ANALYSIS OF MEANS AND METHODS OF CONSTRUCTION IMPROVEMENT IN SINGLE FAMILY HOUSING IN MID-ATLANTIC RURAL UNIVERSITY TOWNS

by

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(Abstract)

The goal of this study was to determine if innovative building methods and materials have the potential to lead to better productivity. Furthermore, this study endeavored to establish the premise that builders who use pre-fabrication, pre-assembly, and modular materials and building methods will perform more productively than those builders who don't. These ideas were pursued by first reviewing the history of home building in the United States to determine trends and patterns in innovation. The experimental phase of the study was accomplished by interviewing local and regional builders about their actual methods of construction used for residential construction. These methods were then analyzed to determine the contribution of these methods to the builder's productivity.

Not surprisingly, builders choose one specific type of construction to build a majority of their projects. They use these methods 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 house. It was determined that residential builders in these rural university towns tend to use traditional wood framing construction methods above all of the other available methods. However, there are builders who do use less-conventional methods including: wall panels, pole construction, and modular unit construction. The actual building methods used by builders are somewhat determined by several factors, including: project type, company size and structure, and area of the country. Furthermore, the builders who choose to use non-traditional construction methods with regularity tend to have higher rates of productivity as well as the ability to take on more projects. Higher rates of productivity and the ability to take on more projects have the potential to give builders a competitive advantage over their competition.

Acknowledgments

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It is important for me to thank the builders who participated in this project. I certainly could not have completed this work without their knowledge and cooperation. Since many of the builders involved in this investigation have asked to remain anonymous, they are not referenced anywhere else in this paper.

I would like to also thank all the guys I have shared an office with over the past year: Chris, Ketan, Bakari, Khaled, Shanon, Derek, as well as Linda Phillips. I appreciate all of their support as well as all of the wonderful conversations we have had. Also, I would like to thank four special friends for all of the time they have spent listening: Clay and Diane Carter, Jason MacDonald, and Michelle Oblinsky. Thank you so much to all of you, I hope you realize all of the help you have been to me.

Dedication

There have been so many people who have helped me get to where I am now. I would like to thank my parents, sisters, and close friends for all they have done for me. However, there is really only one person who deserves the honor of this dedication: my husband, Rik. For the past seven years he has helped me more than anyone. Rik has listened to all of my ideas, good and bad, and supported me regardless of the decision I have chosen. I sincerely appreciate all of the time he has taken to read and edit my work, as well as all the suggestions he has made. But most of all, I am thankful for the times he has just listened.

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Introduction

According to the National Association of Home Builders (1997), the single family housing industry represents roughly 40% of the construction market in the United States. While the majority of single family houses are site built, the manufactured housing industry does produce a significant percentage of them, 12 to 14 percent annually (O'Hare, 1988). The methods used to build all of these homes have evolved over the course of American history. During this time, many methods of construction have been developed and used. Some of these methods are obviously obsolete now, but many of them are still used in residential construction across the United States.

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 include a reduced number of material deliveries to the job site, resulting in less coordination conflicts among trades.

However, many builders avoid using methods of prefabrication or modularization, but instead rely on more traditional methods of construction. These traditional construction methods are numerous, and are not restricted to only one type of material or construction method. I suspect that builders use these methods for various reasons, including familiarity, comfort, availability of materials, and cost savings.

Considering the substantial difference in construction time between manufactured housing and purely site-built housing, one concludes that there must be a more efficient means of producing a home. However, first an evaluation of the current methods of construction and their uses is necessary. This research will include an examination of both the site-built and the manufactured approach to moderate income, single-family housing.

By identifying each of the various methods of construction currently used and available to residential builders, an idea of why these methods are used can be established. Once the materials and methods are established, it can then be determined which methods of construction are most applicable and most efficient to use under given circumstances.

With this knowledge, home builders can learn more efficient ways to produce single family housing. By utilizing these methods, a contractor can build more houses in a year, increasing volume and decreasing overhead to yield a larger potential profit. This data can be used to significantly improve building efficiency in a series of houses with similar designs and location, like many contemporary suburban subdivisions. This is certainly true since it has been demonstrated that low productivity is the highest contributing factor to the rise of construction costs (Drewin, 1982).

The intent of this investigation is multi-faceted. The primary goal is to determine if innovative materials and methods of construction can lead to better productivity in the single-family housing industry. This goal is closely related to the second goal, which is to confirm the hypothesis that builders using pre-fabrication, pre-assembly, and modularization are more productive than those who do not. In addition, this investigation will attempt to determine if manufacturing can contribute technology to site-built construction. It is also necessary to explore the evolution of housing construction in the United States.

The review of literature section looks at the development of residential construction methods through the history of the United States. This section attempts to track the changes and advancements of materials and methods through time. Further, a close look is taken at many of the current methods of construction, both traditional and non-traditional, available to builders. In this way, a level of knowledge is established, that can be drawn upon for the remainder of this investigation. Then there is an analysis of the literature previously reviewed where comparisons between methods and materials is made. Also, an examination of the change, or lack of change of both materials and methods, is made. In addition, trends are identified and studied.

The means and methods of research section sets forth to establish how this study will be accomplished. The questionnaire and other observation methods are discussed and explained, providing the reader with insight into the reasons behind the research.

The results section is an objective look at all of the data collected during the study period. This section provides the reader with technical data without opinion or interpretation by the investigator.

The conclusions and discussion section attempts to delve into the results in a new way; it attempts to draw parallels between builders, and determine trends, similarities, and differences within groups and between groups of builders. Further, conclusions are drawn based on the data collected and presented. Lastly, the summary provides an analysis of the processes used in the investigation, as well as the conclusions that have been drawn. The summary focuses on the value of the results and conclusions, as well as speculates on the future of non-traditional building technologies. In addition, shortcomings of the study are identified, and suggestions for improvements and further investigations are outlined.

Review of Literature

Introduction

Before an analysis of productivity improvement can begin, there first must be an understanding of what needs to be improved upon, and what methods are available for use. Currently, there is very little definite information on residential construction improvement in the United States (Drewin, 1982). Therefore, this investigation should begin with an understanding of residential construction materials and methods.

In order to study the current methods of construction, it is necessary to look at methods of residential construction throughout the history of the United States. By understanding the origins and uses of the different methods currently used, we can begin to have an insight into why they are used, and when they are the most appropriate method to use. Of course, residential construction methods in America have their roots in many different cultures of the world. They cannot be tied to one or two specific countries. Yet, it is the mixing of these methods, and modifications to these methods that made American residences unique.

Housing in the United States has certainly undergone periods of major change over the past three-hundred and fifty years. From the time the first colonies were settled until the present day, Americans have had to house themselves and their families. These structures have varied from simple lean-tos to extravagant mansions using materials varying from earth to glass.

History of Residential Construction in the United States

The first significant colonization of America occurred when the Spanish invaded South and Central America in the 1600s. Much of the Southern United States, including Florida, New Mexico, Texas, and California, were already inhabited by indigenous people, who lived in earthen and mud structures. The native custom was to pile the clay up in layers and then mold it into shape (Handlin, 1985) (fig 1). The Spanish introduced the idea of making precast, sun-dried adobe bricks using a wooden mold, as well as framing the roof with large wooden beams (Handlin, 1985).

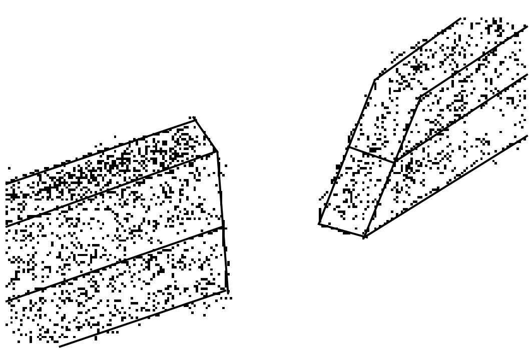
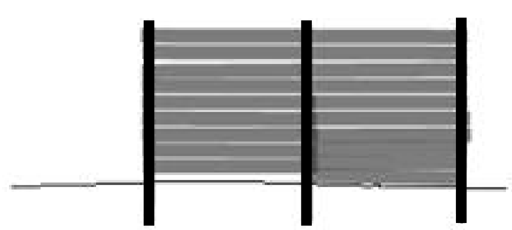


Fig 1: Clay Wall Construction

Fig 2: Post Hole Construction



At the same time the Spaniards were pushing farther northward; the English began colonizing the east coast from Boston, Massachusetts southward through Virginia. Initially, these east coast settlers built shelters that were less sophisticated than those of the indigenous people of the area. The first structures were mainly made of sticks and mud, or were simple enclosures dug into a hillside (Handlin, 1985). Others were small stick huts or even thatched cottages (Calloway, 1991).

During the same time period, settlers also constructed dwellings of stone, wattle and daub (Kostof, 1985), (a form of wall construction using upright posts interwoven with twigs or tree branches, and plastered with a mixture of clay and straw [Flexner, 1987]), and occasionally, limestone covered with stucco (Handlin, 1985). Another variation of these structures was "post-hole" construction, (fig 2) used by the early settlers of Virginia. "Post hole" construction set posts as the structure nearly four feet into the ground, with clapboard like siding to enclose the home (Brownell, 1992). These buildings were usually, small, simple structures, with flat roofs and orthogonal plans. On the prairies in the west, cut sod was used to create coursed walls, much like adobe was being used in the south-west (Calloway, 1991).

However, within a few years of initial settlement, colonists began to build more contemporary and traditional homes. In Virginia in 1611, the first homes were constructed mostly of wood, with brick reserved for foundations and chimneys, and were small, two or three room, single-story structures (Handlin, 1985). By the middle of the seventeenth century, a few larger structures were being erected with as many as five levels inside. Although they were infrequent, they signify the availability of building materials and methods to support such developed homes. Generally, masonry was more prevalent in the southern colonies, as was a small loft space, which was often built into the roof structure (Calloway, 1991).

Homes like these, and later homes of New Jersey and other northern settlements, were made primarily of wood, specifically a heavy timber frame, held together by mortise and tenon joints (fig 3). Within this structure, lighter studs and joists were used for partitions and floors on the interior. The space within the external frame was often filled with wattle and daub or bricks, then clad with clapboards (Handlin, 1985). Still, most of these buildings were simple, efficient volumes of regular spaces, capped with a gable or hip roof to shed rain and snow.

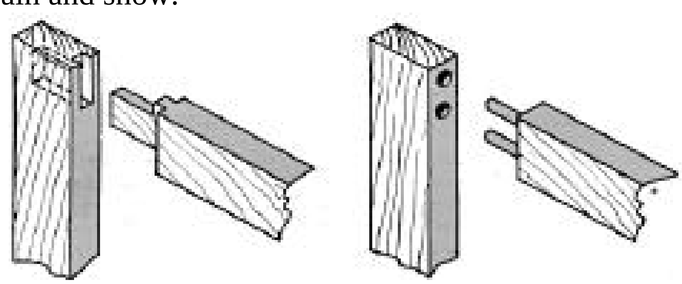


Fig 3. Mortise and Tenon joints used in timber frame construction

Unlike most east coast settlements, the Dutch, who settled between the Hudson and Delaware Rivers, took a much different approach to solving their housing needs. These peasant dwellings were small one room deep, one story high fieldstone structures (Kostof, 1985) having heavy timber framed roofs (Calloway, 1991).

The Germans also brought some ingenious methods of construction into being. Many were built of stone and whole logs, and were both one and two stories, with a large central fire-place and chimney (Kostof, 1985). Alternatively, in the Hudson River Valley, heavy timber "H-shaped" frames were used and then infilled with brick or stone (fig 4). An in-fill of clay or mud and straw was used in both Wisconsin and North Carolina (Calloway, 1991). Also, the Germans were the first to introduce to concept of split level, or "bank" barns. This idea built both barns and homes on the hillside, allowing entry onto both levels, from the exterior grade (Kostof, 1985).

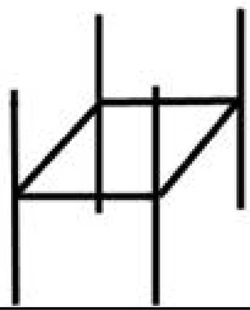


Fig 4: H frames used by German's

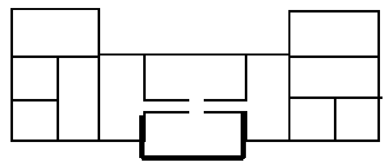


Fig 5: Example of U-shaped plan

In the early 1700s, Williamsburg, Virginia was planned and incorporated. The homes that were built there took on a distinctive and somewhat new style. These homes were grand three story structures, built almost entirely of brick, with a slight U shape (fig 5), as well as dormers, cupolas, and other architectural features (Handlin, 1985).

At the same time, the American Colonial home was becoming the standard. These homes were commonly two story houses, with steep pitched roofs, and an external chimney at each gable end. There were many variations of this style across the country. In New England, the chimney was moved into the center of the house, thereby causing a wooden rafter system to be used for the roof (Kostof, 1985), rather than heavy beams.

This "American Colonial" type of home became the standard until the beginning of the nineteenth century when the "Federal" style came into existence. The Federal style is most well known for the decoration and ornamentation of residences (Kostof, 1985). During this time, more homes moved toward structural brick walls as well as flat roofs or hipped roofs hidden behind a grand balustrade (Calloway, 1991).

One of the main objectives of the industrial revolution was to improve the productivity of manufacturing (Drewin, 1982). This productivity improvement began with small changes in manufacturing techniques, but eventually permeated other industries. In the 1830s, this trend began to impact the construction industry when builders began to utilize a new method of wood construction: balloon framing. This new method of construction was much easier and much faster to erect than heavy timber framing, partially because it uses light pieces of wood joined with nails, not mortise and tenon joints. This made wood construction more practical and more economical, considering that the wooden members were easier to produce, since they did not require large monolithic pieces of wood (Handlin, 1985). In balloon framing, studs are vertically continuous from sill to rafter, with floor boards nailed to their backs (Kostof, 1985) (fig 6).

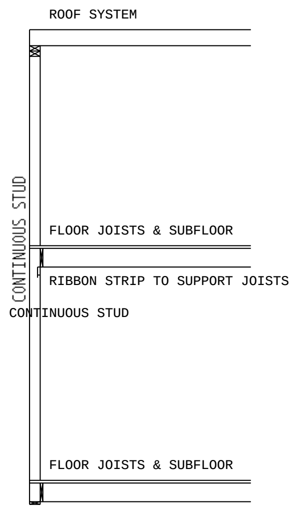


Fig 6: Balloon Framing

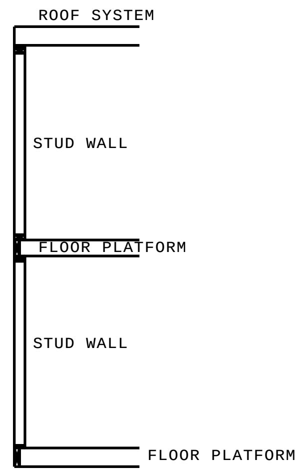


Fig 7: Platform Framing

Sometime later, balloon framing gave way to platform framing or western framing. This method of construction uses the same type of light gage wood members as balloon framing, yet the vertical members do not run continuously from the bottom of the structure to the top. Platform framing stops the vertical members at the top and bottom of each level of the home; therefore, the floor system becomes the platform for the next level (fig 7). In this way, platform framing allows even smaller wood members to be used; these members are often more available, and easier to handle (McAlester, 1989). Since the members are shorter, the lumber needed to make the vertical stud members can also be shorter; this advancement in technology allows more raw material to be used as finish lumber (Brownell, 1992).

