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# Development and Efficiency of Prefabricated Building Components

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***Abstract***

*There are a number of reasons for the success of modular housing in developed countries, the first of which is the demand. Other factors are the benefits that come with factory manufacturing such as energy efficiency, speed of erection, and low cost. This is why many customers choose industrialized housing over conventional construction. This research aims to study and evaluate the prefabricated housing components in terms of efficiency, effectiveness and the time to spend during construction. It also attempts to search for the development and production of low cost housing, the end-users feedback and other institutions that used these materials and its impact in the market*

***Keywords**: Building, construction materials, modular house, prefabricated technology*

## 1. Introduction

During the World War 1 in Europe, there is an increase in the industrialization of buildings. Because of the destruction of many buildings, roads and other structures, and lack of new construction during the intra-war years, there was a demand for economical and simple buildings. Housing saw the greatest progress in prefabrication as architects began to more widely accept the use of standard parts, steel, and glass. One issue with many of the building systems developed during this time was that flexibility was not part of the overall design. These systems did not provide room for a creative response to an architectural problem.

At this point in history, prefabrication found a niche in a world that needed to deal with an increasing number of new technologies. For example, the Orly Airship Hangars outside of Paris were made of prefabricated concrete arches whose repetitive use and high volume of enclosure allowed for the storage of such massive units as blimps [1]. This period also saw the founding of the Bauhaus, a haven for the international style. This school was founded by Walter Gropius in 1919 and became a place where he spread and taught his beliefs concerning the need for new design to be based on mass production. Stark white walls, industrialized parts, and machined details became the hallmark of this style.

World War II was concluded with another housing crisis both in the United States and Europe. Though United States territories had not seen any action, there was a need for housing due to the number of returning soldiers who quickly started families [2]. A population explosion accompanied the end of the war. Once again, prefabrication was used to meet the demand for housing. Entire communities, such as the one in Levittown, New York shown in Figure 1 appeared with row after row of prefabricated, largely identical houses. Thus, the "mushroom farms" were born.

Modular house is the culmination of one of the type of building system. The building process starts with efficient modern factory assembly line techniques. The prefabricated components are brought to the site and erected using building block construction.

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Work is never delayed by pouring time or missing materials and can be completed 30 to 45 working days. Further study shows that it can also lower the total cost of the project by 12% as compare to the traditionally build house using traditional methods.

Now the technology is very popular now days, this is the right time for us to use new concepts and idea where the end-users will benefit, it’s up to owners how they developed, improved and used it.

The study aims to introduce and to provide more knowledge about prefabricated housing components, to educate the market and to address the concerns of every sector of the society for a beautiful, stable but affordable shelter.

## 2. Prefabricated Buildings

The first prefabricated home was built in the 1600’ in England and was shipped to Massachusetts [3]. The prefabricated home was not widely used until World War II when mobile homes were produced to supply housing to military personnel [3].

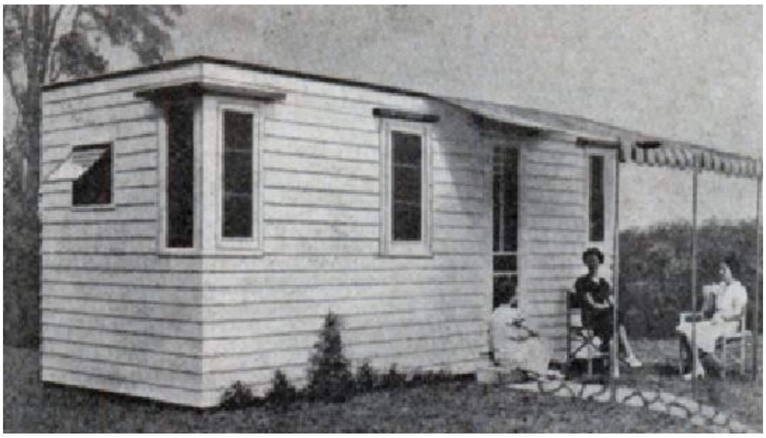

**Figure 1. Prefabricated Home (1937)**

In order to choose the best home a builder or owner must know the construction methods that are available. It is imperative for people to realize the differences between different types prefabricated homes and what is considered a modular home. In today’s construction of homes multiple techniques are often used to produce the desired results.

A stick built home is built on site by skilled labor [4]. The materials are shipped separately to the home site and nearly the entire home is built at the site. Local codes apply. Some of the assemblies to a site-built home may arrive to the site prefabricated such as roof and floor joists. Although a stick-built home is not considered prefabricated it is included in these definitions because it is the home used in all comparisons.

