THE BENEFITS AND LIMITATIONS OF PREFABRICATED HOME MANUFACTURING IN NORTH AMERICA

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Abstract

The purpose of this report is to describe and analyze the potential benefits and limitations of constructing residential homes using the prefabricated manufacturing method found in North America. The ideology behind modular product development and how it is applied to the prefabricated home industry will be explained. This paper aims to educate the reader and provide them with a sufficient understanding of the manufacturing process of prefabricated homes, while comparing the benefits and limitations of this process with the conventional method of 'site-built' construction. Comparisons will be based on both the assembly and manufacturing techniques arising from each method of production. The summary will provide an overview of topics covered throughout this paper as well as a brief projection of the future market potential of prefab home systems.

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Introduction

In North America, the conventional way of building residential homes has been to fabricate most components at the worksite. This method is commonly known as ‘stick-built’ or ‘site-built’ construction. In North America, site-built homes are usually constructed with lumber studs and composite panel sheathing. They often require building materials to be shipped to the worksite in advance so that any contractors and tradesmen are prepared to work as soon as they arrive.

As technology and automation have developed in the recent years another method of home construction has become increasingly popular, prefabricated (prefab) home manufacturing. Prefab home construction uses a ‘systems engineered’ approach to its manufacturing process. This process involves manufacturing a home using several elements or ‘modules’ inside a controlled facility. Modules are most commonly constructed of stud lumber and panel sheathing, similar to site-built homes, but they can be manufactured from structurally insulated panels (SIP’s) as well. The modules are transported by truck to the building site where they can be assembled and constructed in place. The differences between site-built and prefab construction lead to distinct capabilities and end results of the final products.

The purpose of this paper is to compare the benefits and limitations of modern prefab home construction with that of the conventional site-built alternative. The overall focus will be on the panelized and modular prefab home manufacturing systems. However, conventional site-built homes will be referenced in order to help measure the effectiveness of these systems. An analysis of the assembly methods and manufacturing techniques will be evaluated to site-built construction. The topics included in this paper will provide a history of prefab homes, as well as a brief overview of modular product development. The subsequent section will focus on

the prefab manufacturing process, after which, the benefits and limitations will be evaluated. The paper will conclude with a discussion and summarized review of any results.

History

Although, you may think that prefab home manufacturing is a relatively new technique, it is not. Manufacturing homes via prefabrication dates back over one hundred years ago. It started gaining recognition in the early twentieth century. Sears, Roebuck and Co., now commonly known as just Sears, offered its first home package and building plans in a specialty catalogue in 1908. The catalogue 'Book of Modern Homes and Building Plans' featured twenty-two homes styles, each ranging from $650 – $2,500 (Sears Archives 2004). Home packages purchased from Sears, Roebuck and Co. would arrive by railroad and include: pre-cut lumber, carved staircases, fasteners, varnish, and any other amenities needed to construct the house. Families could pick out their houses according to their styles, needs, and financial situations, similar to that of modern prefab homes. From 1908 to 1940 Sears, Roebuck and Co. sold more than 100, 000 homes (Sears Archives 2004). Refer to the appendix to view an illustration of a home plan available through Sears during 1908-1914.

Since the start of their production, prefab homes were considered a source of low-cost housing. They were constructed in towns and cities with booming industrial sectors and allowed more middle-class families to build their own homes. In 1976, the American government approved the U.S. Department of Housing and Urban Development (HUD) building code to set standards for heating, plumbing, electrical, structural, fire safety, and energy efficiency among residential homes (Connors 2007). By 1994 the government updated the HUD code to incorporate even higher standards for prefab housing (Connors 2007). In the last few decades, and especially since the 2007 housing crisis, innovation has tailored this method

of home building to an environmentally conscious and upscale market. Technological advancements have allowed prefab housing to compete, not only on cost savings, but on quality and value as well.

Product Development

Conventional Product Development

The conventional approach to product development has been to base the succession of tasks around uncertainties in the manufacturing process. This method sought to define the initial product concept and then sequence the production process according to activities with the greatest level of ambiguity (Huang 1999). Development decisions would be made further down the line according to the technical knowledge obtained from the previous step (see figure 1). Aside from the initial phase, most processes are reliant on the previous stage of development and have to wait until the preceding process is completed before production can continue . As you can see in, this system would be repeated at each stage of the production process until all components and their adjoining constituents were specified (Huang 1999). The potential time delays and high costs associated with redeveloping interdependent components ultimately forced competitive industries to seek alternative production systems, such as modular development (Huang 1999).