The "Queen Anne" era came into being in the early 1860s, and was brought about by the advent of the balloon frame method of construction. This era was particularly eclectic, with five distinct styles all contributing significantly to the development of American housing. The five styles were: the Italianate, the Second Empire, Eastlake style, Stick style, and the Shingle style. The Stick style, which was most prevalent in New England, is best known for making the wooden frame structure part of the exterior decoration. The Stick style, of the 1860s, used typical balloon framing for the entire structure, but for the first time, roof trusses were introduced in residential roofing (Kostof, 1985). Unlike the Stick style, in the Shingle style, the frame is covered with exterior shingles and not left exposed (Kostof, 1985).

Also during the Queen Anne era, there was a push toward the manufacturing of mass-produced doors, windows, and decorative wood pieces for residential construction (Calloway, 1991). It was during this time period that an entire pre-fabricated house was first promoted as the ideal middle class summer cottage (Kostof, 1985).

From the late 1800's until the onset of the "American Beaux Arts", there were few innovations in residential construction. The "American Beaux Arts" period, from 1880 to 1930, was the period that advanced residential construction innovations into the modern methods that are still utilized today (Calloway, 1991). Concurrently with the innovativeness of the period, another movement was beginning to grow strong. This movement was characterized by a movement back to the vernacular building types of America; such as stone farmhouses in Pennsylvania, and adobe homes in the Southwest (Handlin, 1985). Frank Lloyd Wright was at the forefront of the movement, and he became infamous for building with natural materials; stone, wood, and earth (Kostof, 1985). This trend always included a large, natural fireplace in the center of the home to "anchor" it to the earth, as well as the tendency to extend the home out of the walls, and into the landscape (Handlin, 1985).

As the "Beaux Arts" progressed into the "Art Deco" period, other famous architects began to experiment with materials in residential architecture. By 1913, structural concrete was becoming the material of choice in California and other temperate climates (Handlin, 1985). Even Wright was influenced by the material, building four entire homes of patterned poured concrete blocks in Los Angeles in 1926: The Ennis House, The Freeman House, The Millard House, and The Storer House (Hoppen, 1993). In 1936, Fallingwater, a house made of poured concrete and natural rock, cantilevered over a flowing river was designed and built by Wright (Calloway, 1991) (fig 8).

Fig 8: Falling Water by Frank Lloyd Wright

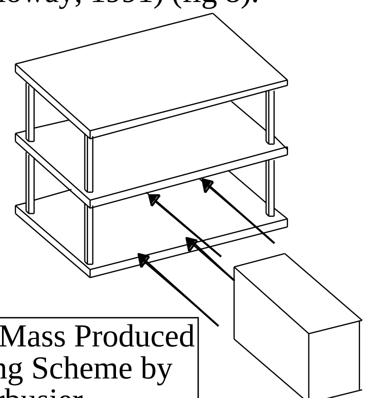


Fig 9: Mass Produced Housing Scheme by Le Corbusier

In 1915, Le Corbusier, a famous French Architect, designed several mass-produced housing schemes (Le Corbusier, 1931) (fig 9). These exact systems were never produced; however, similar systems were built much later as hotels. Over time, many other architects have tried their hands at designing mass-produced housing, including Walter Gropius in the 1930s and Mies van der Rohe in the 1940s (Handlin, 1985), Philip Johnson in the 1950s (Stern, 1977), and Frank Lloyd Wright in 1915 (Hoppen, 1993).

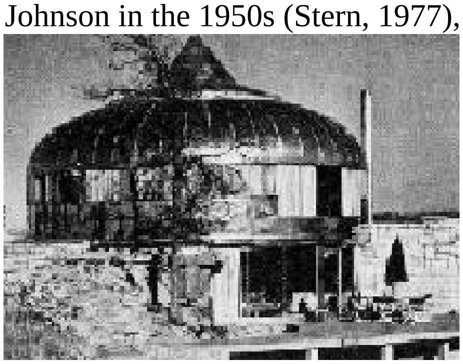


Fig 10: Dymaxion House by Fuller

Beginning in the mid 1920s, Buckminster Fuller began to explore the application of technology to architecture and residential construction. Fuller's most radical design was the 4D or Dymaxion House (fig 10). It was designed to hang from a central mast and was stabilized by guide wires. The home was meant to be made in the factory, much like an automobile, and then quickly erected on the site. The home was constructed mostly of sheet metal, wires, and glass as both exterior cladding and structure (Handlin, 1985).

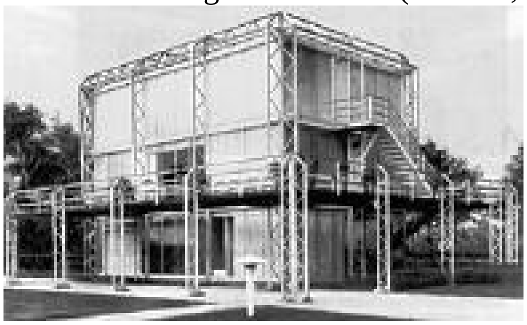


Fig 11: House of Tommorrow

Fig 12: Crystal House

By the early 1930s, George Fred Keck had joined in the movement of producing technological homes and manufacturing housing. His two models were both displayed in Chicago in 1933 (Handlin, 1985). These models, the House of Tomorrow (fig 11) and the Crystal House (fig 12) were both supported by a steel framework and a steel-deck floor system. The exteriors were built from store-front technologies like plate glass, light steel structural members, sheet metal panels, and tubular pipe railings (Handlin, 1985).

The main thrust of the 1930s was to make residential design and construction more rational, and concurrently, lower the price of the average American home (Handlin, 1985). One man, Howard T. Fisher, developed a system of prefabricated panels in order to standardize the building process. These panels were designed to be assembled in a variety of configurations in order to meet the needs of different clients; they were based on wooden stud construction in order to make them more familiar to the average home owner (Handlin, 1985).

In just a matter of years, trailers and other forms of factory built houses began springing up across the country. By the 1940s, several states had enacted laws allowing trailers to be considered buildings, and therefore, houses. By 1947, the first trailer, designed as a house, was manufactured by Spartan Aircraft. And in 1954 Marshfield Homes introduced the revolutionary "ten-wide", as the prototypical "mobile home". This was the first time mobile housing was referred as such (Green, 1994).

At this same time, the "Modern Movement" was moving residential construction ahead by leaps and bounds. From the start, concrete was the material of choice, but now its use had spread all across the country, and generally glass walls completed the exterior (Handlin, 1985). Then in the late 1940s and early 1950s, glass and structural steel found their way, in earnest, into residential construction. Mies Van der Rohe is probably the most famous architect to design and build a house, solely of these materials. The Farnsworth house is an exterior glass-walled home, lifted off the ground and supported solely by four pairs of steel I-beams (Handlin, 1985). Soon, others followed, and structural steel framed houses with exterior walls of glass infill began to show up in several areas across the country from Connecticut to California (Handlin, 1985) (Fig 13). Although this style did not make a substantial impact on the design and construction of the ordinary builder's house, several architects of the time found the style irresistible.

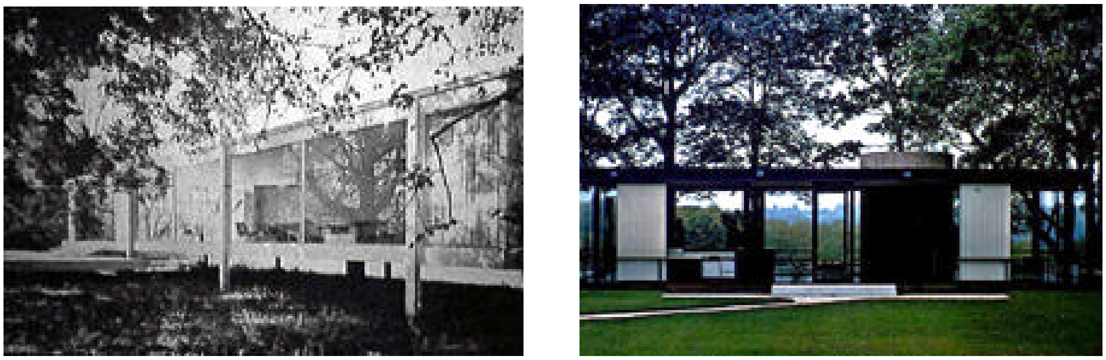


Fig 13: The Farnsworth House (left) and Johnson's Glass House (right)

From the late 1950s to the early 1970s, mobile homes were being manufactured all over the country, without any type of regulatory control. This was because they were not considered to be primary housing, as dictated by building code, and were not considered to be an automobile conforming to automotive standards. In 1974 The Department of Housing and Urban Development (HUD), was granted permission by Congress to enforce a construction code on the mobile home industry. By 1976 a nationwide set of standards was implemented for mobile home construction (Green, 1994).

It was during 1967 that Moshie Safdie, a Canadian architect was constructing his famous Habitat, in Montreal. The Habitat consisted of a heavy support structure made of concrete, that was used to organize and hold together the many individual pre-cast concrete modules. These modules were standard sized living units with individual roof terraces that were placed into the structure (Kostof, 1991). This particular design was reminiscent of Le Corbusier's design in 1931.

Today's prefabrication is not a recapitulation of the intentions of the 1960's, namely intense reduction in variety and mass production. Prefabrication has to be more pragmatic, sometimes at the level of the module, sometimes at the level of the assembly, and sometimes at the level of the components; there is a form of prefabrication that can meet nearly every project's needs. Currently the pressures on the industry are to produce a more-flexible manufacturing technology along with prefabricated systems, that allow entire structures to be constructed out of a single system of parts (Evans, June 22, 1995).

There are currently five different legal classifications of manufactured housing, as defined by the United States Congress; Manufactured Home, Mobile Home, Modular Home, Panelized Home, and Pre-cut Home (RHS, 1991). Each classification differs by code, design, and construction methods.

A Manufactured Home is factory built housing, built in compliance with the Department of Housing and Urban Development (HUD) code, in which one or more units are transported to a site and installed (RHS, 1991). Manufactured homes are built on a steel chassis, and are transported on wheels that are removed from the chassis when the unit is sited. The units are rarely set on an independent or permanent foundation. For the purpose of clarity, this classification of housing will be referred to as "HUD code housing" for the duration of this paper, and "manufactured housing" will be reserved for reference to the entire typology of factory built housing.

Mobile Homes are factory built housing that was built prior to the enactment of the nationwide HUD code. Most of these homes were built according to ANSI standards, and are comprised of one or more units which are transported to the site and installed (RHS, 1991). The homes that fall under this legal classification are no longer in production and haven't been since 1979; however, many are still inhabited across the country.

Modular homes are factory built housing that are certified as meeting both state and local building codes in which the unit will be finally located. This type of housing is comprised of two or more units which are transported to the site and moved onto a permanent foundation system (RHS, 1991).

Panelized homes are factory built housing in which panel components are transported to the site and assembled onto a permanent foundation. Panelized homes are subject to the state and local building codes where the home will be assembled (RHS, 1991). The type of panel varies from manufacturer to manufacturer, and may be a whole wall, or just a small segment.

Pre-cut homes are factory built housing in which building materials are factory cut to design specifications, then transported to the site and assembled onto a permanent foundation. These types of homes are subject to state and local building codes where they will be assembled (RHS, 1991). There are many types of pre-cut homes, including log homes, kit homes, and dome houses.

Contemporary Methods of Residential Construction

Since the early 1950s, the residential construction market has practically exploded (Calloway, 1991). Several different methods of construction have been tried; these methods have used both modern and traditional building materials. Although the most common method of residential construction is still wooden stud construction, either platform framing or balloon framing, many other methods are used, including manufactured housing. These methods can be broken down into several groups, depending on the final product; wall systems, floor systems, roof structures, entire homes, and prefabricated building systems are among those discussed below.

Light Wood & Steel Framing Systems

Both balloon framing and platform framing use dimensionally sawn lumber to construct the entire skeleton of the home, and can be used in conjunction with many foundation systems. The most traditional size and spacing is 2x4 members at sixteen inches, on center. In balloon framing, the studs are continuous for the full building height, from the top of the foundation all the way to the bottom of the roof structure (fig 6, page 10). Also, the floor joists rest on the sill plate, and do not bear directly on the foundation (De Cristoforo, 1977). Contrarily, in platform framing, the studs' height is only one story, and each story begins with the floor joists to form a platform for the next level (De Cristoforo, 1977) (fig 7, page 10).

Balloon framing is built stick by stick, meaning that each piece of lumber is placed individually, and nailed into place. However, in platform framing, this is not always the case. Platform framing allows the walls to be built as a unit, and then placed and secured. The walls can be built flat, either on the site or off, which allows for a great deal of flexibility. Also, sheathing, flashing, insulation, and windows can be placed into the individual walls prior to lifting them onto the floor system (De Cristoforo, 1977).

Framing with steel studs is becoming a cost effective alternative in residential construction. According to Chini, steel stud construction is only about 12% more expensive to use than wood stud construction; however, steel studs cost nearly 3.5% less than their wood counterparts (Chini, 1996). This method of construction is analogous to platform framing with wood studs in overall form as well as the pieces used (fig 14). There are three types of metal studs commonly used in wall construction; the nailable stud, the "C" stud, and the channel stud (fig 15). Steel stud framing is most often used in conjunction with light gage metal floor and roof systems (Ching, 1975) in commercial structures. However, in residential construction, the trend is to use steel stud construction in conjunction with wood joists and rafters or trusses.

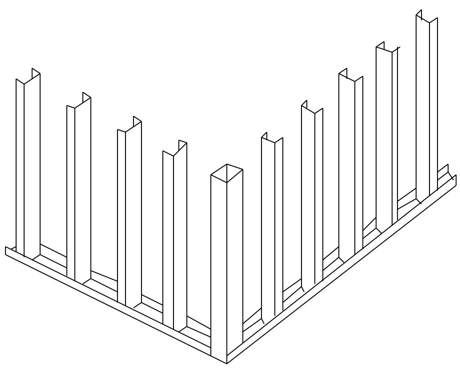


Fig 14: Steel Stud Construction

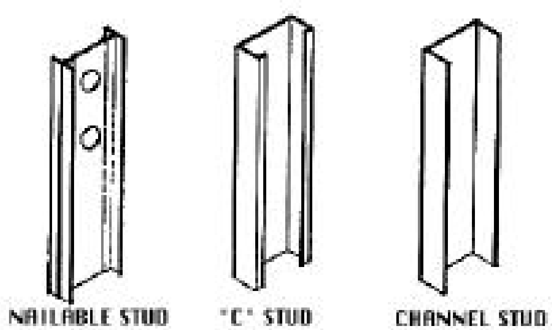


Fig 15: Types of Steel Studs

Prefabricated framing systems usually are delivered to the building site as a system of members that need to be assembled to form the structural frame. At times, the framing system may be partially or fully assembled prior to delivery to the site. For example, entire walls or roofs may arrive at the site ready to be moved into place. These framing systems are complete structural systems used to frame the entire home, and are made of either wood or steel. Since both are common building materials, skilled labor should have the ability to assemble the system using the manufacturer's instructions that are usually included with the components. Framing systems are flexible in that they allow virtually any traditional building material to be incorporated into the system to act as walls, floors, roofing, etc. Also, these types of structural framing systems tend to have the ability to span incredibly long distances, making them all the more flexible.

Wooden floor joists are one of the more common floor framing methods used in residential construction. The joists are light gage, dimensional wood members, that are spaced at regular intervals, usually 16 or 24 inches on center, and supported by the foundation system. A rim joist or header and end joists are usually doubled for additional support of the wall framing system above. This floor system is very flexible in that it can span a wide variety of distances, and be adjusted to fit most floor plans (Ching, 1975).

Steel floor framing systems work very similarly to wood joists. Larger channel joists are used in much the same way as a wood joist would be. At times, small I-beams may be used as girders or main supports (Wass, 1981). Light gage steel joists are often used in conjunction with light gage steel wall framing to form a complete and continuous frame. The frame can be overlaid with either wood sheet products or a steel decking material (Ching, 1975).