A prefabricated home consists of several factory built components that are assembled at the site to complete the unit [3]. Prefabricated homes include modular, panelized and precut homes.

Today, a modern modular home is made up of two or more three-dimensional “boxes” that are shipped complete to the site where they are connected together at the marriage walls shown in Figure 2 [2]. These modules are often built with cabinets, plumbing, electrical components, and almost every other component completed, installed, and finished within a factory setting [3]. They must comply with all local and state building codes [3]. Modular homes are shipped 90% complete [4].

 

A Panelized home is made from two dimensional factory-built panels with doors, windows, and wiring [3]. They are transported to the site stacked flat on a trailer and are assembled at the site. The local building codes where the building site is located prevails [4].

**Figure 2. Modular Home (2015)**

A pre-cut home is made from panels that do not include any additional materials such as doors, windows, and wiring. They are built in the factory and attached together at the site [3]. Pre-cut homes are factory-cut to precise measurements according to design specifications [4]. Pre-cut homes include, log, kit, and dome homes [4]. They must comply with all local building codes.

A manufactured home is a single family home that is built entirely in a factory setting and is built to meet HUD Code and not local building codes [4]. Manufactured homes were formerly known as mobile homes until 1976 when HUD code was introduced and they became known as manufactured homes [3]. Manufactured homes are 98% complete when they arrive to the site [1,5].

Modular homes are three dimensional units that are completed in a factory controlled setting. They are usually 85 to 95 percent complete when they leave the factory [5]. The vast majority of modular homes are built from wood framing but steel and stressed-panels can also be used [2]. The flexibility of design and size of a modular home are virtually endless. Modular homes can be built multiple stories with steep roofs, flat roofs, 8 foot ceilings 10 foot ceilings, fireplaces, and much more. There is one major limitation that must be considered; the maximum size of each module. The modules cannot exceed 76 feet in length, 12 feet in height, or 16 feet in width due to highway safety regulations [4]. These limitations can be overcome by designing multiple modules to work to be marriage together at the site to create any rooms that may exceed any of these dimensions.

### 2.1. System

The system demonstrates a form of low cost, prefabricated construction that efficiently deals with vapor and thermal issues without using the typical layered systems.

This is accomplished through the use of modular panels that will be built at low cost in a factory and used as infill/insulation. Doors and windows may be 14 mounted into the infill panels. These modular pieces are interchangeable, allowing for easy, low cost maintenance.

The developed project includes a catalog of interchangeable parts which can be assembled by a client into a building shown in Figure 3. These are design choices for different arrangements within certain parameters set by the basic structural elements. The structural system is able to stand alone without any material or component imports. However, most of the catalog components and materials are interchangeable with custom parts. The system may be used to create its own building or additions that may interface with other forms of construction.

**Figure 3. System of Prefabricated Construction**

The two systems from which this system is derived are also its greatest competitors. The system must show some advantages over traditional 2x (stick built) construction and standard Structural Insulated Panel (SIP) construction in order to be viable [6,7].

The panels that make up the enclosure walls are derived from the SIP concept shown in Figure 4. However there are two major differences between standard SIPs and the panels. First, all major panels in my system are sized at 4'x 8', which minimizes labor in the prefabrication process as plywood and polystyrene is distributed in this size initially.

Any off-size panels are simply cut in the factory and belong to a limited set of standard sizes. On-site cutting is unnecessary and waste should be almost nonexistent. The second difference is that wall panels are constructed of typical polystyrene boards and plaster board – window or door mountable wall panels have an exterior face of ¼" plywood providing stability. The simple enclosure wall panels possess insulation that is exposed in the ventilated cavity, allowing evaporation of any condensed water that may form at the dew point in the wall. The plaster may serve as interior finish, thereby eliminating further material and labor consumption.

The structure system is derived from a stick frame platform framing system. Essentially, beams have been replaced with trusses and floor joists have been replaced with the SIP floor panel. The greatest difference is that the structure is mostly separate from the enclosure wall and exists in its own ventilated cavity. This would increase the lifetime of the structure by protecting it from mold and rot

 