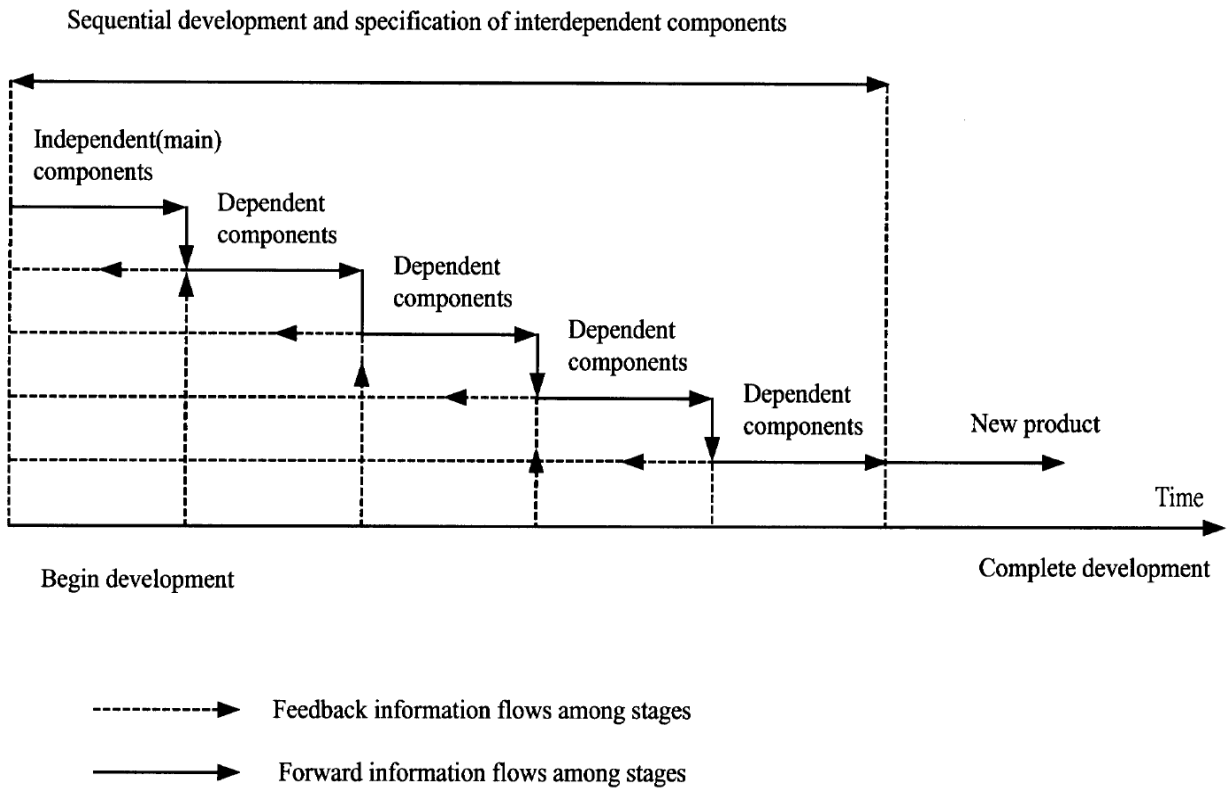

Figure 1 Conventional feedback systems (Huang 1999)

Modular Product Development

Modular product development is an approach to manufacturing that seeks to subdivide smaller parts of a process into independent tasks (modules). This technique enables individual segments of an operation to be easily understood, localizing any discrepancies of production within a particular module (Huang 1999). Individual modules are a collection of components and mechanisms that, when combined, form the overall structure and characteristics of the final product. Modular design seeks to develop a standardized relationship between the inputs and outputs shared by each component in a product (Huang 1999). Unlike the conventional method, modular development manages the information flow throughout the entire system and

defines the desired outputs of production before the process begins (Huang 1999). For this reason, modular product development is widespread in prefab home manufacturing facilities. It allows processes to be completed simultaneously with accurate information management between the adjoining levels of development (see figure 2). The figure below illustrates how concurrent component development is possible in systems with predefined information structures. Modular systems allow for simultaneous development without a lag of technical dependency between adjoining processes, as in conventional systems. Other industries that have adopted modular product design include the aircraft industry, vehicle industry, and computer technology industry.

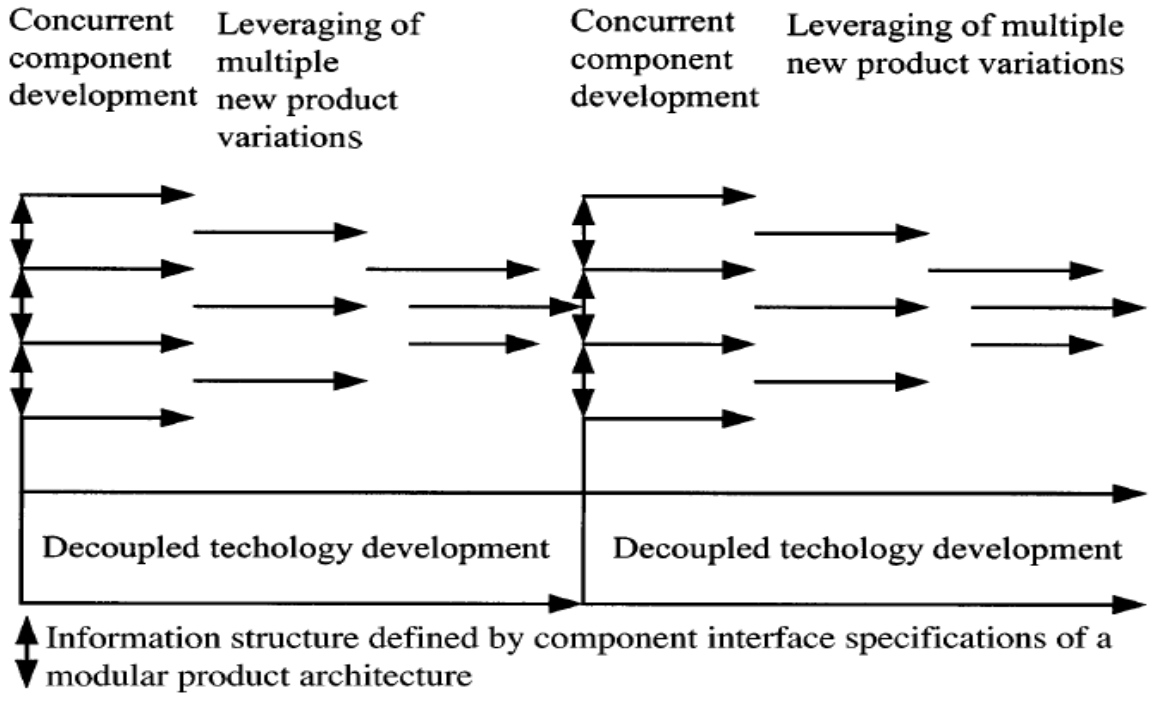

Figure 2 Modular feedback systems (Huang 1999)

Prefabricated Manufacturing Process

Process Flow

Many manufacturing facilities in North America differ in construction technique and their inherent process flow. The size of the firm and their distinct competitive advantages such as proximity to distribution channels, market share, and production competencies determine how much of their operation must be outsourced to other companies. Nevertheless, most prefab facilities follow the type of generic manufacturing steps illustrated below, in figure 3.