Wooden trusses, laminated beams, I-joists, and Open Web Truss Joists are other common methods used for the floor system. These members act very similarly to common joists; however, they provide a higher strength member, and therefore, a can span much longer distances. Trusses enable builders to run other systems, like mechanical vents, through the spaces in the truss, and therefore, the total floor depth can be lessened. Laminated beams and I-Joists are primarily used when a high strength member or a reduction of the total depth of the floor system is required.

Builders are no longer required to build trusses and I-joists themselves with these prefabricated framing systems. Each truss or I-joist is cut by the manufacturer, from individual pieces of lumber, usually laminated, then glued and pressed together to form a single-structural component. (Krygier, 1996) Masonite is also used by different manufacturers, to form I-beam components (Singmaster, 1995). Wood framing systems are usually used for floor and roof construction, as well as wall studs and sills.

Roof rafters are one of the most familiar systems used to build wooden roof structures. When the roof is flat, the system is nearly identical to using floor joists (Ching, 1975). However, in a pitched roof environment, the system starts to become more complex. The exact structure of the roof depends completely on the type and complexity of the roof itself. For a simple gable roof, the rafters are laid out at standard spacing, and span from the top plate of the supporting walls to a ridge board. Depending on the slope of the roof, a collar beam may be used to hold the two opposite rafters together (Ching, 1975).

A hip roof uses the same principle, with the addition of two more sloped faces, in place of the gable ends. For a hip roof, the hip rafter is the member that makes the transition from one slope to the next. It receives the load from the end jack rafters, as well as some of the side jack rafters, and then transfers the load to the ridge board (De Cristoforo, 1977). The mansard and gambrel roofs are again similar, yet are more complex. These roof types add additional support members that intercept rafters and transfer loads to the walls and ridge boards. The mansard roof is a unique combination of the hip roof and flat roof, both in construction and appearance (De Cristoforo, 1977).

Roof trusses are another light gage framing method commonly used in residential construction. Unlike both plank and beam and roof rafters, trusses are individual frames that work perpendicular to the roof plane, not within the roof plane. Trusses are placed at regular intervals along the home to form the roof structure (Ching, 1975). There are several types of trusses available to builders. Most are built from relatively small sizes of lumber, usually 2x4 or 2x6, and are very light weight (Wass, 1981). Trusses are usually pre-engineered and shop-fabricated as opposed to field-fabricated (Ching, 1975).

Post and Beam Construction

Post and Beam construction is a structural framework that is used to form the spaces of the home; in addition the system will need to be in-filled with another type of wall to form solid barriers. The post and beam system is essentially a framework made up of decking, beams, and posts supported by a foundation (Wass, 1981) (fig 16). The floor and roof systems are supported by beams, which are in turn supported by posts or columns that transfer the loads into the foundation. This system forms a three-dimensional modular grid of spaces. Generally, the timber used in post and beam is much larger than in balloon or platform framing (Ching, 1975).

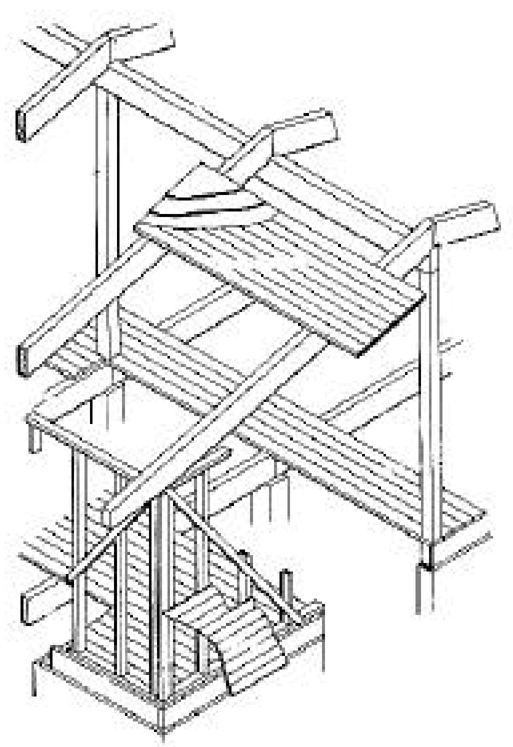


Fig 16: Post & Beam with wood infill

When post and beam construction is used, the floor system is typically made up of planks and beams. This system has fewer members than the traditional joist method, however, the members are larger, but still require less overall depth. Since the actual supports are spaced at large intervals, the system does not work well with large concentrated loads. The planking is usually long, thin wooden members that span between the beams and form a solid covering as well (Ching, 1975).

The plank and beam system of framing works much like the roof rafter system; however, there are much fewer members. This system works with the post and beam method of construction, and uses heavy wood members for the beams. The beams can span either perpendicular to the walls or parallel. When the perpendicular method is used, the two beams meet at the ridge of the roof (Ching, 1975). The perpendicular method may or may not use a ridge beam, depending on the construction of the interior of the home. If a ridge beam is used, it is supported by interior posts (Wass, 1981). However, in the parallel method, one of the beams spans across the ridge of the roof (Ching, 1975). Planks or decking are then added to the beams to complete the structure.

Pole Construction, unlike conventional wood framing, is not built on the land, but above the land. This may be done due to site topography, to capture a view, or to elevate the house above water or marshes. In short, pole construction is suitable to a great variety of terrain, where conventional construction is cost prohibitive or even impossible (HUD, 1974).

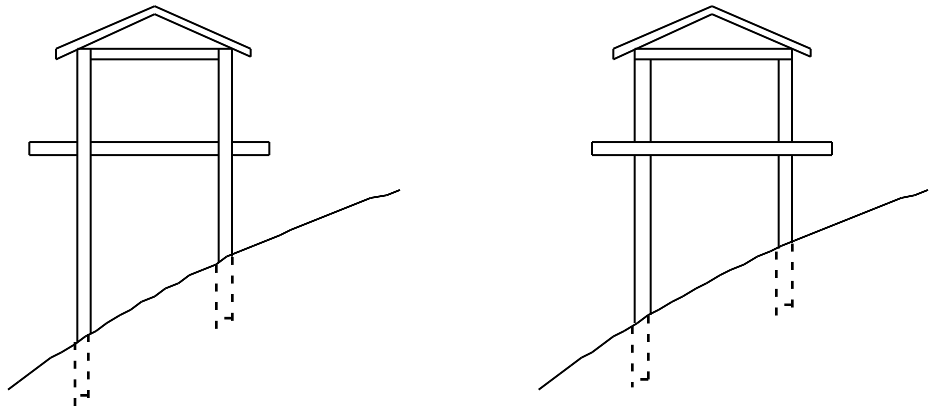


Fig 17: Pole Frame (left) and Platform Frame (right) Pole Construction

The two most common forms of pole construction are platform and pole frame (fig 17). In platform framing, the "poles" are secured either in the ground or to a concrete foundation. Then a platform is framed across the top of the poles to form the floor system. Any light weight method of framing can be used above the original platform to frame the home. In contrast, the pole frame method actually uses the poles as post members in a post and beam like method of framing. The poles become an integral part of the structure, and other light weight framing methods or panels can be used to "infill" between the large members. Poles in both methods must be braced, either with wood members or small metal rods (HUD, 1974).

Structural Masonry

Another common method of residential construction is the use of load-bearing masonry. This wall type is typically only used for exterior walls, and therefore, must be used in combination with other wall types. All masonry walls are made up of modular building blocks that are bonded together with mortar to form a solid wall. These walls can be a single wythe or double wythes, (a wythe is a single width of brick) and can also be reinforced with steel reinforcing bars. Brick, concrete masonry units, or a combination of the two can be used to form a load bearing masonry wall (Ching, 1975).

Concrete masonry units or CMU, when used alone is typically only one block wide, and may or may not be reinforced. The blocks are stacked in a staggered pattern, and when reinforced, the rebar links the blocks through the center core, which is then filled with mortar (Ching, 1975). When brick alone is used, either a bonded double or triple wythe is necessary in order to provide lateral stability. Often the two wythes of block are built up side by side, with every sixth course of brick turned ninety degrees such that one brick spans across both wythes. In other cases, the two wythes are built up with a small space between left empty. This space can either be left open or embedded with steel reinforcing bars, and then filled with mortar (Ching, 1975). In either case, the walls are tied together horizontally with joint reinforcing (fig 18).

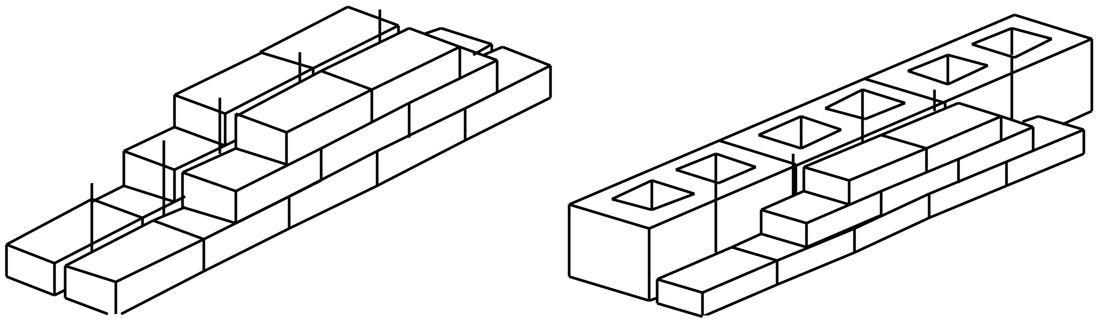


Fig 18 (left) & Fig 19 (right): Structural Masonry Wall Construction

More commonly, CMU is used with brick to form a composite wall. In this case the two forms of masonry are each built in a single wythe, and linked together using horizontal reinforcing (fig 19). Occasionally, cut stone is used in conjunction with the CMU to give a different look to the exterior of the building. In this case, the wall is constructed in the same way, except that the brick is replaced with stone (Ching, 1975).

Adobe is another, completely different method of using the earth to form the home. The materials used to make adobe bricks varies slightly by geographical region. Clay, sand, and fine silt is always part of the mixture; however, straw or broken glass may be added (McHenry, 1985). The bricks can be either sun-dried or kiln-dried, also known as burnt. Terrones are a completely different type of earth brick made of cut sod, and sometimes used in the same manner as adobe (McHenry, 1985).

The mortar used to lay the adobe bricks is very similar to the mud mixture of the adobe itself, with one major difference: there can be no extraneous matter. The mortar cannot contain any rocks or straw or glass, or any other mass larger than 1/4” in diameter (McHenry, 1985). The bricks and mortar are laid-up very much like a conventional masonry wall. Rebar can be used, as well as horizontal joint reinforcement, to stabilize and strengthen the wall, if desired (McHenry, 1985).

Concrete can also be an economical floor system, particularly for the first floor. When a concrete floor is used on the first floor, it is most often formed continuously with the foundation system. A slab-on-grade or basement floor is the most common use of concrete floors in residential construction, and are considered desirable in many areas of the country (De Cristoforo, 1977). Typically, these types of slabs are not fully reinforced, but only use welded wire mesh to help control settling and cracking (Wass, 1981).

Earth sheltered homes are any home that is built “into” the ground. Some homes are built into the side of a hill, others are completely buried in the earth. Unlike most structures, the goal of construction in earth sheltered homes is to retain the earth. Many different materials have been used in earth sheltered homes, including: concrete, steel and wood, although concrete is the most common choice (Sterling, 1979).

Cast-in-place concrete, both reinforced and non-reinforced can be used for the floors, walls, and footings. Reinforced concrete can also be used for roofs and columns and beams. Pre-cast concrete is also commonly used for self-supporting floors and roofs, walls, and columns and beams. Reinforced and plain masonry can be used for retaining walls as well as interior partitions. Steel is sometimes used for beams and columns, and wood has been used for self-supporting roofs and floors, walls, and on-grade floors (Sterling, 1979). One of the latest methods of constructing pre-cast concrete walls is to use stay-in-place form work. These foam forms remain in place after the concrete has cured, and become the wall insulation. This method of construction can cut labor time by up to 30 percent, and overall costs by as much as 40 percent, versus traditional concrete formwork (PCA, 1994).

<u>Prefabricated Building Systems:</u>

The classification of structural components and systems can best be described as the fast growing area of prefabrication, including pre-engineered panels and framing systems. As the name implies, these types of components need to be considered during the design and engineering phases. The building should be designed with the system in mind, to best utilize the advantages of the particular system. Also the chosen system needs to be well specified to prevent major problems during construction. A poorly specified system could result in misalignment of components, or incompatibility of the prefabricated components with other systems, structure, or existing conditions.

Rarely will a contractor decide to implement this type of a system, when the building has not been designed in that manner. Although that has occurred in the past, usually the circumstances surrounding the construction were far from ordinary. These types of systems are either fabricated for a particular project or, as previously indicated, a project is designed to use a system already in production. For this first reason, pre-engineered systems usually have longer lead times than conventional building materials.

These types of systems provide the designer with a large degree of flexibility. Not only are the systems themselves flexible, but the integration of other building materials and stick-built techniques are reasonably simple. Furthermore, the assembly of the system is usually a straightforward process for skilled and semi-skilled labor.

Panels are typically used in exterior walls, roofs, and floors, essentially the building envelope. There are many different types of panels, however, they all have virtually the same configuration. Panels are typically an insulating material pressed between two skins to form a structural section. Some panels have structural studs embedded in the insulating material, while others do not.

A majority of panels utilize standard building materials. The most commonly used panels are fabricated with three types of foam insulation: molded expanded polystyrene, extruded polystyrene, and urethane. The typical skins or facings include: plywood, waferboard, OSB (oriented strand board), sheetrock, and metal.

A recent study by the Wood Truss Council of America framed two identical homes, one using standard platform framing, roof rafters, and floor joists, the other using both floor and roof trusses and wall panels. This study illustrated that the panel/truss system can reduce the construction time by as much as 60 percent (WTC, 1996).

Pre-cast concrete is a well known type of panel system that is currently used in a variety of building construction projects, from renovating townhomes to large scale governmental buildings. Concrete panels vary greatly with manufacturer and use, however two common types of panels are the waffle-crete panels, and solid panels (fig 20). The waffle crete panels are often thick (8” to 10”), with large, regular voids (2’x4’x6”), for insulation and weight purposes.(Rock Hard Homes Homepage) Waffle crete panels can be used for floors, walls, and roofs, with equal success. The panels are pre-fabricated in molds, shipped to the site, and lifted into place with a crane. Solid panels are often much thinner (1” to 4”), although they may also be used as the main structure of large buildings, or as just a facade in residential situations.

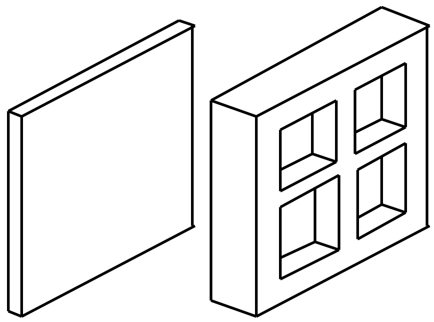


Fig 20: Types pf Pre-Cast Panels

Plastic panel systems have also been developed. General Electric tested two different plastic panelized systems. The first is a three-piece wall composite providing structural support, insulation, and finished surfaces inside and out. The second is a load bearing roof panel which utilizes a three-piece thermoplastic sandwich construction. This panel can be used as a complete roof system, and provides an internal gutter for drainage (Automated Builder, October 1988, p 25). No further development of these panels has been made public.