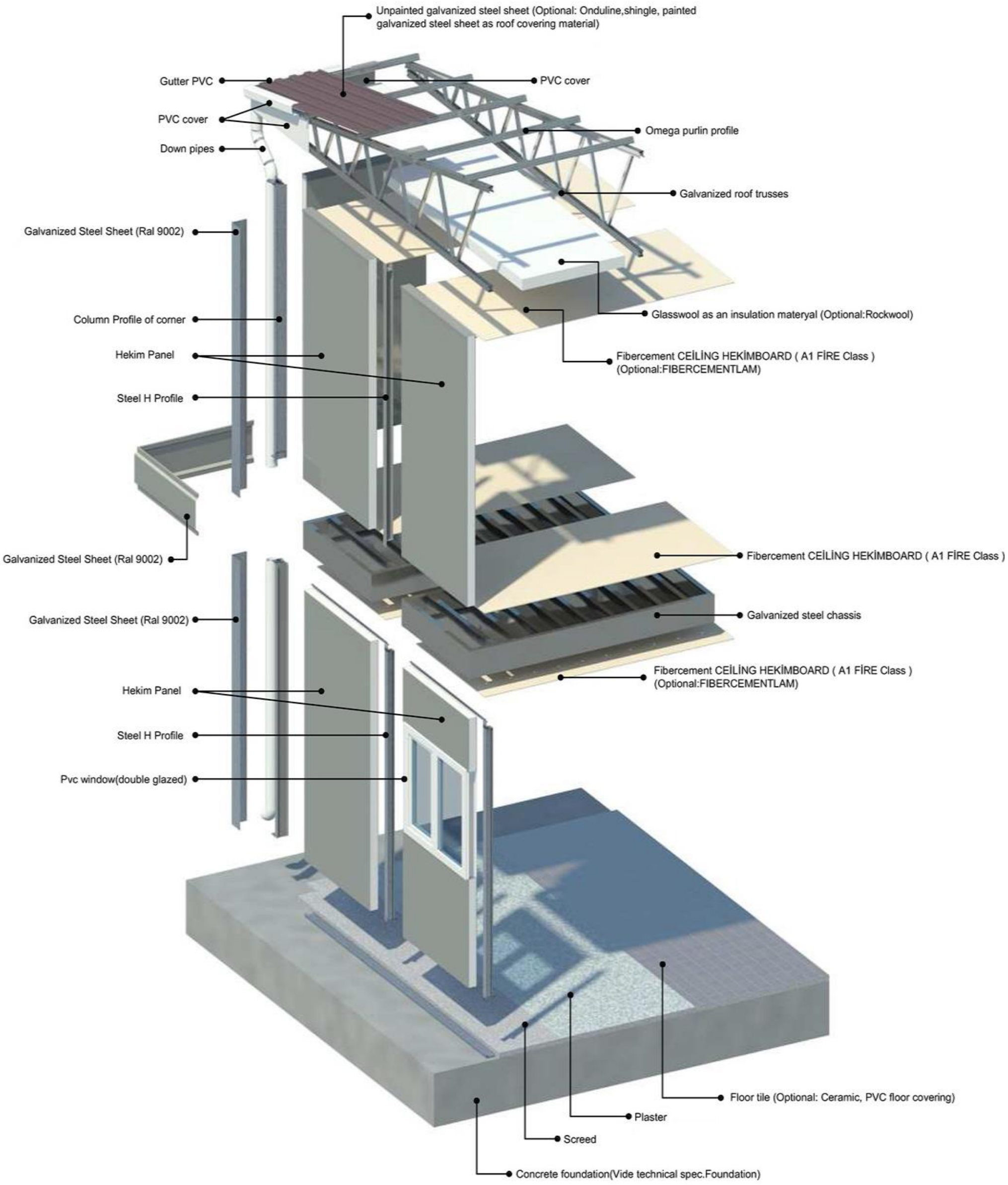


**Figure 4. Hekim Light Weight Steel Panel System**

## 3. Roofing

The roof is another part of the building which is associated with very bad working conditions. Besides the life threatening risk of falling down from the roof, the worker is directly exposed to precipitation and wind. These conditions slow down the production time and require extra temporary safety constructions that have to be removed once the work is finished. This is a severe waste of resources and will yield efficiency if eliminated. In the framework of the symphony concept the roof elements are finished at the factory with roof-covering and roof details dwells mounted. The element has a finished roof drainage construction which is ready to be connected to the building's roof water drainage system.