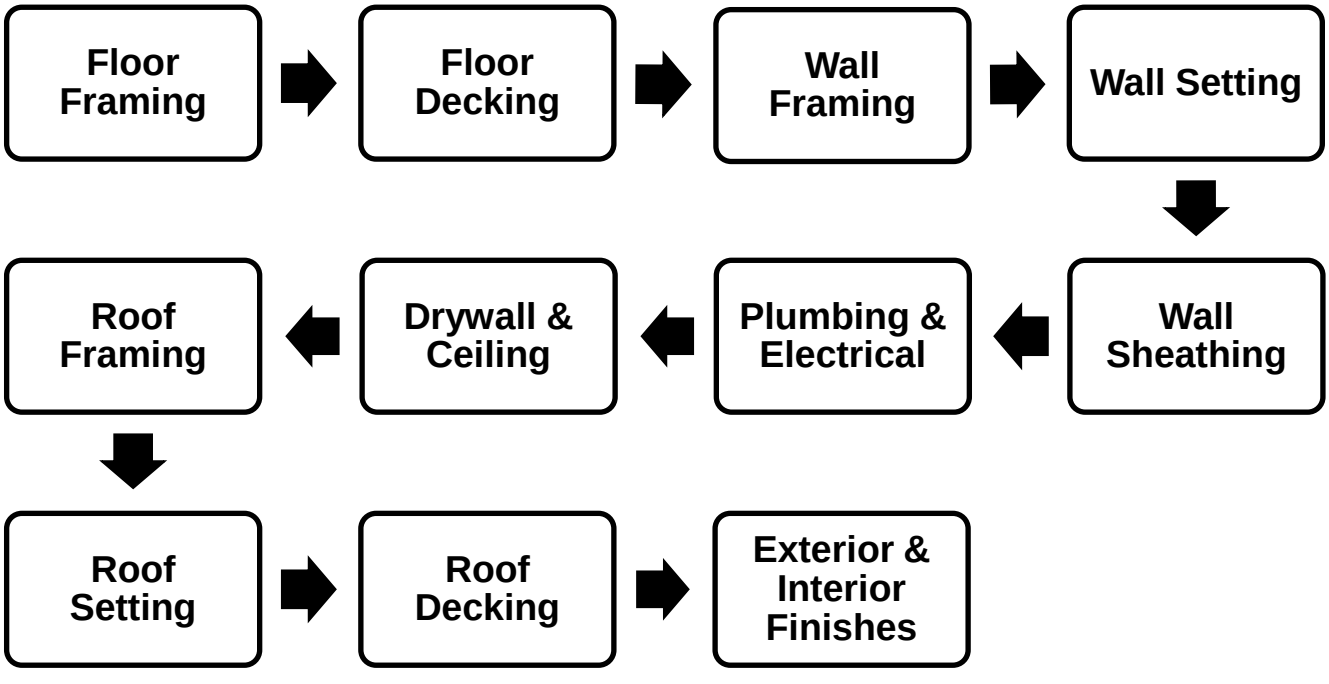

Figure 3 Manufacturing steps in prefab facilities

Floor assembly consists of the manufacturing and installation of the load bearing joist system, followed by the attachment of the floor decking material. In many cases there is a

wood casing under the floor for the attachment of wall panels (Connors 2007).

The wall components are installed in a comparable order. First they are framed, then they are set, and finally they are covered with a sheathing material or SIP alternative. Setting refers to the process where walls are measured and properly aligned to ensure they will fit adjacent subcomponents (Phil Mitchell 2009). The wall assembly is perhaps one of the more complicated aspects of construction because it requires the necessary machining for windows, doors, electrical and plumbing fixtures. Insulation and vapour barriers are also installed during this step of the process.

The roof is constructed in a similar fashion to that of the floor and wall sections. A truss or rafter system is manufactured or acquired and then set to ensure alignment with any adjoining wall components. The decking material and any necessary insulation or vapour barriers are then installed.

Although Figure 3 implies a specific order in production, this is often not the case. Most prefab facilities consist of several subcomponent lines that operate to complete individual segments of the building at the same time. In many cases, a main line brings together the subcomponents so they can be assembled and fitted for a final measurement check. Depending on the manufacturer and the level of customization required, any exterior and interior fixtures may or may not be installed following this final assembly.

Facility Flow Pattern

Prefab home manufacturers typically design their facilities in one of two basic flow patterns: side-saddle flow pattern or shotgun flow pattern. In side-saddle flow facilities (figure 4), the elements move transversely through the factory in a single line whereas in shotgun-flow (figure 5) facilities the elements are arranged end-to-end with multiple lines of production (Phil

Mitchell 2009). Typically, both of these flow patterns are configured in a straight line with the production process advancing linearly through the facility. Other arrangements, however, can also have their advantages and disadvantages (Phil Mitchell 2009). The figures below use floors, walls, and roofs as subsystems to show the difference in progression between the two facility flow patterns.

