

# Whole House Production: Integration of Factory-built and Site-built Construction

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## Abstract

The “Whole House” production concept presented in this paper is based on the integration of factory-built and site-built construction. This position paper attempts to explore current and innovative housing production techniques with emphasis on the factory-built construction. It identifies existing and on-going housing production-related research and, based on the review of available technologies and systems; it presents recommendations for future areas of research related to “Whole House” production. The overall goal is to explore innovative ways to produce better quality homes at a faster rate and lower cost.

**Keywords:** Factory-built Housing, Industrialized Housing, Manufactured Housing, Site-built Housing, Whole House Production.

## Introduction

The demand for quality affordable housing has been a growing concern in the United States. It is estimated that the annual need for housing units typically exceeds 2 million, whereas, annual housing supply has been around 1.5-1.75 million during 1980's and 1990's and is estimated to be around 1.5 million during 2000's (Syal & Mehrotra 2002). The housing industry has tried several alternatives to traditional site-built housing in order to produce quality homes in a time and cost efficient manner. These approaches include limited component-based industrialization on site-built housing, manufactured housing, modular housing, and panelized housing.

Research has shown that many of the above-noted alternatives can result in time and cost savings (Table 1). In addition, factory production process is noted for its faster rate of production and potential for higher quality due to controlled environment. Despite the perceived benefits of factory-built housing production, these products have not been able to significantly penetrate the overall housing market (Table 2), mainly due to negative consumer perception and lack of production and distribution sophistication (Syal & Mehrotra 2002, Mehrotra 2002).

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**Table 1: Cost Comparison of Identical Homes**  
(Source: Mehrotra 2002)

<b><u>COST CATEGORY</u></b> (all 2,000 sq ft and same foundation costs)	<b>Site-built</b>	<b>Modular</b>	<b>Manufactured</b>	
			Individual Lot	Land-Lease Community
<b>Construction Costs</b>	<b>\$77,140</b>	<b>\$65,560</b>	<b>\$47,277</b>	<b>\$47,277</b>
Structure	\$71,123	\$59,543	\$41,260	\$41,260
Foundation	\$6,017	\$6,017	\$6,017	\$6,017
Cost per square foot	\$38.57	\$32.78	\$23.64	\$23.64
<b>Land Costs</b>	<b>\$35,314</b>	<b>\$35,314</b>	<b>\$35,314</b>	<b>\$1,201</b>
Improved lot	\$34,113	\$34,113	\$34,113	--
Site preparation	\$1,201	\$1,201	\$1,201	\$1,201
Monthly land rent	--	--	--	\$250
<b>Overhead/Administration</b>	<b>\$29,380</b>	<b>\$27,652</b>	<b>\$14,644</b>	<b>\$14,932</b>
Overhead & gen. exp.	\$8,394	\$6,491	\$2,441	\$2,489
Marketing	\$3,039	\$2,596	\$1,220	\$1,244
Sales commission	\$4,776	\$4,284	\$1,831	\$1,867
Profit	\$13,170	\$14,280	\$9,153	\$9,333
<b>Financing Costs</b>	<b>\$2,895</b>	<b>\$1,298</b>	<b>\$610</b>	<b>\$622</b>
Construction financing	\$2,895	\$1,298	--	--
Inventory financing	--	--	\$610	\$622
<b>TOTAL COST</b>	<b>\$144,728</b>	<b>\$129,822</b>	<b>\$97,845</b>	<b>\$64,032</b>

**Table 2: Share of Factory Built Homes**  
(Source: Syal & Mehrotra 2002, Mehrotra 2002))

<b>Housing Type</b>	<b>1986</b>	<b>1993</b>	<b>1998</b>	<b>2001</b>
Panelized	7.0%	6.7%	6.3%	6.2%
Modular	2.4%	3.3%	3.4%	2.9%
Manufactured	16.3%	18%	22.7%	18.9%

These factors have prompted the industry and the housing researchers to explore the integration of factory-built construction with traditional site-built construction in order to combine the best of the both approaches.

This position paper attempts to explore current and innovative housing production techniques with emphasis on factory-built production. It identifies existing and on-going housing production-related research and based on the review of available technology and systems, the paper presents recommendations for future areas of research related to “Whole House” production.

## **Current “State of the Art”**

There have been several initiatives in recent years, directly or indirectly related to various aspects of “Whole House” design and production. The following sections summarize existing and on-going research in two categories: (1) manufactured housing production research at Michigan State University and Purdue University/University of Cincinnati and (2) other “whole House” related efforts.

### Manufactured Housing Production Research

National Science Foundation has recently funded two projects (NSF-CMS 0080209 and NSF-CMS 0229856) at Michigan State University and Purdue University/University of Cincinnati to focus on manufactured housing production, facility layout, and material supply chain process, along with an effort to define “whole house” production.