The Agriboard Panelized Building System is an attempt to utilize “green” materials to form a panel. This system is a structural panel manufactured entirely from wheat straw. The panels are extruded through a process of heat, pressure, and the inherent properties of the materials. Agriboard provides thermal and acoustical insulation as well as superior fire resistance, and yet remains cost-competitive with more traditional panel systems. (Sustainable Building Sourcebook, 1996)

An example of a more traditional panel system is the Thermotech 21 from Techbuilt Manufacturing Inc. Thermotech 21 is made of tubular steel and expanded polystyrene with R values ranging from R-32 to R-52. (Automated Builder, May 1994, p 23) The Thermotech 21 system can be utilized as either a wall system, a roof system or both, although the panels vary depending on placement. Since the panels are structural, roofing trusses and joists are not needed, allowing the roof space to be open or even utilized as another story. The steel framing members are recessed into the polystyrene, and joined together using self-tapping screws, and 1 1/2” x 1 1/2” steel angles. (Automated Builder, May 1994, p 23) Thermotech, like many wall panels, accepts virtually any exterior siding material, including masonry, wood, vinyl, or aluminum, which can be applied directly to the panel. Roof panels are finished with OSB or plywood, then felt paper and shingles are installed.

These foam - sandwich panels are known for their shear strength. Recent tests have shown that they are two and a half times stronger than conventional wood framing. This is due to the structural actions of the composite: the foam acts like the web of a beam, and the skins act like an I-beam. The skins take the load and distribute it evenly throughout the foam core (Automated Builder, November 1993, p 27). Also, these panels are known to have the ability to span longer distances than are usually possible with sheet products. These panels also outperform standard wood frame construction R values, primarily due to the air-tight qualities of the panels. As a direct result, heating and air-conditioning systems can usually be down-sized nearly 50% from what is required from an equivalent wood frame system. (Automated Builder, March 1994, p 22) Performance and cost-analysis tests of these foam sandwich panel systems are being conducted by the National Renewable Energy Laboratory, the Structural Insulated Panel Association, the Modular Building Institute (Automated Builder, March 1994, p 22), and the NAHB. (Blocker, 1993)

Several other panel systems have been developed and are currently in use. These vary from pre-assembled wood framing, to glass-like and fiberglass material panels, to sheet metal panels. The use of panels, regardless of the type, is known to reduce building times, often by a significant amount.

Complete Prefabricated Systems allow the most variation of use in that the majority of the building is prefabricated, yet a significant amount of site work is also required. A large range of prefabricated systems to fit into this classification, due to the loosely defined requirements of the classification. Nearly all of the building will be pre-fabricated in some way, and then shipped to the site for assembly.

This classification of prefabrication requires the most planning, and earliest commitment to prefabrication. The owner, designer, and engineer must decide to use a prefabricated structure very early on in the design process. All of the supporting structure needs to be designed with the prefabricated components in mind.

Another system includes the prefabrication of individual rooms that are set into a site-built structure. Several hotels in the United Kingdom have been constructed using this process. A structural skeleton is constructed, then individual guest rooms and bathrooms are slid into the structure. To complete the building the interior hallways and exterior sidings are finished (Guest, 1991). This techniques was also used to construct the Disney Hotel in Orlando Florida in the 1970s. This same process can be used for multi-family housing structures; in this way, the actual “plug-in” module would be the entire apartment unit. This level of prefabrication can use nearly every imaginable building material, including wood, steel, and panel systems. This type of prefabrication requires the most coordination between the on-site contractor, the fabricators, and on-site subcontractors.

The Matrex system by Terrapin is a cold-rolled galvanized steel frame, which is punched, numbered, shipped to the site, and assembled on a ready foundation (World Architect p 99). This type of prefabrication also falls into the complete prefabricated systems classification. There are several systems that use a similar technology. Many “mail-order” housing companies provide this same service. The customer chooses a floor plan, from which the components are fabricated, shipped, and assembled on site. The Lindal Cedar Homes company is one example, along with other “kit homes”, mail order log homes, and many geodesic domes.

The log home is most often a kit of large logs, that are cut to interlock and form the structural system and exterior shell of the home. It can be built using several different methods and styles. Usually, the exterior walls are constructed of logs, while the interior walls are either post and beam or stick framed (Conrad, 1995). To start the home, a log a sawn in half, and laid, flat side down as the foundation log. Each log must be notched to accept the next log. There are many methods of notching, the most common and simple is the saddle notch (Conrad, 1995) (fig 21). The saddle notch is a simple bowl like notch, that is hollowed out of the bottom log, to receive the top log. It is important that each log is notched individually, to accommodate the specific log that will be used (Conrad, 1995). The logs are sealed with mortar, chinking, or other method to join them together into a single building entity. Log building is unique in that each wall is dependent on the next, and they must all be built together.

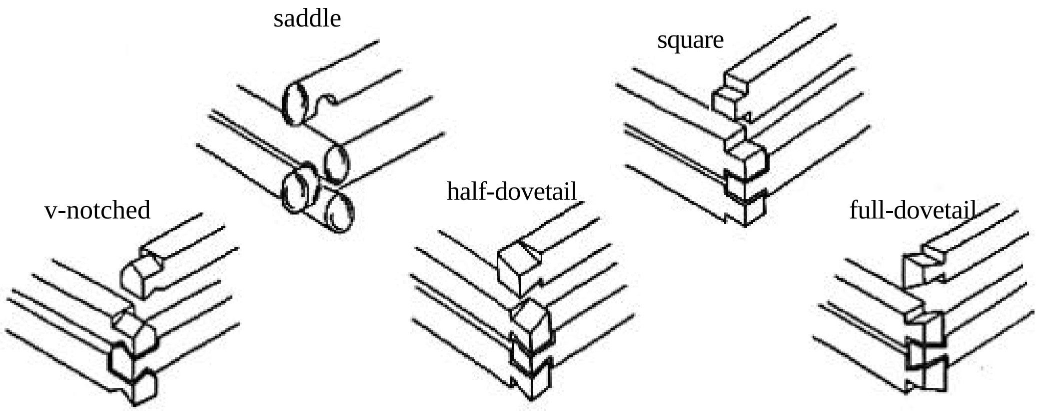


Fig 21: Types of notches for log construction

Geodesic domes were first conceived by Buckminster Fuller in the late 1940s (Rader, 1997). Now, Geodesic domes are used in residential construction all across the country. Domes are one of the most efficient shapes known to enclose an area. Geodesic domes require no interior load-bearing partitions, allowing an infinitely flexible floor plan (Rader, 1997).

Geodesic domes are usually kits that are manufactured, then assembled on the site. The dome is actually a conglomeration of regular triangles in a frame (fig 22). Most kits allow 50% of the lowest ring of triangles to be removed to allow for conventional wall with doors and windows, or hallways leading into a garage or other conventional room (fig 23). In addition, riser walls can be used to raise the height of the dome up to 7 feet. In combination with the basement, a full floor can be added below the main floor (Rader, 1997). These two techniques are often combined on sloping sites so that the entire dome is above grade, and the basement floor is built into the ground.

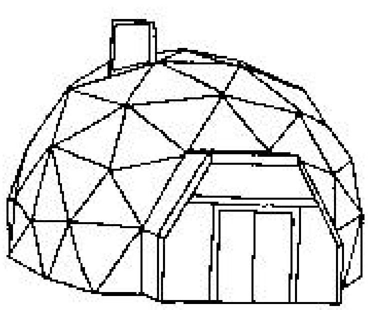


Fig 22: Typical Geodesic Dome

Fig 23: Actual Geodesic Dome House

Modular construction is perhaps the most well known type of prefabrication in this category. Modular construction is mostly a manufacturing process in which several large pieces of a building are manufactured as separate units, then shipped to the site and assembled on a foundation. The units are usually quite large (14' x 60'), and are complete with the exception of the connections between the units. Modular buildings can be constructed using a wide variety of building technologies from light wood frame construction to prefabricated wall panel systems.

Manufactured housing now accounts for nearly one-third of all new single-family homes sold in the United States. (HSH homepage, 1996) Also Manufactured housing does not follow the local building codes. Instead The Department of Housing and Urban Development has developed a nationwide code especially for manufactured housing that is enforced regardless of where the home is manufactured. All HUD Code homes must be built to this code, or the buyer will be ineligible for a mortgage loan.

As previously indicated, most forms of manufactured housing are required to conform to the state and local building codes of the home's final destination. Because these codes vary across the country, minor adjustments may need to be made during the manufacturing process to assure compliance. The home is inspected by the manufacturer's quality control program during manufacturing, and then by local building officials during the site assembly.

HUD code housing undergoes a much different process. Since the code is the same nationwide, the inspection process is regulated by HUD, but occurs in each individual plant. HUD enforces the code through individual states, and the National Conference of States on Building Codes and Standards (NCSBCS). NCSBCS is responsible for monitoring the performance of third-party HUD certified agencies (RHS, 1991). These third-party inspectors inspect the blue-prints of the home for compliance with engineering standards, and then inspect the in-plant process as the home runs through the factory. HUD requires that each manufacturer prepare a quality assurance manual, which includes a list of tests and inspections required at each assembly station in the factory. This manual must be approved by a HUD-certified agency (HUD, 1994).

The in-plant inspection process is timed such that every home is inspected during, at least, one stage of production. During a typical inspection, the inspector will visit each station of production, therefore inspecting anywhere from 10 - 20 homes in each visit. When homes are certified by the manufacturer to have been inspected according to HUD procedures, a label is affixed to the home (RHS, 1991).

Most Manufactured Housing companies utilize similar techniques and technologies to produce their product. And although there are differences from one manufacturer to the next, the magnitude of the differences is quite low when compared with the overwhelming similarities. It is also very important to understand the similarities between Modular housing and HUD Code housing; their construction is virtually the same, with the exception of the inspection process and foundation attachments. A large percentage of the population has viewed HUD Code housing as a sub-standard form of housing over the past 30 years. However, Modular housing is seen as a satisfactory solution to the current economic situation (HSH homepage, 1996).

Analysis of the Literature

After reviewing the literature, it becomes obvious that there have been many materials and methods used in residential construction over the history of the United States. However, when these materials and methods are closely examined, we can see that very little has actually changed. For the most part, current construction practice uses the same materials and techniques, with only minor modifications, that have been used for hundreds of years. Furthermore, the changes that have been implemented, not withstanding manufactured housing, have been a slow progression from many small building blocks to only a few larger pieces to form the entire home.

After careful consideration and analysis, it becomes apparent that there are only four basic methods of construction used for single-family homes: post and beam with infill, stud construction, structural masonry, and modular building units. There have been many variations of each of these methods, using many different materials; however, the final outcome always takes the same form. On a similar note, there have been very few changes in the raw materials used in construction; earth, wood, glass, and metal. Each of these raw materials has been processes and used in various forms to construct homes.

Certainly using earth to build homes is the oldest method of construction. The earth has been used to form mud dwellings, adobe, brick, and concrete. In most circumstances, the earth bi-products are used to make masonry building materials. The methods used to build with masonry are virtually the same regardless of which form of masonry is used; further, other materials such as glass can also be used in this way. The wall of blocks is mearly an organized stack of materials, to form an enclosure. The early Spanish-American homes used adobe construction with large wooden beams for the ceiling structure. Then, nearly one hundreds years later in the eastern part of the country, field stone houses used the same method of construction, including the wooden beam roof structure.

Traditional post and beam construction has come to mean a large timber frame, with an infill of non-structural wood panels, of some kind. However, if the post and beam method is extrapolated, it becomes a form or template for a composite wall structure, rather than a specific building method. This template has been used over and over again in residential construction, from “post-hole” houses and waddle and daub construction to the contemporary method of using stress-skin wall panels as the infill for a large timber frame. Some other examples of infill panels over the years have been brick or stone, straw and clay, and wooden clapboards or exterior shingles. The less traditional applications of post and beam have been steel columns and beams infilled with glass panels, log construction, and pole construction. Further, nearly every other method of wall construction used can be incorporated into post and beam as the infill segment.

The movement from post and beam with wood stud infill to using wood studs as the actual structure was one of the first steps in construction where manufacturing techniques affected building technology. The method of stud wall construction has taken different forms throughout history. However, each of these forms has varied slightly when compared to the other methods of construction used. Stud construction is relatively new when compared to post and beam or structural masonry, and is a biproduct of the industrial revolution. This newer method uses both wood and light gage metal as the structural members; further, stud construction is now used as the basis for most structural panel systems.

Regardless of the method of construction used, the building materials have evolved quite a bit over time. While the same raw materials are still being used, manufacturing has changed the final product. In the early years, earthen materials were used in their raw forms: mud, clay, waddle and daub, and stone. Similarly, whole logs were often used. As time progressed, the material changed to better suit building methods; adobe blocks were formed, and heavy timber members were cut from logs. Them the materials began to undergo processing of some sort. Bricks were formed by baking the clay, concrete was made by combining cement, water, and small rocks and sand, and small wooden members were milled out of whole logs. These refinements began to show builders that the material could change the building methods.

To imply that the refinement and progression of materials did not go hand in hand with the innovations in building methods would be misleading. The changes in both methods and materials have displayed a slow progression from a simple, multiple repetitive unit approach to a modular composite building unit approach. This can be illustrated when wood construction is analyzed.

Wood construction methods began with very large timber pieces, that were joined with detailed joints to form a framework for the building. That framework was then filled with any number of materials, but mainly many small wooden boards. This post and beam method of construction used two distinct systems of construction; namely the heavy timber frame and the infill system.

Then light gage framing methods were developed and used. First balloon framing used many light weight, long wooden members to create a light, simple structure. This system did not require a second infill system, only an exterior membrane. At first this membrane used several small boards or shingles to create a solid cover for the framework. As manufacturing processes progressed, large sheets of wood were used to cover the framework more effectively.

The movement from post and beam to light gage framing was a significant change both in material and method. No longer were large, heavy timbers needed; smaller members were used. This allowed construction to proceed much quicker than it previously had. Further, two distinct types of construction (the frame and infill) were not used; this allowed the construction to flow and move more quickly. In addition, the materials were easier to obtain, easier to handle, and easier to assemble. The introduction of sheet goods, like plywood, OSB (oriented strand board), waferboard, and gypsum board, also significantly increased the speed of construction. Now an entire area could be covered more quickly, more cheaply, and more effectively. The movement from balloon framing to platform framing only reinforced many of these same improvements.

However, the progression from light gage framing to panelized wall systems was significant. Much in the same way that sheet goods changed the process of covering the framing, the advancement to panelized wall changed framing altogether. Now entire sections of the wall could be constructed and assembled more quickly than ever. No longer were walls framed stick by stick; instead the entire panel was built, and then placed. Even if the panel used stud construction, there was the potential for time savings, since the panels could be built prior to the time when framing could otherwise begin. While the industry in general has not fully embraces all of the possibilities of panelization, most builders have been exposed to the concept of panels.

A similar movement from individual pieces to units of building materials can be seen in trusses. Both roof and floor trusses provide a very similar advantage over joists and rafters that wall panels provide over stick framing. By using either a pre-fabricated or pre-assembles roof or floor truss, the builder has the potential to not only save time, but use less skilled labor to assemble the parts.

The movement from building units, like panels and trusses, to modular construction is one of the latest movements in innovative building materials. This innovation allows entire building sections, (like roofs, exterior walls, and rooms) to be pre-assembled, either on-site or off, and then installed on the building site. Regardless of the form, modular construction is currently pushing the envelope of building innovation farther. These typically wood framed units now arrive at the site ready for installation, allowing the builder a significant opportunity for increased time savings. This time savings is again realized by overlapping construction activities. The concurrent construction of foundation, walls, and roof structure can compress the entire construction schedule, thereby saving builders and owners time and money. Further, many times these modular building pieces are fabricated in a controlled environment, which allows for even more time savings.

This same movement from individual building blocks to entire modular construction units is also evident in other construction material types. For example, earth construction has followed a similar evolution. Beginning with piling the clay in layers, and then moving to block units, the materials and methods became more refined. This innovation was furthered when cast-in-place concrete was first used, allowing an entire wall to be constructed at one time. The latest advancement of this innovation is the use of permanent forms. No longer is the process of forming the wall seen as additional time spent; now the form remains as a part of the wall section, thereby becoming functional. In this way, an entire step is removed from the construction process.

