.

From the result in the high buildability score, the prefabrication method achieve total 17.49 compare to the onsite method just 14.76. This means that the prefabrication not uses too many expert, skilled labor and site labor for installation of roof truss but only use unskilled labor for installation. So that, this also can increases in quality of roof truss in the site and offer more design flexibility. Besides that with the mean 4.6 for truss clean, this show that the prefabrication method is strongly agree can reduce cost for waste cleaning and state that this method is environmentally friendly. Prefabricated roof truss methods have replaced conventional or onsite construction roof trusses methods for 55% of residential construction.

Finally, from the analysis result we can know that the highest mean and lowest standard deviation are showing the better solution or better method and popular method in Malaysia. These result come from the respondent either contractors or consultant answering the question. So that the prefabrication method with the highest means value and the lowest standard deviation are suitable and effective method that can achieve the CIDB target and vision. This because the respondent selects all factors



in the questionnaire determines and select the prefabrication method is the best solution in the quality issue, time of construction, cost and also other beneficial factors.

## **Site Observation Results**

### *Prefabrication*

One very basic reason is quite straightforward, it is logical to expect manufactured roof trusses method or prefabrication method to enjoy some inherent cost savings over built onsite due to fundamental differences in the production process. The prefabrication can deducts some of the cost because the size of prefabrication member normally smaller than consultant conventional designs especially when detailing at joint (top and bottom chord smaller and also with using suitable and better connection between member). Then, the prefabrication method built in low cost areas where prevailing wage rates are lower can achieve a competitive advantage by selling finished products into markets where the wage rates for similar work performed onsite would be much higher. These savings are attractive to the extent they outweigh the costs of transportation and installation that are unique to prefabrication. In addition, capital investment for plant and specialized equipment used in assembly-line operations shifts the mix of labor and capital inputs and raises labor productivity.

Besides that, this method can reduce cost by reducing the workers and carpenter, control the workmanship with no double works (reduce man-hours and increases productivity) and using less skilled workers. The system can reduce cost because by reducing labor hours and by using less skilled workers. Unskilled, less expensive labor can be used more effectively when production takes place on an assembly line and can be organized into simple, repetitive operations. Of course, to some degree a smaller labor share will be offset by higher costs of capital for any firm with investment in fixed production facilities, but the successes of industrialization throughout the economy is powerful evidence of the opportunities to reduce production cost by substituting capital for labor. The factory setting offers other advantages that can help control cost. It minimizes delays due to poor weather, exposure to theft and vandalism, and damage to building products and materials stored for use in construction.

Easy to control by shop drawing and this methods have guarantee and warranty. Easier to supervise in site and did not always been checked and supervise easy to manage at site. Time reduce saves cost. If there have complex shape design trusses method and can take long time to construct it in site so this method can be alternative to save time. Besides that it can maximize or optimize use of machinery on ground or lifting. With less wastage as standard sizes and requirement specified in advance. Production of new homes with prefabrication in a factory differs in many important ways from construction onsite and general opportunities for efficiency exist in this centralized, controlled environment compared to construction on scattered sites. Workers in the plant are generally employees of the firm, not subcontractors and as such can be scheduled, managed, trained and deployed by a single authority in the interests of productivity and efficiency. Consistent quality and performance as inspection done on ground so it always in that point and view.

The disadvantage come from prefabrication method is the transportation cost must be considered and crane cost. If have something mistaken in dimension and length because error in construction so difficult to adjust and modify it. Besides that in deliv-

ery schedules subject to ransom if money not paid in advance. The method provides a consistent and uniform product quality and it depends on quantity and design.

### *Built Onsite*

The carpenter use onsite structure dimension to make sure the trusses is fixed perfectly and can make slow work but it's fixed nicely. One roof trusses needed about one week depend on the how it designs. The built onsite trusses method not difficult to construct at site, it saves double handling if it is prefabricated. The method will suit actual site conditions that tailor made to suit some irregularities or inaccurate work by others.

Prefabrication type may need crane handling that can make the extra or additional costs. Few skilled workers or small contractors or with few experienced also are able to built onsite. However for prefabrication, it takes an organization or company to produce prefabrication roof trusses method. Skilled workers are difficult to become contractors or their own bosses if prefabrication structures are to be provided because they will have to rely on other companies to provide prefabrication structures to them. If a lot of residential houses are built, there may be economy of scale to use prefab type to save time and possibly cost as well. The accuracy of work and its quality can be well checked and assured. But then it lacks flexibility to change like say the concrete beam/wall is not too straight or level to allow proper seating of roof trusses.

Whether it is to company/ manufacturer who produce prefab roof trusses or skilled workers doing it built onsite if the design is the same that means the work will be repetitive. To do some standard repetitive work will somehow be easier both at the factory for prefabrication work as well to the site workers who work as built onsite method. One the work become easier to do and is repetitive, the rate of work will be faster hence more productive in that sense.