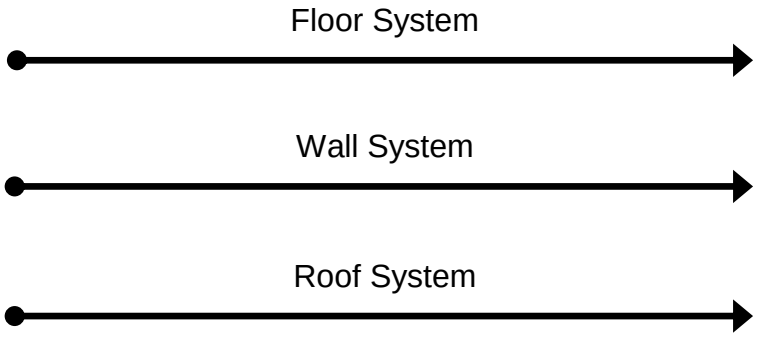

Figure 4 Side-saddle flow arrangements

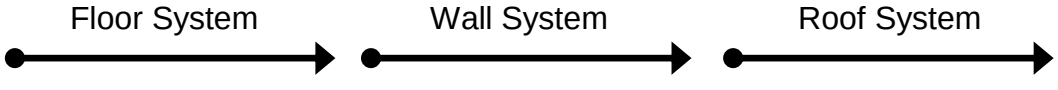

Figure 5 Shotgun flow arrangements

Material Components

The material components utilized by most North American prefab manufacturers are relatively similar to the components found in the site-built construction industry, with a few exceptions. Unlike site-built construction, prefab manufacturers use 2 x 6” lumber instead of 2 x 4” lumber for the post supports, or studs. Another distinction commonly practised in prefab construction is the replacement of nails by screws and the addition of glue to the joints

(marriage walls). Prefab companies follow these standards to ensure that the elements (or modules) remain rigid and intact during transportation and assembly. Other than this structural difference, the type and method of prefabrication (i.e. panelized, modular, or some combination) determines what materials will be suitable for the desired application. The level of product quality sought after by any particular company is another factor that influences the type of material components found throughout the manufacturing process.

Levels of Automation

Because of the diverse nature of manufacturing methods found in the North American prefab housing industry, three separate levels of automation will be explored. These three segments have been adopted from the United States Department of Agriculture's (USDA's) Technology Assessment of Automation Trends in the Modular Home Industry (2009). The three levels of automation are classified as manual, semi-automated, or fully automated. Between these distinct levels, the man-power and machinery employed will vary greatly. Segmentation will be based on the material transportation, material sizing, material fastening, and machining technology at the facilities.

Manual

Prefab manufacturers under this segment have the lowest degree of automation in the industry and typically employ the most labourers and tradesmen in order to compensate for lower productivity versus the automated methods. The table below illustrates several common material processes and the machines or tools used in a manual prefab home facility.

Table 1 Automation found in a manual prefab facility

Material Process	Machine / Tool Used
Sizing sheathing	Table Saw
Sizing stud lumber or joists	Saw
Transporting sized components	Carts
Attaching studs or joists to frame element	Manual nail gun
Transporting gypsum or sheathing onto element	Manually (by hand)
Fastening gypsum or sheathing to element	Manual nail gun
Flipping element	Crane
Inserting components into element	Manually (by hand)
Manufacturing stairs	Manually or CNC router*

*Computer numerically controlled router (Phil Mitchell 2009)

Semi Automated

Most facilities in North America fall under this class of automation. This setup allows companies to save costs by automating their major processes, but also allows them enough flexibility to continue to serve a dynamic marketplace. Some of the common machines used in this type of arrangement include Computer Numerically Controlled (CNC) equipment, pneumatic powered fasteners, and butterfly tables. CNC machinery produces consistent, accurate cuts and is significantly faster than manual chop saw machinery. Some companies actually have their CNC machines wired into the facility network, thus allowing an operator to download a new program or file without leaving his or her station (Phil Mitchell 2009). Table 2, below, shows the machines and tools used in a semi-automated prefab facility.

Table 2 Automation found in a semi-automated facility

Material Process	Machine / Tool Used
Sizing sheathing	Table saw or CNC router
Sizing stud lumber or joists	CNC saw
Transporting sized components	Carts
Attaching studs or joists to frame element	CNC nail gun
Transporting gypsum or sheathing onto element	Manually (by hand)
Fastening gypsum or sheathing to element	Nail gun bridge
Flipping element	Butterfly table
Inserting components into element	Manually (by hand)
Manufacturing stairs	CNC router

(Phil Mitchell 2009)

Fully Automated

Most of the facilities that utilize fully automated manufacturing methods are found in Europe, Germany in particular. These standardized facilities have extensive automation in regards to material handling systems and machining capabilities. Requiring only a fraction of the number of workers as a manual operation, some of these fully automated factories have the potential to produce up to 1,000 homes annually (Phil Mitchell 2009). It is common to find multi-function CNC machines in facilities with this level of automation. These CNC's can combine three or more material processes into one function. For instance, one multi-function CNC can frame a panel, place sheathing/gypsum on the panel, and fasten the sheathing/gypsum to the

panel in a fraction of the time it would take two labourers. Table 3, below, illustrates some of the machining technology found in this type of highly automated prefab facility.

Table 3 Automation found in a fully mechanized facility

Material Process	Machine / Tool Used
Sizing sheathing	CNC router
Sizing stud lumber or joists	CNC saw
Transporting sized components	Conveyor system
Attaching studs or joists to frame element	Multi-function CNC
Transporting gypsum or sheathing onto element	Multi-function CNC
Fastening gypsum or sheathing to element	Multi-function CNC
Flipping element	Butterfly table
Inserting components into element	Manually (by hand)
Manufacturing stairs	CNC router

(Phil Mitchell 2009)

Packaging & Shipping

Prefabricated homes are packaged into elements according to both manufacturing style and level of completion of the finished product. One must remember that there are several forms of prefabrication and each of these methods may require different packaging systems. Although differences arise in the dimensions and type of packaged elements, the basic transportation method remains the same. Almost all prefab homes are packaged and delivered on drop deck (low bed) trailers. These 50 – 60ft.long drop deck trailers allow manufacturers to maximize their transport volumes and minimize their overall freight costs. Most prefab

companies are willing to coordinate an additional transportation scheme in the event that the semi-trucks are not able to access the site. Winton Global, a panelized prefab company operating out of Prince George, B.C., estimates that an average size home requires between 1 and 3 trailer loads. “As a general rule, each trailer has the capacity to fit an 1,100 - 1,200 sq. ft. Package” (Winton Global n.d.). After the panel elements (or modules) are delivered to the worksite, the home may be assembled.