Regardless of the material type, the evolution from raw material to refined single pieces to composite units is apparent. Certainly this process of innovation has been driven by the more efficient use of materials, a better use of time, and material availability. Yet it lacks the widespread acceptance that often comes from innovation.

The reasons for this resistance to innovation is not fully known; perhaps it is due to ignorance on the part of most builders. By not understanding what technologies are available to them, and the impacts these methods could have on their businesses, they are slow to change from the known to the unknown. The actual reason could be rooted in the lack of understanding of the potential time savings. Furthermore, many builders may feel that these innovations are costly, or that they do not have the resources to handle the technology. For the most part, the building industry is slow to change; builders, on the whole, tend to stick with the conventional methods that they know and understand.

Means and Methods of Research

A goal of this research was to identify the various methods of construction that are currently used to build single-family housing in Mid-Atlantic college towns of the United States. Construction methods were determined by interviewing actual residential builders in these types of towns. Once these methods were identified, an analysis of their efficiency and productivity on a project were determined in comparison with one another. This was accomplished using both builder input and direct observation of these construction methods. Further, after each method had been evaluated on the basis of productivity, other methods of construction, such as prefabrication and modularization, were evaluated using the same criteria.

Questionnaire for Builders

In order to determine which methods of construction builders use and prefer, the following list of questions were put together and presented to 30 builders (Appendix A). A majority of these builders are located in the Blacksburg area, most of the others are located in towns very much like Blacksburg, Virginia. These other towns were selected based on their population, geographical location, and the location of a large sized university within the town limits. By interviewing these builders, a large amount of practical knowledge and real-life data was obtained that cannot be found in any published form. Builders were interviewed in two different ways: all of the builders in Blacksburg 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 builder to complete the questionnaire on their own, and then return it to the investigator. Each question was designed to extract specific information from each builder or company.

The first four questions were: **What is your most common type of project? What is the mix of new homes & remodeling jobs each year? How many single-family homes do you build in a year? and What is the average size (SF) of a home you build?** These questions were meant to establish what type of company is being interviewed. In general, the size of the company, the scope of work undertaken by the company, and the focus of the company were all determined in these first questions. This group of questions enabled different builders to be grouped together based on similarities in their products and their company size. This grouping allowed for a more comparative evaluation of construction methods.

How are your building plans prepared for your projects? This question looked at the processes that occur before construction, and helped to determine the level of involvement of the builder in this stage of the project. Further, this question determined if the builder had any control over the design phase, and if they could be instrumental in incorporating alternative methods of construction into the planning of the project.

What trades do you perform with your own labor? This question began to determine how the much the builder was involved in each project, and what the builder's direct technical involvement in the materials and methods was. Builders who do not perform the trades that were being evaluated in this study may not have the same technical information as a builder who self-performs these trades. Further, this builder may not have control over the methods of construction used on their projects, or may not use any one method with enough consistency to make any relevant conclusions. However, the same builder could have an insight about the overall efficiency and productivity of certain methods through management of subcontractors. In addition, the builder may have a more objective opinion about methods that they have been involved in that can be gained from being slightly removed from the actual process.

What is the most common method of construction that you use for floor systems? walls? roof structures? These questions began to get at the kernel of a builder's construction methods. The first segment probed into the exact method and materials each builder used to build the floor systems of a home. The second question then asked builders to define the materials and methods they use to put together the walls of a home. This question gave builders the opportunity to differentiate between the exterior and interior walls, if the method of construction varies. The third segment of the question delved into the materials and methods of construction that the builder used for the roof structure. This group of questions allowed several different methods of construction for the floors, walls, and roof structures to be identified and understood before any analysis on these methods was performed.

Why do you use these methods? Do you consider this to be an efficient method of construction? These two questions began to look at the motivation of the builder and identify their concerns and priorities. Some builders may perform in a certain way based on monetary motivation, or customer satisfaction; other builders may have different motivations. The combination of these two questions tried to identify when this was the case. The heart of these questions however, lies with the objective question of efficiency and productivity. Here builders had the opportunity to provide information about the advantages of the system or method they currently use. The combination of these two questions tried to identify both efficiency and productivity concerns of the method of construction used.

How long does it take you to frame-out the average size home previously identified using this method? This question acted as the primary method of productivity comparison between methods of construction. This question intended to create a baseline of comparison for different methods of construction, within the groups established by the first set of questions.

What alternative methods of construction have you built? Why? Why not? These questions began to look at other construction methods that the builder had tried or been directly involved in. Once these secondary methods were identified, a comparison between the two methods could take place. Once again, the motivation of the builder becomes significant.

How were these alternative methods used? With what frequency? These questions gave the investigator an idea of exactly how familiar the builder was with these other methods. The level of exposure to these methods could have significant bearing on how the builder views each method. The intent of this question was to identify builders who could provide reliable insight into alternative methods of construction.

Were these alternative methods successful? Economical? This question began to establish that success and economy are not always synonymous, but also gave the builder a place to express what he really felt about using the method. This question went past the pros and cons, and began to ask why it worked or didn't work, how could it work better, and under what circumstances or conditions would this method be ideal for builders. This was also the only place that builders are specifically asked to evaluate a method based on the economics of the materials and method.

Do you feel that these methods improved productivity? why or why not? This question took a look at a comparison of the two methods, based solely on time and productivity issues. It began to determine why one method is preferred over another, and how the labor force dealt with the alternative methods.

How do you measure your productivity on a project? As a follow-up to the previous question, this question determined the various methods builders used to evaluate productivity. It also helped in qualifying the previous answers based on the methods used to determine if a method is more or less productive.

What would be the ideal method of constructing a home for you? Why? This question was designed to identify which building method a builder would choose under ideal circumstances. This question was aimed to answer any of the questions about why builders choose to use a specific method. This question gave builders the opportunity to address a method of construction they think would be better, if conditions were different from what they actually are.

What is the least conventional method you have ever used to build a home? Just in case there is any other method that has not been established prior to this question, this question allowed builders to speak about very unusual projects that they have been involved with.

What changes in your construction methods can make your crews more productive? This question was designed to get builders to respond to the overall productivity and changes they have made to their current method of construction, to improve this productivity.

What is your biggest productivity challenge? This question gave builders the opportunity to discuss what they feel is the biggest obstacle effecting productivity of the labor on their jobs.

Can prefabrication, preassembly, modularization be incorporated into your projects? If so, how? This question was designed to see if builders are aware of the methods of prefabrication, preassembly, and modularization that are available to them at this point in time. Also, it determined if builders would use these methods in their projects, and why or why not.

Observation of the Methods

After each method of construction had been identified by the builders, there was a period of observation by the investigator. This observation was made during a visit to a project where the construction methods defined by the builder were being used. During this on-site visit, the method of construction was closely observed and documented with notes and photographs. Exact construction methods and crew size were determined or clarified as needed. This on-site observation was only conducted for construction projects in the Blacksburg area.

The method was evaluated based on the speed of production, the ease of construction, and the efficient use of crew time. These evaluations were made based on conversations with labor and craft foremen, as well as observation by the investigator. Each method was compared with other similar and dissimilar methods to determine the overall productivity and efficiency of the method.

Methods of Analysis

In order to evaluate each method of construction, several steps were taken. The first of these steps was to use the first four questions on the builder questionnaire to place the builders into groups. These groups were formed by placing all builders with similar products, product sizes, and company profiles together into a group. Several groups were needed to encompass all of builders questioned.

Once these groups were formed, the methods of construction used by each builder with a group were identified. This identification occurred individually within each group. If more than one type of construction is used by a builder, these methods were considered independently of each other, as if the two methods were performed by two distinct builders.

Once each method was identified and defined, each group was studied to identify similarities and differences within the group. Once these were identified, insight into the possible motivations of the group of builders as a whole was explored. Further, these similarities were used to contribute understanding of the method of construction that was not evident from the evaluation of a single builder.

Next, each method was evaluated for overall productivity within the group of builders. This evaluation involved the responses from the builders as well as the site observation defined previously. Once each method had been evaluated, the methods were compared with one another and ranked on the basis of comparative efficiency, based on time.

Lastly, the results from each individual group were compared with the results from the other groups to determine if there are any similarities between groups. Further, industry wide trends were identified. These results were then measured against known manufacturing and prefabrication productivity to establish the potential to use the alternative methods in the future.

Observation of Manufacturing Methods

In order to observe the methods of construction used by the manufactured housing industry, three manufactured housing plants were visited. These plants were owned and operated by R-Anell, Nation Wide Homes, and Oakwood Homes Inc. Each plant manufactures housing for distribution across the entire United States. Timber Truss

Housing Systems Inc., a component manufacturer with a plant in Salem, Virginia was also visited.

R-Anell Custom Homes is ranked as the 23rd highest industrialized home-builder by gross sales volume (Automated Builder, December, 1996). The factory and company headquarters are nestled around Lake Norman, in the tiny town of Denver, North Carolina.

R-Anell is in a unique manufacturing situation; they manufacture both HUD Code homes and Modular homes on the same line. HUD Code homes are the legal classification of homes with are built to the HUD building code, often referred to as a mobile home. Modular homes are factory built homes, that are built to local building codes, and set on a permanent foundation once it is brought to the site. All of their homes are made of at least two units, and a few as many as six units. HUD Code homes are always one level, but Modular homes are either one or two levels. R-Anell gives customers the opportunity to modify floor plans slightly, in order to better suit the needs of the user. In some lines, major changes can be made, without compromising the structural integrity of the units.

Oakwood Homes Inc. is ranked as the 3rd highest industrialized home-builder, by gross sales volume (Automated Builder, December, 1996). The company headquarters is located in Greensboro, North Carolina, with manufacturing plant scattered across the country. Oakwood Homes produces both single and double-wide HUD Code homes. The plant observed for this research is located in Richfield, North Carolina, and only manufactures double-wide HUD Code homes.

There are two individual lines at the Richfield plant, each line is responsible for producing one line of homes, with 4 to 6 different floor plans (Oodey, 1996). Each line averages 12 floors/day (6 homes), and employs 140 men. In order to keep the line as productive as possible, Oakwood produces several of the same models, back to back, and then switches the entire line to a new model.

Nation Wide Homes, Inc. is ranked as the 31st highest industrialized home-builder, by gross sales volume (Automated Builder, December, 1996). The factory and company headquarters are located in Martinsville, Virginia. All of Nation Wide's homes are made of at least two modules, and a few as many as six units, both one and two stories. Nation Wide sells homes to both the general public and builders, and gives them the opportunity to modify floor plans slightly, in order to better suit the needs of the user. Nation Wide offers three lines of housing, each built to the same quality standards, but vary in the quality of finishes.

The Timber Truss plant manufactures stressed-skin wall panels, interior wall panels, roof and floor trusses, doors, and windows. The company provides builders with all of the materials needed to build a pre-planned home, including trim and basic finishes. Builders may use any of the pre-planned homes or bring their own plans to the company. Timber Truss engineers can design the appropriate panels and trusses to build the home. Builders can also buy individual building parts from the plant, including trusses, wall panels, and doors and windows.

By visiting these plants, and observing the production of homes and building systems, the investigator was able to identify the methods of construction used in manufacturing. Further, these methods were able to be evaluated based on the overall efficiency and productivity of these techniques. In addition, specific production information was obtained from the manufacturing plant historical files. These results will be used to establish the potential to use the alternative methods in the future. Furthermore, it will be determined if these methods from manufacturing and prefabrication are applicable to the identified groups of builders.

Results

Questionnaire and Site Observations

Thirty residential builders were interviewed about their methods of construction, using the questionnaire defined in the means and methods section. These thirty builders were all located in rural university towns in Virginia, North Carolina, and West Virginia. Twenty of the builders were located in Blacksburg, Virginia; seven other builders were located in Greenville, North Carolina, and the remaining three were located in Morgantown, West Virginia. After the interviews were complete, the builders were divided into six groups based on the type of work and quantity of work performed. These six groups are: 1) primary remodeling, 2) 1-2 homes per year, 3) 3-8 homes per year, 4) 8-20 homes per year, 5) 20+ homes per year, and 6) builder/developer. These groups were not predetermined, they were defined quite easily after a brief assessment of all of the builders involved.

Group 1: Primarily Remodeling: This group of builders is involved in remodeling or adding onto existing residential construction in 50% or more of their projects. The methods used by this group of builders are traditional platform stick framing. The most common method of construction used for floor systems were wood joists; although, when the situation allows, a few builders do use floor trusses. Every builder interviewed in group 1 uses 2x4 platform framing to construct the walls. The walls are framed flat on the ground or subflooring. Both the sole plate and double top plate are laid out, and then the studs are attached to both (fig 24). Lastly, headers, jacks, and cripples are added, then the wall is raised into place (fig 25). A few of these builders also attach the sheathing while the wall is flat on the ground (fig 27). Nearly half of the builders use rafters, the other half use trusses for the roof structure, and many indicated that they use both depending on the complexity of the roof as well as the relationship of the new roof to the old roof.

Fig 24: wall framed flat on subflooring

Fig 25: wall is raised into position

Fig 26: sheathing attached while flat

This group of builders has had the opportunity to try many alternative methods of construction including: pole construction, modular units, panelized wall systems, a masonry block house, and log cabins. The builder's opinions varied significantly on why these alternative methods were better or not. Many builders identified floor and roof trusses as much better methods of construction, as long as they were feasible for the given project. And two builders who had tried pole construction found that it was very successful when the terrain was very irregular, and would require large amounts of excavation using any other construction method.

Nearly half of the builders had tried panelized walls of some kind, and none of them found them to be a viable alternative to stick building. Complaints about the panels ranged from panel imperfections that caused extra work to the inflexibility of the system. For the most part, group 1 builders felt that prefabrication, pre-assembly, and modularization had no significant role in remodeling projects.

<u>Group 2:</u> 1-2 homes/year: These builders primarily build new homes, but often fill their time with small renovation projects as well. This group of builders also tends to use very conventional stick framing methods. The most common construction method used for the floor systems is wood joists, although trusses and composite wood "I" beams are used. All group 2 builders use field assembled, pre-sheathed 2x4 platform framing to build their walls; with the exception of one builder who pre-assembles his walls in an off-site shop, delivers them to the site, and then sets them into place (fig 27). Several install house wrap on the panels prior to erection. Once again, builders are divided equally in their use of roof rafters or roof trusses.

Fig 27: Pre-assembled wall panels

This group of builders has tried far fewer alternative construction methods than group 1. The methods they have been involved in are: therma-form concrete walls, panelized walls, log homes, and stress skin panel construction. The builder who used the therma-form concrete wall system felt that it was less efficient than platform framing, although it did have other benefits, such as energy efficiency, and structural integrity. This construction system uses pre-formed Styrofoam forms, that snap together to make a continuous wall form (fig 28). The forms can be cut to work around openings in the wall (fig 29). Then the forms are filled with reinforcing bar (fig 30), and finally the concrete is poured into the forms. The forms are not removed, since the foam acts as the insulation for the wall (fig 31).

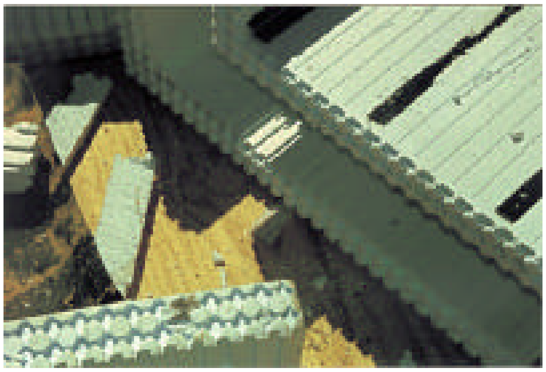


Fig 28: Styrofoam forms

Fig 29: Forms are assembled

Fig 30: Reinforcement in forms

Fig 31: Completed walls

Builders of 1-2 homes per year using formed insulated wall panels believe that it is not a productive method of construction. This opinion was based on the the amount of time the crew spent fixing the perceived imperfections in the panels. One builder felt that the use of stressed skin panels in combination with timber framing saved time, but was not economical in comparison to 2x4 studs. In the author's opinion, this was attributed to unfamiliarity of the labor to the building methods, and could be overcome with repetition.