Both methods will have their merits. It all depends on the number or the economy of scale. It for a few houses, it would be costly to ask for prefabrication roof trusses but if the quality is large the situation may be different. Built onsite method is not advisable because of the quality of the truss which is difficult to maintain due to workmanship.

## **Conclusion**

In this study, the results from the questionnaire that we obtained from the respondents (contractors, consultants, manufacturers) were analysed. It was found that the prefabrication method was a good solution in residential construction. Four cases studied from the contractors and manufacturers were compared and evaluated based on the overall advantages and disadvantages. This was accomplished by using the contractors' expertise, intuition and measured knowledge as well as some direct site observation and interview. From the bar chart or histogram that we obtained from the mathematical program analysis, the mean score for prefabrication method is 4.4651 and the mean score for built on-site method is 2.4272, indicating that the prefabrication method is a good and suitable method of construction.

The prefabrication method promotes better quality compared to the other method because specialists will prepare these trusses while ordinary workers will construct the trusses onsite. The prefabrication method results in better quality and save time while the quality of built onsite is dependant on the performance of the contractor and the

site workers. For prefabrication roof trusses, the quality control should be better as they are made within a controlled environment in a factory. The method results in more accuracy in dimension as per specification compared with the other method. The manufacturer was using better and sophisticated equipment and software to design this system. Manufacturing and prefabrication in home building, offer a range of potential benefits to those who choose to use them. Quality control and precision can be sustained at a higher level in prefabricated building components. This is because factory working conditions can be controlled and more advanced technology is available than at building sites.

Other benefits or advantages include a reduced number of material deliveries to the job site, resulting in less coordination conflicts among trades, better inter-trade communication and shorter overall construction period. While these time savings neglects to include fabrication time for the components, it is often the case that fabrication will occur during the same time period as site work, foundations and other initial preparations. The prefabrication has been seen as the answer to the low-income housing shortage issue. Not only do the prefabrication process offer quality control, precision, cost effectiveness and a more rapid installation but also these manufactured modules tend to lend themselves to placement on small. All of the various types of roof trusses shape use simple connection as the connect for every member because the designs use short spans and thus are structurally adequate and less expensive, easier to handle and more readily available than onsite trusses.

It can be concluded that the percentage difference in time of the roof truss completion between prefabrication and built onsite method is around 40 percent to 50 percent. This may be because the manufacturing industry strives to produce the highest quality product in the shortest amount of time. Because this method involved mass production, the methods used in the factory are the most efficient methods available for this type of construction. The use of automation and assembly line methods make an efficient process. Another obvious advantage the plant has over site construction is repetition and the ability to build components before they are needed.

However many builders avoid using the prefabrication method but instead rely on more onsite methods of construction. These onsite construction methods are numerous and are not restricted to only one type of material or construction method. We suspect that the contractors use these methods for various reasons including familiarity, comfort, availability of materials and cost savings. Considering the substantial difference in construction time between prefabrication method and built onsite method, it can be concluded that despite the higher cost, the prefabrication method is a more efficient means of construction roof trusses and the higher cost can be justified by the better quality and faster construction time.

The percentage difference in cost between the prefabrication and built onsite methods is around 15 percent to 25 percent. It can be concluded that the prefabricated method is more costly compared to built onsite. However, by using the prefabrication method, time will be shorter compared to built onsite method. Additionally, it is to establish the premise that contractors who use prefabrication, pre-assembly, modular materials and building methods will perform more productively than those contractors who do not. These ideas were pursued by first reviewing the history of home building to determine trends and patterns in innovation. Finally, the contractors who choose not to use onsite construction methods with regularity tend to have higher rates of productivity as well as the ability to take on more projects (Melissa Lynn Obiso 1997). Higher rates of

of productivity and the ability to take on more projects have the potential to give contractors a competitive advantage over their competition.

## Recommendations for Further Research

If this study or research were to be continued, several things should be done to standardize responses. In general, during the course of this study it became quite apparent that contractors are most often very conservative. This conservative nature is obvious both in construction materials and methods as well as the way that they run their business and manage projects. For example, very few contractors considered making changes to their means and methods of construction to control their productivity. Quite simply most builders are just unwilling to make the switch from conventional methods to the innovative building system that is currently available. So that makes some detail study on the productivity or quality of the both methods.

So the prefabrication offers a range of potential benefits to those who choose to use it including quality control, precision, controlled working conditions and available technology. Furthermore, contractors/ builders need to recognize the advantages factory production has over the built onsite process and respond to them. These benefits are automation tools and equipment such as jigs, repetition of the process and designated workspaces for each step. Contractors have the opportunity to set-up small production lines on most residential construction projects, yet few do so. The incorporation of a repetitive process and minor amounts of automation and jigs has the potential to make a significant impact on the built onsite process. There is a need to conduct a more detailed study on the overall cost benefit of using the prefabrication method.

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