On-Site Assembly

Before assembly can take place, the manufacturer and clientele must ensure the site is ready for construction. Several issues must be addressed prior to assembly, such as: building permits, contractors and foundational requirements. Depending on the manufacturer, the extent to which the company is involved in the actual on-site assembly process can vary. Modular prefab companies tend to have more involvement on-site because of the complexity and liability involved in assembling a modular home package. Panelized manufacturers, on the other hand, usually maintain a comprehensive list of contractors whom they rely on to assemble their panel elements. In the latter case, it is usually up to the contractors or customers to acquire the necessary building permits from the local building authority. Establishing a suitable foundation for the home to rest on is an equally important aspect and must not be overlooked. Usually the type of foundation is known before the house is manufactured and it is up to the customer and any contractors to have it completed before the product is delivered.

Panelized homes can be erected to a ‘lock-up’ stage within 1 - 2 weeks, depending on the size and complexity of the package (Winton Global n.d.). Building a home to a lock-up stage requires completion of all structural components, exterior windows, and doors so the home can properly be secured (Accent on Homes Pty Ltd 2008). As a comparison, modular

prefab homes can take as little as 1 - 2 days to reach this stage.

The lifting equipment and machinery used for the assembly of prefab homes can be provided by the manufacturer or an outside contractor. For panelized homes a crane, hiab, or forklift equivalent capable of lifting 5,000 lbs should suffice in off-loading and erecting the wall panels. For a modular home however, a crane must be able to lift several times this amount due to the weight and dimensional constraints of each module (see figure 6).

Figure 6 A crane lifting a module into place on the worksite

Benefits of Prefabricated Home Manufacturing

There are many potential benefits associated when producing and constructing homes by prefabrication. The following sections have been broken down under two headings in order to logically present these ideas. The construction / assembly benefits section will primarily consider improvements associated with the actual assembly of prefab systems, whereas the manufacturing benefits section will examine the advantages arising from the production of these systems in a controlled factory setting. Site-built construction is used as a base of comparison among methods, and qualitative/quantitative data from the industry is included to support the rationale.

Construction & Assembly Benefits

In relation to the conventional method of site-built construction, prefab systems offer construction companies many opportunities to shave costs and improve on their bottom line. Since the 2007 housing crisis, North Americans have come to witness a deflated housing market. The inability to secure financing for home buyers has driven down housing starts, and consequently, the need for a large portion of the residential construction industry. With this sudden increase in market competition, many contracting outfits and construction companies have come to rely on prefab housing components as a means for increasing their profit margins. As you will see in subsequent sections, prefab manufacturing can reduce on-site labour and reduce the overall raw material waste provided in constructing a residential home.

Reduced Labour Hours

One of the largest conveniences with constructing and assembling homes with prefabricated components is the ability to reduce the number of on-site labour hours. For many

construction firms this is crucial because every extra hour you remain on the worksite your liability, overhead costs, and workers compensation increases. The following table was adapted from a study performed by the Wood Truss Council of America (WTCA) and the Building Systems Council of the National Association of Home Builders (NAHB) (2008). It provides a comparison in the labour hours required to construct two identical 2,600 sq. ft. homes, one framed with prefabricated components and the other framed conventionally on-site.

Table 4 Man hours to frame 2,600 sq. ft. home

Elements	Man Hours to Frame	
	Site-Built Method (hrs)	**Prefab Method (hrs)**
Floor Truss Framing	38	12
Roof Truss Framing	256	99.5
Wall Panel Framing	93	26.5
Total	**387**	**138**

(Structural Building Components Association 2008)

As you can see in Table 4, constructing and assembling site-built homes can require a substantial amount of labour hours, as compared to the prefab alternative. A similar study performed by FP Innovations – Forintek Division (2007), on two 3,100 sq. ft. triplexes, found that prefab was able to construct the building to lock up stage in 395 man hours, compared to its conventional site-built counterpart at 551 man hours. This significant reduction in labour provides construction companies with the opportunity to cut direct labour costs, and any residual overhead that may result from sitting idle at the worksite. This decrease in assembly time is not just a benefit for the contracted companies, but an important aspect for homeowners who value quick building times as well.

Reduced Material Waste

Studies show that in the actual manufacture of identical homes, prefab systems typically utilize a similar level of materials as site-built construction. The FP Innovations – Forintek (2007) study demonstrates that prefab panelization used 2.3% more lumber but 1.8% less OSB sheathing than the site-built approach. Although total material consumption may be similar, prefab homes provide far less on-site waste in contrast to conventional home construction. The table below illustrates the values collected by Forintek in the 'Build Alberta: Framing the Future' project (2007).

Table 5 'Build Alberta: Framing the Future' construction data

	On-Site Building Time	**Lumber Consumption**	**OSB Consumption**	**Lumber Waste**	**OSB Waste**
Units	Hours	FBM*	Sq. Feet	FBM*	Sq. Feet
Panelization	395	13,421	6,784	482	357
Site-Built	551	13,107	6,912	745	570

*Feet board measurement (FP Innovations - Forintek Division 2007)

The last two columns in table 4 confirm that site-built manufacturing produces significantly more on-site material waste than assembling with panelized prefabrication systems. In this study, site-built construction accounted for 55% more lumber waste and 60% more panel waste. These factors are higher in site-built construction because of the increased amount of machining that must occur on the job-site. In the study performed by WTCA and Building Systems Council of the NAHB (2008), expenses resulting from accumulated waste on the job-site were recorded to be $425 for site-built and $100 for prefab (Structural Building Components Association 2008). This may not seem like all that much per home, but if your company

constructs on average 45 of these 2,600 sq. ft. homes each year, you are saving around $15, 000 annually. The majority of these waste savings are due to the fact that prefab components are machined in a controlled environment. As you will see in the next section, manufacturing homes in a closed facility provide superior work atmospheres for both employees and industrial equipment. By reducing the amount of machining and manufacturing that occurs on-site, prefab systems allow builders to produce less waste and incur less expense in recycling and disposal fees.