Builders of 1-2 homes per year expressed the willingness to incorporate pre-fabrication, pre-assembly, or modularization into their construction projects. Most of these builders have tried pre-fabrication or pre-assembly, and feel it could work well in the future, with an advancement in the quality control, and the education of labor.

Group 3: 3-8 homes/year: This group is involved only in new residential construction. The most common method of construction used for the floor systems are floor trusses, although nearly half still rely on wood joists some of the time. Floor trusses are pre-engineered trusses that are used in place of the joists (fig 32). The trusses allow utilities and HVAC systems to pass through the floor system, without interruption to the structure. Trusses are generally stronger than joists and can span greater distances with less depth (fig 33).

Fig 32: Floor trusses

Fig 33: Floor Trusses

The wall systems vary, with the majority of builders using 2x4 platform framing with sheathing attached. Other builders use log wood construction, steel stud and expanded polystyrene panels (RAD-VA), and post and beam. Nearly all prefer roof trusses to rafters; one builder uses primarily modular construction.

Most of these builders have tried some unconventional alternative methods of construction including: wood and foam panels, structural wall panels, Styrofoam formed concrete walls, balloon framing, metal studs, and prefabricated walls. One builder feels that modular construction is an ideal method of building. Both builders who have used the Styrofoam formed concrete walls feel that the method saves quite a bit of time, in contrast to group 2, although they are no more cost effective than traditional platform framing methods.

Most of these builders have tried panelized walls of some type; all agreed that there is a significant time savings over standard platform framing. One builder uses the wall panels when there is a need to accelerate the schedule. However, each builder also expressed a concern with the cost of using panels, stating that the materials costs were significantly more expensive than platform framing. This makes the method faster and more productive, but no more cost effective.

Eighty percent of this group already incorporates some form of prefabrication, pre-assembly, or modularization into their projects. In fact, forty percent stated that they moved into these systems to increase their overall productivity. A common consensus among these builders is that the prefabrication movement will become the most commonly used method in the future.

Group 4: 8-16 homes/year: These builders are more conservative, yet more experienced than group 3, and tend to use more traditional framing methods. They each self-perform only carpentry activities, and tend to be more involved in managing the project than any previous group. The most common method of construction used for the floor system is wood joists. Only one builder uses trusses as a primary method of construction. 100% of this group use roof trusses for roof construction.

The walls are commonly 2x4 platform framing, with sheathing attached prior to setting the wall. One builder often builds the walls at an off-site location while the foundation is being built to save time, and to allow building to progress despite the weather. Another builder uses a "northern platform" framing method. This method attaches the sole plate of all of the walls to the subflooring, then builds the double top plate separate. The three plates are then aligned and marked for the location of each stud (fig 34). The studs are then attached to the double top plate, while they are flat on the ground (fig 35). Then the wall is lifted into place, and finally the studs are toe-nailed into the sole plate (fig 36). A third builder uses the RAD-VA steel and EPS panels for all exterior walls, with steel stud interior walls.

Fig 34: the plates are aligned and marked

Fig 35: studs are attached to top

Group 4 builders have tried the widest variety of alternative construction methods including: timber framing, floor trusses, geodesic domes, panelized walls and roofs, steel studs, pre-stressed wall panels, and rough sawn lumber framing. One builder believes that the cost of timber framing is about the same as platform framing; however, this same builder thought that timber framing is more difficult to build with and often takes much longer. Another builder made the observation that it cost nearly 17% more , total labor and materials, to use a panelized wall and roof system; however, it was a much faster method of construction. A second builder agreed that the panelized homes are much faster to build with, stating that he had recently completed a project with panels in fourteen days, that would have normally taken over twenty days, using conventional methods; however, there was no material cost savings to the builder.

Fig 36: Wall assembly is lifted in place

Every builder interviewed expressed willingness to use pre-fabrication, pre-assembly, or modularization in a project, as long as the home buyer requested it. One builder even identified stressed skin panels as an ideal method of construction because of their energy efficient properties.

Group 5: 20+ homes/year: These builders use a mix of both conventional construction methods and other methods. The most common method of construction for the floor system is the conventional wood joist. The roofs are almost always built from pre-engineered wood trusses. One builder even assembles the trusses off-site, pre-fabricates the roof, and then transports the entire roof structure to the site.

The methods used for wall construction vary; 50% use 2x4 sheathed platform framing, while the other 50% pre-assemble the walls in some way. These builders have very limited exposure to alternative methods of construction; however, may of them have tried modular housing. Many that have tried modular construction feel that it is not cost effective for the builder at this point in time; however it is faster. One builder identifies pre-fabricated building components to be an ideal method of construction for both his company and the owner.

Group 6: Builder/Developers: These builders construct single-family, multi-family, and light commercial structures. For the most part, these builders sub-contract nearly all of the actual construction, and act only as the managing and coordinating agent. This causes these builders to be highly concerned with the cost of the project, along with the duration.

Both roof and floor trusses are the most common method of construction used by this group, with over 80% using both. Wall construction is split with 50% using 2x4 sheathed platform framing, and the other 50% using metal studs, framed the same way. One builder uses the steel and EPS (RAD-VA) panels for the exterior walls.

These builders have tried alternative construction methods, including, modular housing and wall panels. Opinions were mixed on the productivity and economy of modular construction; one builder believes it is cheaper, faster, and produces less overall waste on the job, and another stated that both panels and modulars were not any faster nor more economical due to the unfamiliarity of the labor with the process. A third builder felt that time and cost savings are apparent only when the modular units require no customization at all.

Nearly all of the builder/developers state that they already incorporate pre-fabrication, pre-assembly, or modularization of some form into many of their projects. In fact, one builder stated that the move into modular units has increased productivity by over 100%.

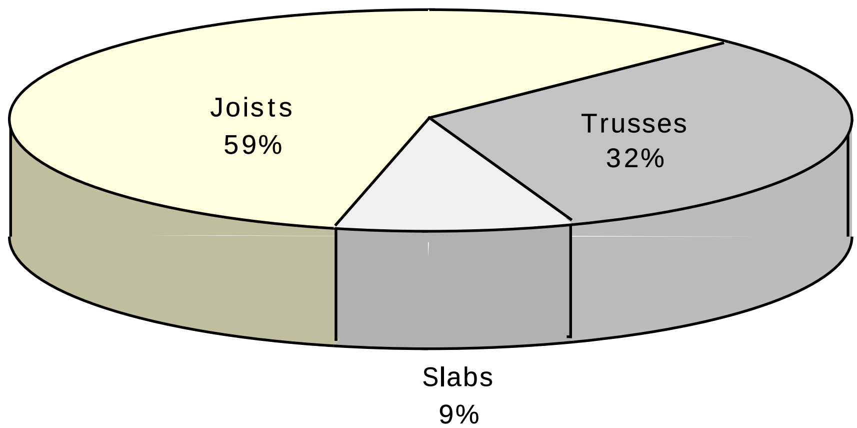
The following chart summarizes the most common methods of construction used by each group for floor systems, walls, and roof structures (Table 1).

Table 1: Summary of Most Common Methods of Construction per Group

Group	Floor System	Walls	Roof Structure
1	wood joists	2x4 platform, built flat	rafters (55%) trusses (45%)
2	wood joists	2x4 platform, built flat	wood trusses
3	trusses (55%) or joists (45%)	2x4 platform, w/ sheathing	wood trusses
4	wood joists	2x4 platform, built flat	wood trusses
5	wood joists	2x4 platform, w/ sheathing 2x4 platform panels	wood trusses
6	wood trusses	2x4 platform, w/ sheathing metal studs	wood trusses

The following pie charts designate each method of construction used by all of the builders, for floor systems (Chart 1), walls (Chart 2), and roof structures (Chart 3).

Chart 1: Construction Methods Used for Floor Systems



These charts show the break down of the methods of construction used for the floor systems, walls, and roof structures respectively. They do not separate the builders by group, but instead depict the true percentages of the total population of builders interviewed.

Chart 2: Construction Methods Used for Walls

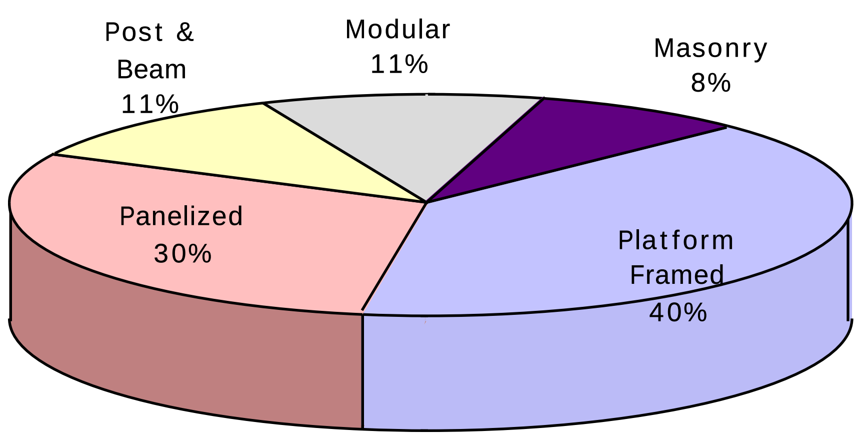
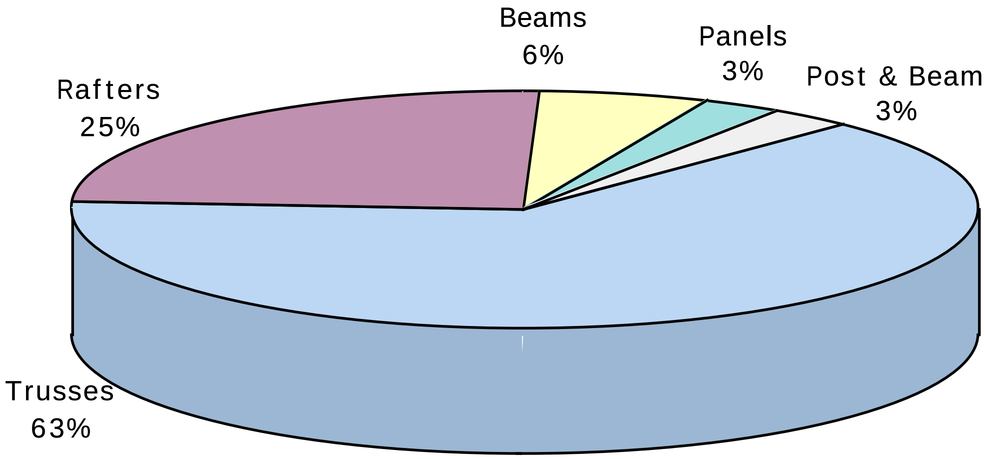


Chart 3: Construction Methods Used for Roof Structures



Productivity:

Very few of the builders interviewed believe that the actual method of construction was contributing to productivity problems. The most common productivity problems were: 1. lack of skilled labor (53%), 2. getting and keeping subcontractors on the job (31%), and 3. keeping the labor on the job working (19%). Most builders have made minor modifications to increase productivity including: changing to nail guns and screw guns, using machinery where-ever possible, training labor, and minor material modifications.

Almost without exception, each builder interviewed thought that their method of construction was the most efficient method available in their geographical area. Further, a majority of the builders measured their productivity against the budget or estimate that was determined prior to construction. It should be noted that this method does not actually measure productivity, but rather is a measurement of budget variance.

A few builders measure productivity against a pre-determined schedule, based on anticipated man-hours or historical cost data. However, nearly 35% of all those interviewed use an intuitive measure of productivity rather than a quantitative measurement. Further, many of those that used quantitative methods did not evaluate their productivity until the job was complete. This made it difficult, at times, to determine where the inefficiency was occurring - whether or not they were related to actual construction methods.

On the whole, Group 1 builders had a systematic and quantitative methods for measuring results; measuring against the schedule was the most common tool. Several used more intuitive methods. Groups 2 and 4 builders tended to use the budget or estimate as the basis of comparison, mostly concerned with the total profit for the job. Once again, group 3 builders seem to be ahead of the rest, with more than 75% of them measuring productivity in terms of man-hours worked versus planned. 50% of group 5 builders did the same; however, the other 50% used more intuitive measures. Group 6 were very schedule oriented, measuring productivity against the planned time for construction.

Manufacturing Observations:

Floor Systems: When a unit, either HUD Code or Modular, is begun, several individual pieces are brought together to form the floor system. The steel chassis, made mostly of I beams, is welded together to form the structural undercarriage, and then coated with a protective paint. For all HUD Code units the chassis will become a permanent part of the home; Modular homes will be moved off the chassis at the site. The floor system is usually built up-side down, beginning with the joists, which are aligned on a jig, with double headers and rim joists. For HUD Code homes, 2x6 joists are used, but in Modular homes 2 x10 joists are used (Jones, 1996).

After the joists are laid out, screwed and glued together, the plumbing and HVAC are laid into the flooring system. The plumbing system is made of small, flexible plastic pipes, which are joined together, using rubber connectors. The entire plumbing system is connected off of the line, and then placed into the floor. Lastly, insulation and a poly vapor barrier are attached to the top of the system (fig 37), and it is flipped over and placed onto the steel chassis. HUD Code homes are lag bolted through the floor system into the steel chassis.

Once the floor has been flipped into its proper position, Oriented Strand Board (OSB) is glued and stapled onto the top of the flooring system. Then openings are cut in the floor to allow HVAC and plumbing connections to be made. The entire floor is power sanded, and the areas around the plumbing openings are sealed with a waterproofing coating (fig 38). Next pre-cut padding, carpeting, and vinyl floorings are applied to the appropriate areas of the floor. The plumbing lines and HVAC vents are brought up through the floor, for future attachments. A chalk line is used to locate the placement of interior walls, and finally the floor is covered with plastic to protect the surfaces during manufacturing (fig 39).


Fig 37: The Complete Floor System


Fig 38: Sanding the Sub-Flooring


Fig 39: Padding for Carpeted Floor

The Walls: All of the walls are constructed off of the line, on either a table or a flat jig (fig 40). The walls are laid out on the gridded table, with pre-cut studs, top plates, sole plates, jacks, and cripples. The jig is cut to allow 2x4s to be placed 16” on center, for standard walls, as well as additional wood to be placed for wind-zones 2 and 3, as designated by HUD code (Oodey, 1996). The studs are laid out, with window and door openings, and then base plate and top plate are attached. All wood for both walls, floors, and roofs arrives at the plant pre-cut to the proper lengths, and with electrical notches pre-cut (fig 41). Sheet rock is glued and screwed onto one entire side of the wall, and the exterior walls are fully insulated. All walls are 2x4s with the exception of the two unit mating walls, which are 2x3 construction. Also, exterior walls can be upgraded to 2x6s, for an additional charge on most HUD Code homes, and all Modular homes (Jones, 1996)(Crotty, 1996).