The main purpose of the first research project was to model the manufactured housing production and material flow process and to develop and implement simulation models in order to identify the bottlenecks in this process. In addition, preliminary aspects of production facility layout were explored. As part of this research project and other related research efforts at Michigan State University and Purdue University/University of Cincinnati, following theses and reports were produced.

- ?? Production and Material Flow Process Model for Manufactured Housing Industry (Senghore 2001)
- ?? Simulation Modeling for Manufactured Housing Processes (Abu Hammad 2001)
- ?? Performance Assessment Of Planning Processes During Manufactured Housing Production Operations Using Lean Production Principles (Chitla 2002)
- ?? Facilities Design Process of a Manufactured Housing Production Plant (Mehrotra 2002)
- ?? Manufactured Housing Industry: Material Flow and Management (Barriga 2003)
- ?? Manufactured Housing Trends and Building Codes (Syal & Mehrotra 2002)

As part of the second research project, investigators have completed work on detailed aspects of production facility layout and supply chain management. The completed work has resulted in following theses and reports.

- ?? Material Flow based Analysis of Manufactured Housing Production Plant Facility Layout (Banerjee 2003)
- ?? Decision Support System (DSS) for Manufactured Housing Production Process and Facility Design (Abu Hammad 2003)
- ?? Supply Chain Analysis and Simulation Modeling for the Manufactured Housing Industry (Jeong 2003)
- ?? Methodology for Evaluating and Ranking Manufactured Houses based on Construction Value (Barshan 2003)

Presently, investigators are working on integrated approach to facility layout, production process, and material flow in a housing factory. Towards the end of this research project, investigators are planning to explore “Whole House” design and production.

#### Other “Whole House” Related Research

A number of research efforts in recent years have investigated various aspects related to “Whole House” design and construction. These include:

- ?? Modular housing as part of the U.S. Department of Energy’s Building America Program and University of Central Florida’s Housing Constructability Lab. (Mullens 2003)
- ?? Whole House and Building Process Redesign Road map developed by NAHB Research Center and Partnership for Advancing Technologies in Housing (Whole House 2001, Whole House 2003). Some of the key efforts summarized in the road map literature include:
  - The Hickory Consortium (University of Central Florida, Pella Corporation, Harvard School of Health, the University of Texas and several modular builders) with a focus on integrating green home designs and advanced modular homebuilding technologies.
  - Owens Corning has put many of their products together in a program they call “Systems Thinking” that includes siding, insulation, windows, and roofing. These components/products are being engineered to work together as a system that is optimized for cost, function, and performance.
  - Robust Home – offered as a total building system. It is offered by an alliance of companies who claim that a steel and concrete house can be built by 3 persons in only 10 days.
  - Optimum Value Engineering (OVE) - NAHB Research Center effort that considers the framing process as a whole in order to optimize the use of material and labor cost, while providing higher quality and improved energy efficiency. OVE reduces framing cost while meeting the structural requirements of the building codes.
- ?? Systems integration of building utility systems, including electrical, plumbing, and mechanical systems (Whole House 2001, Whole House 2003)- the objective of this strategy is to improve the design and installation of all mechanical systems included in a building design. This would be accomplished by first, disentangling the mechanical

systems which would constitute the identification of practices that minimize interference among systems. This would then, lead to an integration of mechanical systems with the structural systems to come up with a comprehensive solution. The overall goal is to improve the design of homes to make them easier to construct as well as maintain.

?? Technology road mapping for manufactured housing (MHRA 2003)

This Roadmap contains five broad topic areas - the Home, the Factory, the Site, the Market and the Consumer - each with a set of key challenges. For each challenge, the Roadmap lays out a vision, and potential research and development focus areas.

?? Building Better Homes-Government strategies for promoting innovation in housing (Building 2003)

The recognition of innovation in the housing industry and its positive impact on the housing market has led the US government to seriously consider the state of its regulatory landscape. This report summarizes ongoing attempts to promote innovation in housing technology and stresses that the regulatory procedure should be made flexible enough to assimilate such innovation. For e.g. the *Stevenson-Wydler Technology Innovation Act of 1980* approved the transfer / licensing of technologies developed at public research laboratories to states, localities, and industry.

?? Lean production process in homebuilding (Mullens 2003 and Womack & Jones 1996)

The overall objective of Lean Production principles is simply to use less of everything to design and produce products economically, to lower volumes with fewer errors.

?? Open Building design concept and case studies (Open Building 2002)

The intention of Open Building concept is rooted in a comprehensive outlook towards building design and execution. As per this concept, the built environment is the product of an ongoing design process and that all building systems are replaceable and can be integrated and may transform periodically. There is a dynamic approach to the built form and design.