The full economic figures provided by the 'Build Alberta' (2007) project and the 'Framing the American Dream' project (2008) can be found in the appendix.

Manufacturing Benefits

Whether the prefabrication system is modular, panelized or some combination, manufacturing residential housing components in a controlled facility provides several opportunities compared to building entirely on-site. The following two sections will describe these manufacturing efficiencies and explain what benefits they provide to the prefab housing sector.

Enclosed Work Environment

Ask any construction company in BC's lower mainland area, and they will likely agree that weather interruptions cause the greatest delay in building times. Manufacturing a large portion of the home in a controlled environment eliminates many headaches that you may encounter on the job site. For instance, because panelized and modular construction takes place in an enclosed facility, building materials are less prone to weather degradation. In the construction of the 3,600 sq. ft. triplexes, Forintek recorded that site-built manufacturing accounted for 551 hours of total building time (FP Innovations - Forintek Division 2007). This

works out to be between 11 and 13 weeks that the building is subject to any weather damage that may develop over that period. In most cases the damage is not so obvious to recognize right away but will later become more evident in the form of checking, decay, and even mold.

A higher measure of quality control is another important feature commonly attributed to manufacturing components in a factory setting. In comparison to most site-built construction, prefab companies are more likely to have quality-control programs implemented into their manufacturing process (Phil Mitchell 2009). Enclosed buildings provide a more comfortable work environment for their employees as well, potentially improving efficiency and productivity of the manual labour. Figure 7 is a photograph of two workers installing floor joists in an enclosed prefab facility. As we will see in the next section, facilities also provide an ideal setting for computer optimized equipment.

Figure 7 Manual installation of floor joists in an enclosed environment (Phil Mitchell 2009)

Computer Optimization

Computers and optimization equipment are becoming increasingly important in today's manufacturing industries. With ever-increasing wages, a shortage of skilled workers and a rise in competition, the prefab industry is always keen to adopt new technology for their existing operations. Acquiring equipment and machines that rely on computer optimization is one way in which these manufacturers have been able to minimize costs and increase annual productivity. Manufacturing housing components in a controlled environment allows companies to utilize this computer optimization equipment to its full potential. Several benefits that coincide with the use of this equipment include reduced manufacturing duration, an increase in project safety, an increase in product quality, and the ability to manufacture different elements simultaneously (Carlt Haas 2000). These computer systems are used in inventory management applications, part listings, basic material breakdown schemes, and even in advanced CNC machining processes.

The potential throughput and productivity of new automated processing equipment is substantial in relation to what it was a decade ago. Automated multi-function processing units, such as the new Hundegger SC-3 (figure 8) are capable of machining over 3500 truss parts or 18,200 ft. of I-Joists in a single 8-hour shift (Hundegger USA 2010). Although this may seem excessive for most facilities, companies that produce 300 homes or more on an annual basis can really benefit from such high output machinery.

The superb level of machining quality and limited variation between cuts is another advantage to using computer automated equipment. Programmable CNC routers and advanced panel saws are much more accurate than the skill saw and measuring tape of an on-site construction worker. These machines also produce far less waste, and what waste they do produce is more likely to be salvaged and reused.

Figure 8 Hundegger SC-3 automated component saw (Hundegger USA 2010)

Limitations of Prefabricated Home Manufacturing

Although there are many benefits associated with constructing and manufacturing homes using prefabricated systems, several limitations can also exist. Most of the concerns arise from transportation issues faced by the prefab home industry. The following section will address some of these potential concerns.

Transportation Limitations

As mentioned in section 3.5, prefab manufacturers ship their elements by semi-truck and trailer to the job site. Depending on the nature of the prefab system and location of the site, certain complications can arise in transport for this method of home manufacturing. Because of the inherent differences in the level of completion of modular and panelized homes, shipping limitations will vary. Modular homes are typically shipped from the facility with drywall, electrical

fixtures, plumbing, carpet and cabinet work already installed. Panelized manufacturers on the other hand, generally ship singular, unconnected, structural components. The wall panels, floor sections, and roof trusses are shipped separately with a bulk of the hardware being installed on-site.

Shipping Constraints

Shipping constraints are likely the largest limitation facing the prefab housing sector. The average prefab home typically ships within 250-400 miles as a maximum tolerable distance from the facility (Peter J. Cameron 2007). Anything over this distance is deemed impractical due to the federal/regional road restrictions. Difficulties faced throughout the shipping process include: dimensional constraints, load constraints, and any potential delays due to permit authorizations or customs issues. In the United States, it is not uncommon for transport vehicles to deal with as many as three separate governmental agencies while travelling through a single state (Peter J. Cameron 2007).

Size and load restrictions will vary internationally and between states and provinces. That being said, typical maximum dimensions are 13 – 14’ in height (including trailer), 15 – 16’ in width, and 50 – 70’ in length (Peter J. Cameron 2007). These limitations are of particular concern to the modular prefab industry because they transport a large portion of their home packages as preassembled units. In order to satisfy these conditions, modular facilities may standardize their product dimensions, eliminating many potential design freedoms for architects and homebuyers. Panelized prefab companies are affected by these dimensional restrictions but to a lesser extent. They are only partly affected because they do not preassemble their units to the degree of modular home systems. Nevertheless, manufacturers of panelized components are still confined in their product dimensions, mostly by height restrictions. In

terms of material transportation, conventional site-built construction fairs quite well compared to prefab manufacturing. Given that 90% of the manufacturing takes place on site and that raw material packages have become developed in standardized sizes, site-built fabrication is able to eliminate many shipping headaches.