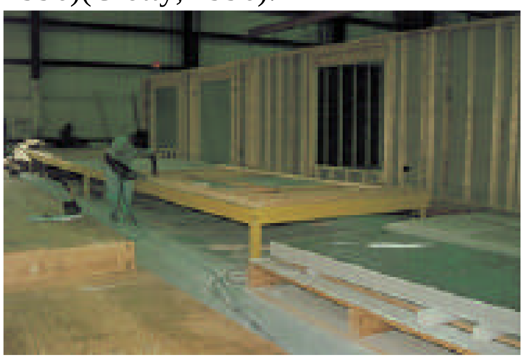


Fig 40: Wall construction, on table

Fig 41: Pre-cut wood stored below

Once the sheet flooring has been applied, the interior walls are lifted and placed onto the unit. This is accomplished using an over head, electronic, cable and hook system. The wall is hung from the hook by straps, similar to a crane set-up, and then moved across the plant into the appropriate position. The wall is then lowered, screwed into the flooring system, and then detached from the hook. Concurrent with the placement of interior walls is the placement of all interior plumbing fixtures (tub, showers, toilets, water heaters, and mechanical units). The fixtures are hooked immediately to the plumbing line which was previously installed.

At the fourth station, the exterior walls are brought to the unit, and screwed into place. Then, small notches are removed from all of the exterior wall studs, and electricity is wired through all interior walls, and along the exterior walls, in the small notches. These notches are then covered with small metal plates, to avoid nailing through the wiring in the future (fig 42). Once all the wiring is in place, sheet rock can be glued and screwed onto the second side of the interior walls, and OSB is attached to the exterior walls.

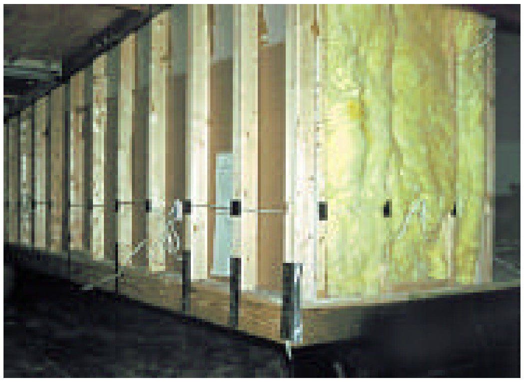


Fig 42: Notches for electrical wiring

Fig 43: Pre-Built stud assemblies

Wall Panels: The walls are assembled on a flat jig system in five steps. All wood members are cut prior to the assembly and stock-pile near the first station. Stud assemblies, like corner posts, and double studs are also pre-cut and assembled, then stock-piled near the first station (fig 43). Exterior walls are either 2x4 or 2x6 construction, and most interior walls use 2x4 construction.

At the first station, the wall panel diagrams are pulled-up off of the computer system, and elevations of each panel are printed out. Then the studs are laid out on the jig, and the top and bottom plates are attached. At the second station, all headers, cripples, and jacks are put into place as well. When the wall reaches the third station, the skin is glued onto the stud-panel, then the panel passes through a large press. The builder has the choice of four different skins for each panel; they can choose from OSB, plywood, 1” rigid insulation, or gypsum board. Interior walls usually receive no skin at all. At the fourth station, the skin is screwed onto the studs, and then the computerized router cuts all of the openings (fig 44). Lastly, the panel is trimmed, labeled, and stacked (fig 45).

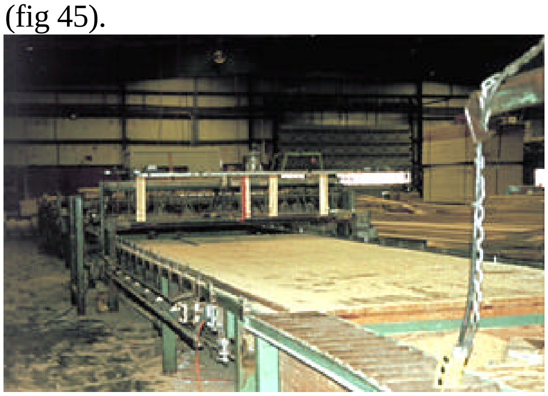


Fig 44: Panel receives skin

Fig 45: Panels are stacked together

The Roof: The roof is assembled on a second story platform, parallel to the main line. The trusses are constructed directly below the roof platform, then brought up and assembled to form the roof structure. The system is built in three distinct steps, beginning with the assembly of these large roof trusses (fig 46). Both standard 5/12 and 7/12 roofs are completed and attached to the unit for transport. The 12/12 roofs are constructed and then shipped separately, to be attached at the site (Jones, 1996). Lastly, there is the option of a hinged roof, that is assembled and attached to the unit, but requires completion on the site.

Fig 46: Trusses assembled to form roof

Fig 47: Gable end attached with hinge

If a hinged roof is being used, the upper section of the rafters are attached to the lower section of the rafters, using a large piano hinge, so that the upper portion of the roof can be folded back over the lower portion during transportation. If a gable end hinge is being used, the rafters are hinged to the ceiling joists using a large wooden hinge joint (fig 47). Also, the knee wall is hinged beneath the rafters, allowing the entire system to fold down flat (fig 48). Modular homes utilize any of these roofs, depending on the design, and the desired esthetics. HUD Code homes are only built using the 5/12 and 7/12 systems (Jones, 1991).

Once the roof structure is complete, sheet rock is glued and screwed to the interior of the roof, and then finally sprayed with a textured ceiling compound. Once the roof is dry to the touch, it is moved across the plant on a roller, attached to the top of the unit, and secured with metal straps. Lastly, regardless of which type of roof is used, insulation is placed between the rafters, and then OSB, a poly vapor barrier, and roof paper are nailed to the roof. After the roof is securely attached to the unit, insulation is placed into the roof area from above, and finally shingles are all applied to finish the roof.

Fig 48: Hinged roof with knee wall below

Floor and Roof Trusses: Once the truss system is designed, each of the truss members is entered into the computer system. When the manufacturing process begins, a computer print-out of each different truss is produced, as well as individual tags for each member of the truss. The drawings and tags are used to cut each wooden member to the proper size and angle (fig 49). Then the tags are attached to the members, and they are moved to the assembly tables on large dollies.

Fig 49: Tagged wood waiting to be cut

Fig 50: Truss assembled on table

When the actual assembly begins, the truss table is set-up for that specific design. There are many kinds of tables used for truss assembly; most of them use a metal member bolted into the table as a guide for each member. Once the table is set, the wooden members are put into place using the computer print-out and the table-guide. The metal plates are then set into place by hand (fig 51). Next a large roller presses the truss to embed the plates into the members. The truss is then moved onto a serious of rollers, which moves the entire truss through another heavy press, (fig 52) and then they are stacked in the main yard (fig 53).

Fig 51: Truss is pressed in roller

Fig 52: Trusses are stacked in yard

Conclusions/Discussion

Certainly, throughout the history of the United States, builders have tried several different techniques in residential construction. Many of these techniques, including manufacturing, are still being used by the builders interviewed in this study. However, many of these methods are no longer the most efficient and productive methods available to builders. This is because methods have evolved and new innovations are becoming available almost on a daily basis. However, as previously discussed, builders are resistant to these innovations and are very slow to change their ways.

In this study, six groups of builders and manufactured housing techniques were compared and evaluated based on the overall time efficiency and productivity for residential building. This was accomplished by using the builders' expertise, intuition, and measured knowledge, as well as some direct site observations.

Group 1 (Remodelers): The common methods of construction used by small remodelers are traditional methods for residential construction. These methods, mainly platform framing, floor joists, and roof rafters, are probably the simplest and most straightforward methods to use for additions and renovations. This is true because it is desirable to use methods consistent with the existing structure when adding on or making changes. Also, many builders expressed the need to use the most flexible method of construction possible, in order to be able to accomplish the customization and complexity desired by the home owner. They believe that their current methods provide them with this flexibility. Further, light gage wood framing is the most well known construction method and material for a majority of the labor involved in remodeling projects.

The use of trusses in the floors and roofs, wherever possible shows that these builders want to use the most efficient method possible. However, they must analyze when each method will be the most efficient for each project. The high level of customization and complexity of many remodeling projects may preclude these builders from using methods involving standardized construction. The fact that most of these builders had tried panels and found them to be unacceptable for renovation work, reinforces this conclusion. It is important to realize that on the whole, these builders are using technology developed and made popular during the American Beaux Arts period, and that this technology has been in use for nearly one-hundred years.

Group 2 (1-2 homes/year): These builders are also traditional in their methods, perhaps because they build so few new homes each year. The most common methods are floor joists, platform framing, and roof trusses. Also, since they are involved in renovation projects, as a secondary project type, they may not want to switch between two different methods. Therefore, they chose the method that works best for both situations. Builders with this company structure rely on materials that are easily available, since bulk purchasing and long-term material storage are not feasible. Light wood platform framing uses very common materials that are readily available in most situations.

Many group 2 builders only build custom homes, with very specialized plans and details. These builders believe that customization can make alternative construction methods difficult, expensive, and even impossible to use. Many group 2 builders have simply stated that standardization of their homes is not possible, and that for any type of prefabrication to be used, customers need to be willing to give up many custom details. Further, many of these builders believe that the general public sees platform framing as the best method of construction, and views prefabrication, pre-assembly, and modularization as substandard construction methods.

However, many of these opinions may not be valid. By viewing projects from a systems method of construction and not a piece by piece assembly, builders could certainly use minimal forms of prefabrication and pre-assembly to improve their overall productivity. Further, since most of these builders are involved in preparing the plans, they could have a significant impact on the type of building materials and methods that are incorporated into the project. For example, when the builder is involved in the early planning stages of a home, he has the opportunity to modify the design to accommodate most any prefabrication or pre-assembly that would improve productivity during construction. Further, many panel fabrication plants, such as Timber Truss, have the ability to produce custom panels to accommodate custom designs and details.

The public view of these less traditional construction methods is most likely the result of a lack of education. There is a lack of understanding by the general public of the quality products that are currently manufactured. For this reason, it is unreasonable to expect homeowners to request these methods. This may be due to the negative image that early unregulated mobile home construction has conveyed on behalf of the entire manufactured housing industry. However, most of the prefabricated building components, and today's manufactured housing products are higher quality products than many site-constructed assemblies.

In group 2, some of the builders have begun to experiment with the traditional method to make it more efficient or faster under certain circumstances. Building the walls in an off-site location or attaching the sheathing and house wrap before the wall is raised are examples of modifying the method of construction without changing the final outcome. These methods still allow the builder to make the simple transition between new construction and renovations. Further, the builder is achieving a slightly higher level of productivity without changing their materials in any way. With the exception of these few builders, the group 2 builders are also using hundred year old technology to construct a majority of their projects. However, even the more innovative members of group 2 are quite behind the times; these builders are using methods that were developed during the early 1930s, when pre-assembled wall sections were first used.

Group 2 builders relate their productivity, and its measurement to the project budget. While this method is flawed, since it does not actually measure productivity of the construction methods, it does indicate that this profile of builder views success as money. Since these builders are very small, and do not seem to want to expand their work load, this makes sense.

Group 3 (3-8 homes/year): These builders have a much higher volume of new homes than group 2, and are not involved in renovations at all. Further, group 3 builders do not, usually, build only custom homes. These three conditions make the group 3 builders much more open to new, modern, or less traditional methods of construction, specifically, trusses and wall panels. The most common methods among group 3 builders are the same methods that the adventurous members from group 2 are using: floor trusses, pre-assembled wall sections, and roof trusses. These methods are among the more recent technological advances in the single-family housing construction industry.

The group 3 builders are the smallest volume builders who begin to use alternative materials and methods on a regular basis. Group 3 builders use steel, log construction, post and beam, and even modular housing as primary or secondary methods of construction. Some builders in this group, use alternative methods of construction specifically to increase productivity when time is of the essence. Also, many builders use these products especially because of the predictably high quality that can be attained in the factory. Numerous builders have cited less call-backs as an added benefit of using these alternative methods. These alternative construction methods represent the most current innovations and advances in the industry.

Group 3 builders do enough business that they can realize the cost savings that lower volume builders cannot. This group of builders can benefit from a method of construction that increases their overall productivity. The actual earnings on individual projects may be lower; however, increased volume resulting from productivity improvement will reap great profits. Group 3 builders are the first group to realize that time is money, because, by building more homes, they are in a position to increase their total profits, and afford slightly more expensive materials and methods.

These builders measure their productivity concurrently with the project, by comparing man-hours used versus man-hours planned. In this way, they have the foundation for a firm understanding of their productivity problems and challenges. Furthermore, these are the builders most actively pursuing alternative construction methods. It is this profile of builder who is advancing the technologies to make new innovations available to the industry.

Groups 4&5 (8-20 and 20+ homes/year): Strangely, these builders use methods that are similar to the group 2 builders; however, there are different reasons. Unlike group 3 builders, who have the time to increase their volume, the group 4 and 5 builders state that they are building at the top of their capabilities. This is most likely because they have stopped growing and are now maintaining the company at the status quo.

These builders are once again looking for ways to increase productivity, and profit, using the common materials. This is often accomplished by assembling large wall sections and entire roofs at off-site locations, then transporting them to the site, as well as setting-up assembly lines for wall sections on site. This gives the builder a faster, and therefore cheaper method of construction that is still easy and common to most labor. While this is a much different solution than group 2 builder, it works for group 4 builders because of their product is not custom homes.

These builders are using the technologies that made them most productive during their growth phase, including: simulating manufacturing techniques on site-built projects. Due to this fact, a majority of these builders are using 20 to 30 year old technologies, not current methods. Both groups have tried various methods of pre-fabrication and modularization and confirm that the methods are more productive than any site-built methods. However, the builders feel that these alternative methods are too expensive for them to use on a regular basis. What these mature builders fail to realize, in the author's opinion, is that methods that are more productive, although more expensive, will result in a lower final cost to the builder. The amount of money lost as a result of poor productivity will most likely far outweigh the slight difference in price. By incorporating systems building into their everyday methods of construction, these builders could possibly realize a cost savings over more traditional methods.

Further, this group of builders is under the impression that customers view pre-fabrication and modularization as substandard. The methods they use provide their clients with a quality product that is predictable, and delivered within a reasonable time frame. Similarly, many builders shy away from less traditional methods because of subcontractors who charge higher rates to work with these materials. Further, there are only a few subcontractors that are willing to work with the unfamiliar materials and methods. There are many easy solutions to this problem, including: repetitive use of both the materials and specific subcontractors.

Group 4 builders measure their productivity with their profit, much the same way that group 2 builders do. However, group 5 builders use a schedule. This indicates that their focus is directed toward time, and that they understand that productivity issues are related to time. Perhaps this is due to the fact that they have such a large volume of work, that they realize that time savings would lead to cost savings. However, they are unwilling to spend the extra money, up front to move to more efficient and productive construction methods.

Group 6: Group 6 builders/developers tend to use methods of construction that are less conventional in single-family housing, but more conventional in other project types. Since these builders are also directly involved in multi-family housing projects and light commercial construction, it only seems logical that they would use methods of construction that can be used for all product situations. Methods like metal studs, floor trusses, roof trusses, panels, and modular buildings are equally adequate for all of these building types. Unfortunately, group 6 builders are not using the most up-to-date technologies, either, but are instead working with innovative methods that are 10 to 20 years behind the current methods.

Since these methods can be used across all of these building types, it becomes the most economical method for the builder/developers to use, much for the same reason that the group 2 builders stick with the more conventional methods. For a group 6 builder to use standard 2x4 platform framing could be more expensive and more time consuming than the less traditional home building methods they currently use. This can be true, considering that different subcontractors, materials, and tools would be needed for single family projects, thereby adding to the overall cost of the project.

This group of builders are the most involved in multi-family development projects. These projects are nearly an ideal situation for modular housing units, and prefabricated structures, since each unit is the same. By incorporating these modular technologies, the developers should have the ability to turn over the project much faster, and therefore, provide their clientele with the units sooner. In multi-family development as well as commercial structures, customers have more critical timing deadlines than are typical of single-family residential projects. This fact alone, certainly supports the use of non-traditional building technologies.