One of the projects initiated by the Building Futures Institute at Ball State University (BFI 2003), in collaboration with a private residential developer, proposes to define the tasks and costs required to design and construct empty shell town homes. This will include a range of fit-out kits to assemble a variety of floor plans, including variable locations of bathrooms and kitchens and variations in these. These kits will be produced at an off-site location and assembled on site.

?? Advanced panelized construction (Advanced Panelized 2002)

This construction system propagates the idea of building panels with multiple functions with consistent levels of performance. Their pre-fabrication renders them easy to order, deliver, assemble and integrate.

?? Information technology to accelerate and streamline home building (Information 2002)

The implementation of information technology in the Home building process has been slow primarily due to the variable sizes of the firms and the cyclic nature of the market where automation is seemingly an unnecessary investment. But, with the advancements in the production process and the impending assimilation with on-site construction processes, integration of information technology can become a reality.

?? Industrializing the construction site (Industrializing 2000, Industrializing 2001)

The first report refers to the industrialization of the construction site itself through the use of technology such as Design for Manufacture and Assembly (DFMA) and Enterprise Resource Planning (ERP) to reduce production costs, improve productivity and improve production quality. The second report addresses documenting the flow of information, filtering and disconnects observed in the information flow within all players and all event points for each production process or home building enterprise.

Pulte Homes, one of the largest homebuilders in the country, claim to have developed a system of production of a house as components in a factory setting. These components include a multi-usage pre-cast foundation and structural insulated panels (SIP's) as wall assemblies pre-designed with space for conduits. Since the construction site will only deal with integration of these components, possibilities of error are reduced (Pulte Homes 2003).

?? On-site House factory (Cohen Brothers 2003)

Cohen Brothers Homes LLC has patented the concept of the "On-Site" factory, which is a manufacturing unit set up on a job-site for the duration of the project. The Comprehensive Residential Building System (CRBS) developed by Cohen Brothers LLC (Denver), is a 50,000 sqft structure which includes parallel production lines where structural sub-assemblies are constructed. These are delivered to the third assembly place perpendicular to the sub assembly lines where the home is erected. Alongside, on the site, the foundation is placed and site is landscaped and a specialized conveyance trailer is used to place the home on the foundation without disturbing the landscape.

## **Future Research Directions**

As summarized in the earlier section, several research efforts in recent years have looked at various technologies that can lead to producing quality housing in a time and cost efficient manner. These existing and on-going research efforts can lead to innovative ideas for future research. Some of the suggested future research areas are listed below.

- ?? Evaluation of causes and design of possible solutions to reduce negative social perception of factory-built housing
- ?? Development of design and construction management systems to support integrated factory-built and site-built approach
  - Design and visualization tools
  - Management systems with dual focus on factory production and on-site construction
  - Material management systems
- ?? Redesign of house and its components to make it conducive to factory production, e.g., hinged wall panels
- ?? Structural and utility systems integration to provide flexibility in installation and maintenance.
  - Open Building concept
  - Systems integration through flexible design
- ?? Use of products including Pre-cast concrete panels, Polymer based panels, and Sandwich panels using Bio-based products such as, recycled paper and soy-based resin, as part of the panelized construction system (Advanced Panelized 2002, NSF-A 076).
- ?? Lean production practices in factory and on-site construction
- ?? Integration of factory-built and site-built construction
  - Higher level of industrialization of site construction, e.g., bathroom and kitchen cores, pre-built staircases, panelized construction
  - Industrialization of residential construction site
  - Automation of the construction site using systems such as Contour Crafting (NSF-A98)
  - Evaluation of unique design and construction aspects of site-built, manufactured, modular, and panelized construction leading to design of a hybrid housing unit
  - Industrialized production of components for site-built homes as initiated by Pulte Homes and others (Pulte Homes 2003)
- ?? On-site or mobile housing factory – this is an important upcoming area that can provide tremendous opportunities to revolutionize the “Whole House” design and construction process. The on-site or mobile factory facility can provide diminished product variation, possibility of splitting tasks between factory built and site built to save production time, lower costs for transportation, and higher assurance of quality so as to minimize the need for warranty claims (Cohen Brothers 2003). In addition to more overall detailed analysis of this concept, some areas that need further research include:
  - Production process mapping to identify and remove bottlenecks,
  - Regulatory issues which may hinder the functioning or optimal usage of such a facility,
  - Applicability of automation and robotics technology, and
  - Material and Bio based panelized products to facilitate the deployment of the efficiencies of the factory environment to on-site construction

This position paper summarizes existing and on-going research related to factory-built housing and “Whole House” production. The authors envision that integration of factory-built housing production with site-built housing construction can lead to a new way of designing and building homes. Therefore, the paper proposes potential areas of research that can assist in integrating the

best aspects of factory-built and site-built construction. Such integration, in the long run, can lead to producing better quality homes at a faster rate and lower cost.

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