Transportation Costs

Transportation can be a costly expenditure for prefab manufacturers and homebuyers. The actual shipping cost is based on several important factors. Transport distance, permit allocation(s), and the number of trailers can all affect the cost structure of transporting a prefab home. Transportation distance from the facility to the final building site is usually the single most important factor in shipping prefabricated homes. Whether or not they will require any permit is determined by the motor vehicle jurisdiction in which they travel through. In an ideal circumstance transportation permits cost the manufacturer little to no expense. However, when the truck is deemed over-capacity, costs become unavoidable. In many cases, state law will require police escorts during the night time to avoid obstructing local traffic (Peter J. Cameron 2007).

Figure 9 Prefab home being transported by truck and trailer

Summary

Although prefab homes have existed in North America for over a century, their potential for high quality, low cost applications is just now being realized. Prefab housing systems can provide contractors and independent home owners with a quick, cost-effective alternative to conventional site-built construction. With the aid of modular product development schemes, facilities are capable of performing simultaneous processes in order to complete the manufacture of home components faster and with less discrepancy.

Most manufacturing facilities are segregated into three main subsystems: flooring, walls, and roofing. This arrangement allows the major elements of the home to be completed in a synchronized manner. The level of automation employed at each facility depends on the annual production, labour costs, and processing requirements of the company. Home packages are delivered to the worksite on drop deck trailers and are then erected with the help of cranes or forklifts.

Several benefits arise in the construction/assembly process and manufacturing process of prefabricated home systems. The construction and assembly benefits include reduced on-site labour hours and reduced material wastage. Manufacturing benefits include the ability to manufacture homes in a controlled environment and the ability to implement the use of computer optimization.

The main limitations facing modern prefab home manufacturing are transportation costs and shipping constraints. Transportation costs will vary depending on distance, permit allocation, and number of trucks required to haul each home package. Shipping constraints include but are not limited to size, load, and federal/regional road restrictions. Site-built construction is able to reduce many of these potential costs by transporting and manufacturing the raw material at the worksite.

As North America recovers from a depressed housing market we will likely witness a long and slow recovery in the residential housing sector. Low levels of annual housing starts will directly impact the construction industry and any related fields for years to come. Prior to the 2007 recession, panelized and modular prefabrication gained a 5% share in North American construction methods through 1997-2005 (see figure 10) (FP Innovations 2009). Over the same duration, site-built construction lost 10% of its total market share (FP Innovations 2009). Many home builders and home buyers have already begun to realize that purchasing prefabricated home systems can improve their bottom line.

Through the next decade, we can expect to see a steady shift from conventional site-built manufacturing to prefabricated home manufacturing. The major factors influencing this shift include: tight margins faced by home builders, skilled labor shortages, changes in consumer perceptions towards prefab systems, a push for 'greener' construction alternatives, and an increasing demand for energy efficient homes. Although the last two factors were not discussed in detail throughout this paper, they are becoming increasingly important in today's market. Some alternative materials and energy efficient processes already implemented in parts of Europe are beginning to make their way into North America. Consumers are starting to realize that the long-term environmental and economic benefits offered by these materials/processes are well worth the initial investment. As the industry advances in the near future, the North American residential housing market can expect to witness a change towards prefabricated manufacturing.

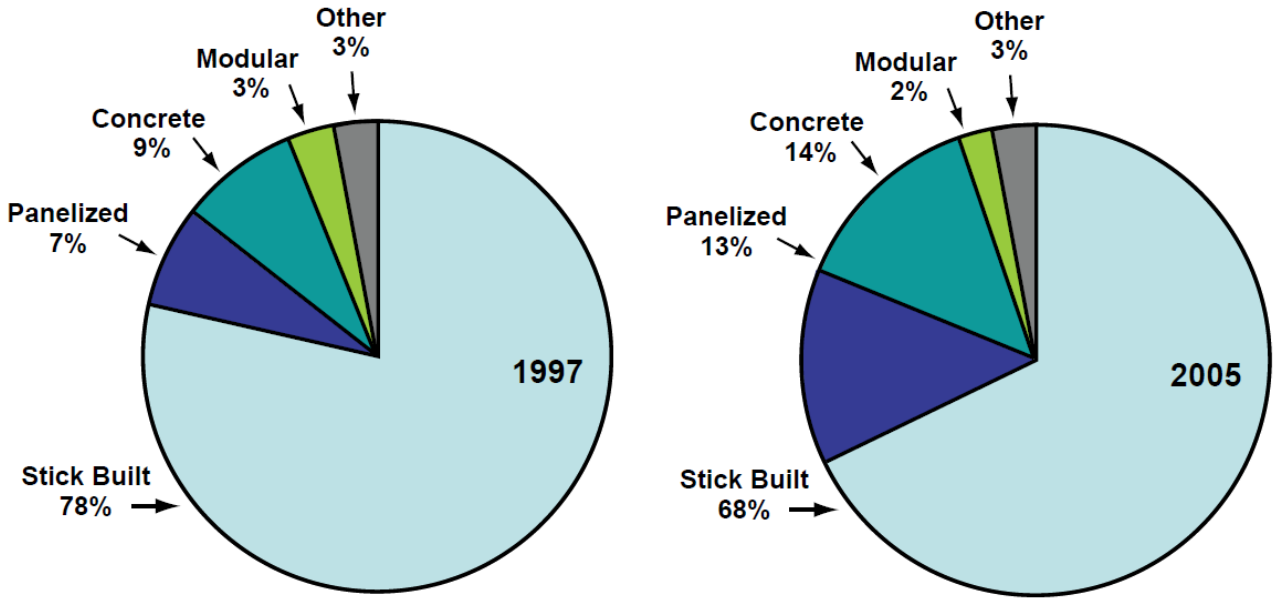

Figure 10 Construction methods in North America (FP Innovations 2009)