### 3.1. Roof Construction

It is not economical to design light weight low slope roof elements that span over the whole building between two outer-walls without load-bearing partition walls [8]. The large span can lead to complex and expensive solutions when excessive deflection of the roof is to be avoided. It is therefore important to have total control of the roof deflection and design of the internal partition walls with respect to these movements. With the Scandinavian snow loads the CBZ profiles will be able to span a maximum of approximately 5 meters depending on the design [8,9.10]. Hence, the Symphony roof elements are once again used as secondary construction elements which will transfer the loads to be primary construction. The design of the primary construction of the roof is dependent of the geometry and climatic conditions of the building in question. With the primary structure in place the roof elements will be mounted easily with cranes which significantly reduce for workers on the roof. The roof will not be completely finished when mounted but the working hours on the roof are substantially reduced. The building of the roof construction and is different layers is limited to the fastening of the roof elements while the finishing of the roof covering is limited to the covering of the joints between the elements. It is seen clearly that bigger elements will yield reduction of the on-site working hours.

### 3.2. Roof Water Drainage

The roof elements will be delivered with required inclination and the roof covering finished at the factory. Even the roof drains will be mounted on each roof element together with the piping needed to connect to the roof water drainage system. Each roof element that leaves the factory is thus a water tight unit with a functioning drainage system. The drainage system is designed to be easily connected to the finished drainage system but also to function during the construction time. The surface material of the roof covering is dependent on the roof inclination and thus also of the architecture of the building. High inclination with protruding eaves will require different materials than low inclination roofs with vertical roof edgings as part of the outer-walls

### 3.3. Installations

The costs of the installations mount to approximately 20% of the total production cost in the case of dwellings [9]. A reduction in this field will yield a large impact on the total cost of the building. The installations include all the piping for water and sewage, ducts for ventilation and the electrical cabling. The Swedish building codes require mechanical ventilation for all apartments [10,12]. This leads to a great deal of ventilation ducts and equipment that needs to go through the whole building. These equipments often require constructions for hanging and fastening and so on. The installations are often outsourced to several subcontractors, usually one for the electricity and one for the HVAC systems. The prices offered by the subcontractors are difficult to evaluate and include both material and working hours. The mutual agreements and discounts between the subcontractor and the detailer are all affecting the price. The prices of each post in the offer are not transparent. This absence of transparency makes it difficult for the client to evaluate the price in relation to the value, quality and efficiency of the contract [11]. Separating materials and working hours could yield large savings for the client. These Savings would in turn have a strong impact on the total production cost. It needs also to be mentioned that the cost per hour of the installation workers on site are higher than assemblers at a factory [12,13]. As shown in Figure 5, integrating parts of the installations into the prefabricated elements will not only save time but it will also mean that factory assemblers are doing the same job for a lower cost. Moreover it will open the possibility to buy the materials directly from the detailer and in that way benefit from the discounts.

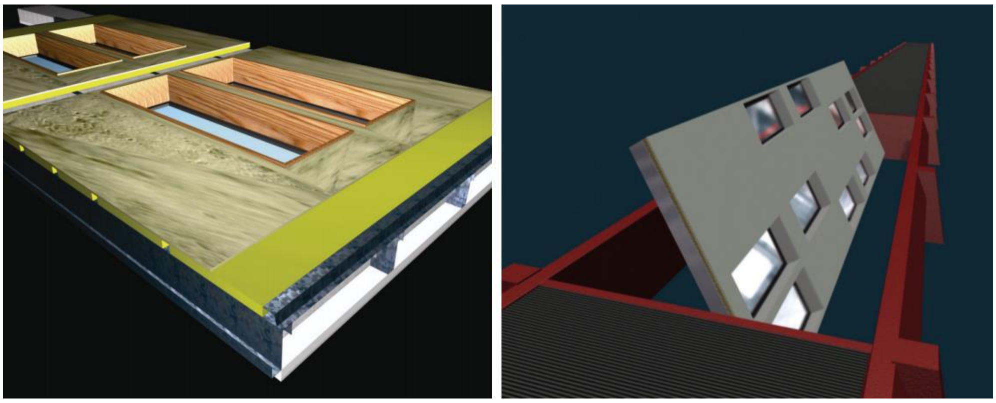

**Figure 5. Symphony Outer Walls called CasaBona System**

### 3.4. Exterior Finishing

The purpose of the symphony concept is to reduce the working hours needed at the building site by producing prefabricated elements with a high degree of prefabrication. The outer-wall elements are therefore delivered with finished exterior surfaces. Also the arising joints between the elements need to be covered in a time efficient way. Other details needed on the exterior of the building are the downpipes for the water drainage system. The work needed for the finishing of the exterior façade when the building is mounted require operating on high altitudes which takes more time and involve special equipment and temporary constructions. Reduction of this type of work will thus lead to larger savings than the actual reduced working hours. Even the joints are consequently designed as prefabricated elements to be mounted on site. The piping for the water drainage system is integrated into the joint elements which results in hidden downpipes and an undisturbed façade while the assembly time for the downpipes is almost eliminated.