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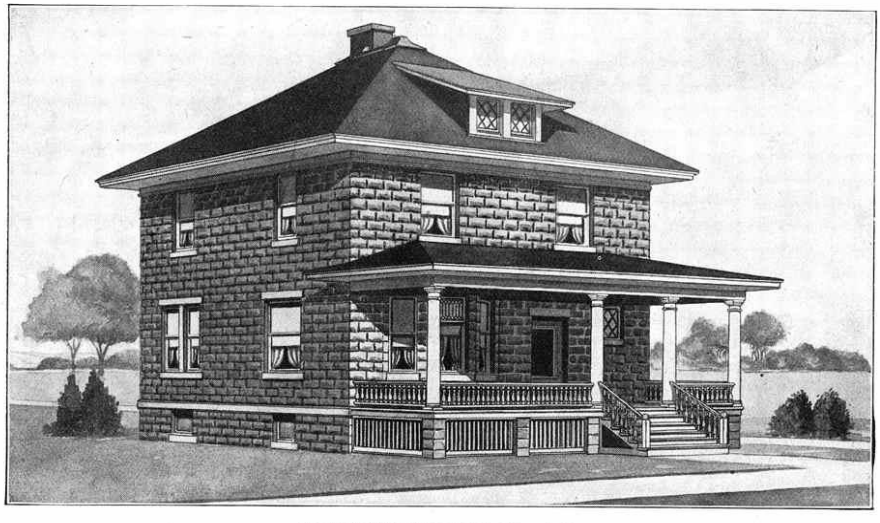
Appendices

$1,995.00 and Our FREE BUILDING PLANS

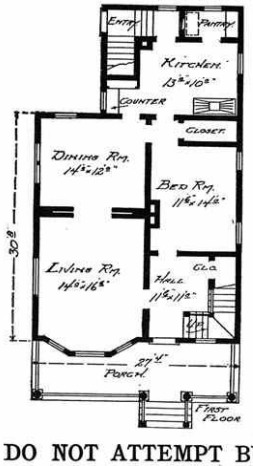
WILL BUILD, PAINT AND COMPLETE, READY FOR OCCUPANCY, THIS MODERN NINE-ROOM $3,000.00 HOUSE

HOW TO GET ANY OF OUR PLANS FREE FULLY EXPLAINED ON PAGE 2.



MODERN HOME No. 52

Concrete Block Construction. On the opposite page we illustrate a few of the materials we specify on this our $1,995.00 house.



OUR $1,995.00 HOUSE

illustrated above, consists of nine good sized rooms and bathroom, as shown in these floor plans

FIRST FLOOR.

Kitchen	13 feet by 10 feet
Pantry.	
Dining Room	14 feet by 12 feet
Living Room	14 feet by 16 feet 6 inches
Reception Hall	11 feet 6 inches by 11 feet
Bedroom	11 feet 6 inches by 14 feet

SECOND FLOOR.

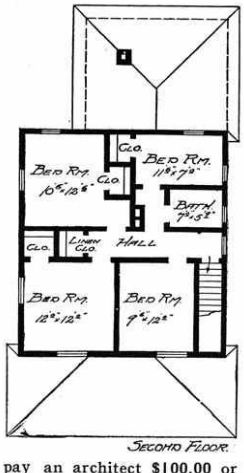
Bedroom	12 feet by 12 feet
Bedroom	9 feet 6 inches by 12 feet
Bedroom	10 feet 6 inches by 12 feet 6 inches
Bedroom	11 feet 6 inches by 7 feet
Bathroom	7 feet by 5 feet 9 inches

Linen closet and hall. Bedrooms have closets.

The Arrangement of Our Houses

is such that they can be well heated with very little expense. Our $1,995.00 house is but one of the many frame or concrete houses for which we are able to furnish our free building plans and specifications. No matter what price house you may want to build, remember we can save you from 25 to 50 per cent.

Size of Modern Home No. 52: Length, 47 feet 10 inches; width, 27 feet 4 inches, exclusive of porch.



DO NOT ATTEMPT BUILDING WITHOUT PLANS, don't pay an architect $100.00 or $150.00 for plans which in no way compare in accuracy or detail with the plans we will furnish you free of charge on condition that you send us a small portion of your mill work order. If you were to attempt to build a house similar to the house illustrated above, it would cost you from $500.00 to $1,000.00 more.

See how you can get the plans for this house free on page 2.

Sears, Roebuck & Co., Chicago, Ill. —40— BOOK OF MODERN HOMES

Sears Roebuck Co. - Modern Home No. 52 ($782 - $1,995) (Sears Archives 2004)

‘Framing the American Dream’ economic figures

	Site-Built	Prefabrication	Savings
Total Labour Hrs	401	148	253
Labour Cost ($20/Hr)	$8,020	$3,460	$4,560
Total Bd. Ft. Lumber	20,400	15,100	5,300
Total Lumber Cost	$12,928	$14,457	($1,529)
Total Lumber / Panel Waste	17 Yards	4 Yards	13 Yards
Total Scrap Cost	$425	$100	$325
Total Cost for House	$21,373	$18,017	**$3,356**

(Structural Building Components Association 2008)

'Build Alberta: Framing the Future' economic figures

	Site-Built	Prefabrication	Savings
Lumber / Panels[1]	$7,150	$2,349	$4,801
Panelized Systems	$0	$10,247	($10,247)
Transportation	$220	$1,630	($1410)
Labour	$24,775	$17,775	$7,000
Tipping Fee (Waste)	$85	$56	$29
Roof & Floor System	$12,500	$12,500	$0
Crane	$800	$800	$0
Total	$45,530	$45,447	**$83**

(FP Innovations - Forintek Division 2007)

[1] **Refers to the lumber/panels used on-site**