### 3.5. Fire Safety

The fire protection of the building is divided into two parts, fire protection of the primary constructions and fire protection of the secondary constructions. The primary construction includes the steel framing and the hollow core concrete elements. These are the skeleton of the building and carry all the loads. It's important to protect these components from the fire during a longer period to prevent the building from crumbling. Now the concrete floor slabs and shear walls have a natural fire protection because of the material. The steel framing and the metallic joints need to be protected. This is done mostly by embedding the steel frame into the rest of the construction but has for the remaining parts to be met by using fire-resistant paint and protective sheeting. The steel frame is painted before delivery and does not need to be treated at the building site. The secondary constructions being the Symphony outer-wall and roof elements do not call for the same strict fire protection since they are not load-bearing. These elements are protected according to the Swedish building code during 30 min. The fire protection needs to prevent the spread of fire and the transmittance of high temperatures. This could be achieved with the combination of a double layer of dry sheets and mineral wool insulation shown in Figure 5.

Each layer of gypsum board corresponds to ca. 15 minutes. of fire protection according to the producers [10,14].

 

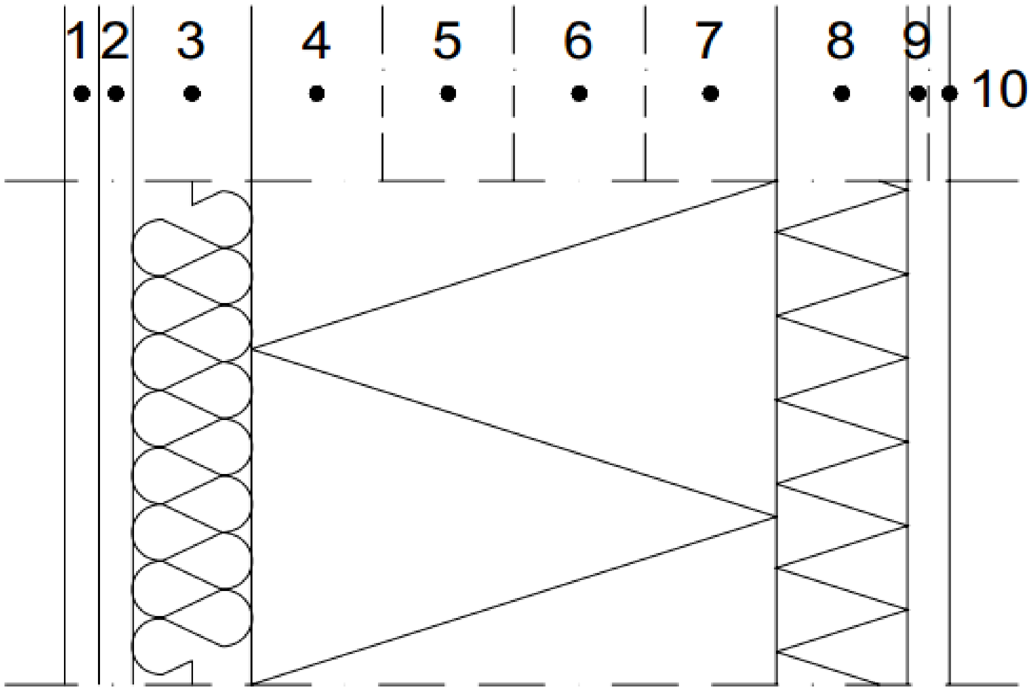


**Figure 5. Wall Section**

## 4. Conclusions

Prefabrication technology has not transferred as easily when compared with other technologies because it is a production technology or knowledge based and not a consumption technology or product based.

In many cases users are asked to help with many of the transfers that are occurring by way of global practice or working for multi-national firms that are producing prefabricated components and entire buildings. However, there are a few limits to prefabrication technology but they are usually not encountered in a multi - family building project.

The advantage of this technology is that workers in the factory use lasers to cut the wood and jigs to place the pieces together, the quality is very consistent. The workers are also very efficient because they do the same job repeatedly, which increases their skills and reduces errors. Very little waste is created and no materials are damaged by moisture, which creates a home with very good indoor air quality that is far superior to the average stick-built home knowing the price of a project upfront is important, modular construction can offer far more precision.

This is especially helpful when building rental properties because an accurate estimate for return on investment can be easily calculated. Knowing the price upfront also benefits investors in that they can know exactly how long it will take to get a return.

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