In general builders building 3-8 homes/year were most open to innovations and non-traditional building materials and methods, as a group. Builder/developers were the next most willing group, followed by groups 4 and 5. As previously indicated, the group 1 and 2 builders were quite resistant to these innovations, as a direct result of their product types and volume.

The individual builders who were most often actively using building systems and other building innovations were those builders who were also involved in development or real estate. It is important to note that some of these builders did not fit the group 6 profile, and were therefore placed in another group. This classification of builder is more open to the newest technologies because they have a vested interest in their projects, above and beyond that of a typical builder. In addition, these people are much more involved in the housing industry than a traditional home builder, and therefore, are more likely to be aware of the technologies as well as the benefits of using them.

It is important to realize that although the trend of each group of builders showed that platform framing was the most frequently used method for the wall systems, that when the responses from all of the builders were viewed together, that building systems or alternative methods of construction were used just as frequently in wall construction. This is illustrated in Chart 2 of the results section. This indicates that building systems, including panelized walls and modular construction are beginning to capture a significant percentage of the total market.

While the responses of builders tended to be very similar across the three towns involved in the study, there was one significant variation. Nearly all of the builders from Greenville, North Carolina expressed the inability to incorporate modularization, and pre-fabrication into their projects as a result of the economic situation of the area. Apparently, builders feel that due to the large amount of available labor, and lack of manufacturing in the area, using these techniques is a serious cost hindrance.

In general, during the course of this study it became quite apparent that home builders 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 contractor considered making changes to their means and methods of construction to control their productivity. However, most of these same builders admitted that they could probably perform more effectively if they were to use these methods on a regular basis. Quite simply, most builders are just unwilling to make the switch from traditional building methods to the innovative building systems that are currently available. This conservative nature is certainly understandable considering the nature of the construction business, and more specifically home building.

Several builders in many of the groups openly admitted that although they thought that there were more productive methods of construction available to them, they were unwilling to use these systems due to their clients. Subsequently, many of these same builders stated that they would in fact incorporate any building system or method of pre-fabrication that the owner requested. This willingness to accommodate the wishes of the owner reinforces the underlying idea that the owner often is the party to initiate changes or innovation into the building process. This is certainly evident throughout the history of home building. In addition, this conclusion explains why group 2 builders are less likely to introduce building systems into their new construction process, despite their opportunity to do so during the planning stages. However, with the realization that builders are much more knowledgeable about the methods of construction available and their potential benefits, it is unrealistic to expect less knowledgeable homeowners to initiate these innovative changes.

One of the last, but strongest forms of resistance to these new technologies involves subcontractors and labor. Nearly all of the builders interviewed mentioned the resistance they feel from subcontractors when they choose to use less conventional building materials or methods. Moreover, builders themselves also cite unskilled labor or the unfamiliarity of labor with innovative building methods as their reasons for not using them on a regular basis. This seems counterintuitive; because the alternative materials and methods are faster and easier to use, they often require less skilled labor than framing. In addition, a majority of the labor used in manufacturing facilities to assemble the trusses, panels, or other building modules are unskilled or semi-skilled.

Prefabrication and Manufactured Housing: The idea of prefabrication in building construction is certainly not new. In fact, prefabrication goes back over several centuries in many cultures around the world; designs for manufactured housing systems have been around since the early 1900s. Manufactured housing and prefabricated wall assemblies were actually produced beginning in the early 1930s, with Fuller, Keck, Gropius, Le Corbusier, and Fisher. Mobile housing trailers were the popular form of manufacturing in the 1940s and 1950s, followed by large scale assemblies in the 1960s, much like Safdie's Habitat. The 1970s saw yet another boom involving single-family manufactured housing; so much so in fact, that HUD developed building codes to regulate construction practices used in manufacturing.

Prefabrication offers a range of potential benefits to those who choose to use it, including: quality control, precision, controlled working conditions, and available technology. Similarly, the off-site work force is more stable, more efficient, and more reliable. The average on-site crew will accomplish 4 to 5 hours of actual work in an 8 hour work day. Comparably, in a manufacturing plant, nearly 100% of a shift will be used productively. (Chevin, 1991) Other benefits include a reduced number of material deliveries to the job site, better inter-trade communication, and a shorter overall construction period. By using a prefabricated building system, as much as 50% of the total construction time can be cut out of the schedule.(Blocker, 1993) While this 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.

Over the past fifty years, prefabrication has been seen as the answer to the low-income housing shortage issue. Not only does the prefabrication process offer quality control, precision, cost effectiveness, and a more rapid installation, but these manufactured modules tend to lend themselves to placement on small, narrow lots, which are found abundantly in poor rural areas. These prefabricated houses, or mobile homes, as they are commonly known, are typically viewed by the majority of the United State's population as a substandard form of housing. Not only do these structures sit up high off the ground, but they are long and narrow, and are often placed in close proximity to each other. These obvious differences between site-built housing and prefabricated housing caused a stigma to be placed on many forms of manufactured housing, including modular construction.

All of the various types of manufactured housing use simple joists as the floor system for every home because the designs use short spans and thus are structurally adequate, and less expensive, easier to handle, and more readily available than floor trusses. Those homes that are not built on a chassis are a maximum of sixteen feet wide, and therefore, there is no structural need to use trusses.

The wall systems used in the factory setting are very efficient. The use of pre-cut lumber, and jigs or tables allow several walls to be quickly assembled in a minimum amount of time. By attaching the sheathing for both interior and exterior walls prior to installation, another step, and therefore time, is saved.

The manufacturing industry strives to build the highest quality product possible in the shortest amount of time. Because these modules are mass produced, 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, even more so. Another obvious advantage the plant has over site construction is repetition and the ability to build components before they are needed, allowing them to be stock piled.

This point is easily illustrated with the roof assembly. The roof structure itself is built in many steps. These steps; however, do not begin after the walls are attached to the floor. The roof is often begun much earlier in the process, and then meets the rest of the structure at the appropriate time and place. This is rarely done in site-built housing construction.

However, probably the most easily applicable and most beneficial type of prefabrication are those in the structural components and systems classification. These include framing systems and structural panels for walls, floors, and roofs. These systems are among the methods of construction that several builders identified as either ideal or most productive. By incorporating an entire prefabricated system into site-built housing, the builder can now realize the full benefits of standardized building materials.

The current range of prefabrication levels, techniques, and technologies is vast. Prefabrication has become much more than a building technology, it is now a process of building, and is likely to become an industry within itself. Over the past twenty years, prefabrication has expanded into so many types and forms, from simple one piece units to complex assemblies; almost to the point that any building material or component is available in a manufactured form.

We are now at a point, however, that owners, designers, engineers, and builders alike must begin to understand the prefabrication process, and work toward its use in a project. If the use of prefabricated building materials is desired, for any project, there is a type of prefabrication and even a specific product available to fulfill the needs of that particular project. It has been over one hundred thirty years since the development of the roof truss; however, it is now the dominant method of roof framing. Wall panels and pre-assembled wall sections have been available for use since the 1930s, and they are now, over sixty years later, beginning to represent a significant percentage of the market.

A builder who has the ability to incorporate individual components like roof trusses, can use prefabrication just as easily as the builder who chooses to develop with full modular housing units. While the overall productivity improvement of these builders will most likely vary, each builder is using these non-traditional technologies to improve efficiency and productivity to an extent.

Furthermore, builders need to recognize the advantages factory production has over the site-built process and respond to them. Namely these benefits are automation of tools and equipment such as jigs, repetition of the process, and designated work spaces for each step. Builders 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 site-built housing process.

Therefore, it is time for the building industry's knowledge of these materials and processes to catch up with the technology. The prefabrication industry will continue to advance in the coming years, as new technological breakthroughs with materials and manufacturing methods are made. It is up to the building industry, if we want to stay current with this new industry, to make a concentrated effort in that direction.

Summary

After the completing this study, it is apparent that this investigation has only begun to scratch the surface. There is a vast amount of knowledge to be gleaned from the builders who were interviewed and others like them; however, this study has turned over enough information to support further work in this area.

The process used to obtain data from the group of builders was the questionnaire previously discussed, see appendix A. This questionnaire was administered in a variety of ways. A large majority of the involved builders, including all of those located in Blacksburg, were interviewed either in person or over the telephone. This method allowed the investigator the opportunity to expand on questions that were not answered fully, as well as to filter out information that was not related to the topic. Furthermore, the investigator lead the interview, and could control the amount of time, the level of detail, and the direction of the questions.

Many of the builders in Greenville, North Carolina, and Morgantown, West Virginia were not available to interview in person or over the telephone. Therefore, a large majority of these builders completed the questionnaire on their own, and then returned it to the investigator. While this method allowed the builder to answer the questions at their leisure, the investigator could not act or influence the interview process at all. Not surprisingly, the answers obtained from these builders tended to be less directed, and at times, off the mark. Furthermore, occasionally questions were misinterpreted, and therefore, not answered in a way that was useful for this study.

If this research were to be continued, several things should be done standardize responses. Primarily, the questionnaire should be modified to avoid situations where the questions could be misinterpreted. Questions should be modified to be less open-ended, using either a rating system or multiple choice system. This results in questions being rewritten in order to better extract what information the builder is being asked for, as well as to clarify what is really being asked. A sample of how this same questionnaire could be modified has been included in appendix B. Lastly, it is recommended that all builders be interviewed using the same method.

To achieve a greater standardization of responses, a slightly different approach should be taken when furthering this research. Primarily, the initial questionnaire should be issued to a group of students to ascertain where the questionnaire is unclear or misleading. Then minor modifications may be made before a sample group of builders are interviewed. The results from these builders can be used to give the investigator an idea of how the questions are received by actual builders, and allow the opportunity for further modifications and changes. In addition, the responses of this initial group would give the investigator an insight into the types of answers that would be gathered from the final sample group. Lastly, the final questionnaire would be administered to the final sample group of builders. This should involve more builders than were used in this study, as well as a more equal spread between each town that is sampled.

To improve the knowledge base in this area, a broader research investigation can be explored. Primarily, the builders who were interviewed all came from three university towns; however, the balance of builders from each town was not equal. In order to obtain a more even sampling of the builders, an equal number of builders from each town should be interviewed. Also, this study was limited geographically to a very small segment of the eastern United States. A broader study would have been able to take a sampling from several other towns on the east coast, with a similar profile to those already identified. In this way, a more uniform response could be determined, and regional variations would not impact the study significantly. All of these limitations could be overcome by designing the experiment; this would allow for a statistical analysis of the results, which would be desired.

An inherent value to the information that has been gathered and analyzed is that a builder or student who reads this will have a better understanding of what methods of construction are available, as well as how each of these methods is used. Further, they will have the knowledge of what profiles of builders are using each specific innovation or technology, and what benefits these technologies could provide to their organization. For example, a builder that fit into the group 3 profile would gain the insight that was gained from the collection of information from all of the group 3 builders interviewed.

On the same note, a builder would finally have the data to either support or set aside their prejudices about pre-fabrication, pre-assembly, and modularization in relation to construction productivity. They would now be able to make an educated decision about the use of these innovations in their own practices. After looking at the information gathered, it would be possible to determine if their organization was similar enough to those organizations that experience significant time and cost savings from using non-traditional building methods.

In addition, builders could begin to understand how their methods and innovative building techniques compare to those interviewed. In this way, it could be determined if there were more productive means and methods that could be adapted to their specific project and organization. Further, new building innovations may be discovered, that could be implemented.

Hopefully, after reading this study builders would be more open to the latest building innovations, including pre-fabrication, pre-assembly, and modularization. In this way a builder may find the opportunity to try a non-traditional method for a special project, or recommend one of the latest building techniques to an owner who is looking for a more efficient or productive means of building their home. Similarly, a builder who has read this study may feel more comfortable updating their current methods to gain a competitive advantage over local competition.

In general, this study has given owners, builders, and any other home building participants the knowledge base to explore all of the options currently available in building materials and methods. By opening the industry to these non-traditional building technologies, an advancement and general acceptance of these practices can begin to occur.

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Appendix A

Questionaire:

Company ____________________ Contact _________________ Date _____________

1. What is your most common type of project?

2. What is the mix of new homes & remodeling jobs each year?

3. How many single-family homes do you build in a year?

4. What is the average size (sf) of a home you build?

5. How are your building plans prepared for your projects?

6. What trades do you preform with your own labor?

7. What is the most common method of construction that you use for floor systems? please explain.

8. Walls? Please explain how this is performed.

9. Roof structures? Please explain how this is performed.

10. Why do you use these methods? Do you consider that to be an efficient method of construction?

11. How long does it take you to frame-out an average home using this method?

12. What alternative methods of construction have you built (ie. prefabricated systems, etc.)?

13. Why? Why not?

14. How were they used? With what frequency?

15. Were these methods successful? Economical?

16. Do you feel that these methods improved productivity? why or why not?

17. How do you measure your productivity on project?

18. What would be the ideal method of constructing a home for you? Why?

19. What is the least conventional method you have ever used to build a home?

20. What changes in your construction methods can make your crews more productive?

21. What is your biggest productivity challange?

22. Can prefabrication, preassembly, modularization be incorporated into your projects? If so, how?

Appendix B

Modified Questionaire:

Company ____________________ Contact __________________ Date ____________

1. Please circle your most common project type?

   Single Family Housing   Remodeling   Multi-Family Housing

   Commercial   Other

2. What percentage of your projects (based on time) are new homes?

3. How many single-family homes do you build in a year?

4. What is the average size (sf) of a home you build?

5. Who prepares your building plans for each project?

   self prepared   from a plan book   by an architect/engineer   by the owner

6. Please list the trades that you preform with your own labor?

7. What is the most common material and method of construction that you use for floor systems? please explain.

8. Walls? Please explain how this is performed.

9. Roof structures? Please explain how this is performed.

10. Why do you use these methods?
Do you consider that to be an efficient method of construction?

11. How many working days does it take you to frame-out an average home using this method? What is the typical crew size?

12. What alternative methods of construction have you built (ie. prefabricated systems, etc.)?

13. Why? Why not?

14. How were they used? With what frequency?

15. Were these mothods successful? Economical? How so?

16. Do you feel that these methods improved your productivity? why or why not?

17. Would this method improve your productivity if you began to use it exclusely? Why? Why not?

18. What method do you use to measure your productivity on project?

19. What would be the ideal method of construction for a single-family home for you? Why?

20. What is the least conventional method you have ever used to build a home?

21. What changes in your construction methods can make your crews more productive?

22. What is your biggest productivity challange?

23. Can prefabrication, preassembly, modularization be incorporated into your projects? If so, how?

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Education	Virginia Polytechnic Institute and State University Blacksburg, Virginia Master of Science in Architecture; QCA: 3.95/4.00 Concentration in Construction Management; May 1997
	Virginia Polytechnic Institute and State University Blacksburg, Virginia Bachelor of Architecture, May 1995 QCA: 3.49/4.00 Minor: Mathematics
Professional Affiliations/ Certifications	Tau Sigma Delta, National Honor Society for Architecture Certified Registered Roof Observer by RCI, 1996 - present AGC - Student Member, 1996 - present ABC - Student Member, 1996 - present NAHB - Student Member, 1996 - present American Institute of Architects, Associate Member 1995 - present American Institute of Architecture Students 1994- 1995
Publications	Two Component Manufactured Housing System Design - Patent Filed,1995: This two component mobile home system can be combined to form a single home, in various configurations to best fit the user's needs and the site. This system provides flexibility and possesses the advantage of many unique floor plans, and works well with a variety of unusual sites, unlike the standard mobile home.
	Poster session at the A.S.C.A. Southeast Region Conference, Mississippi State University, October, 1994.

Employment

HDH Associates/872 West Main Street Salem, Virginia
August 1995 - present/Intern
As an intern at HDH, I have had the opportunity to be involved in many different projects. Many of our projects are renovations and additions to existing educational facilities. I have been involved in a variety of tasks throughout the duration of many projects. This includes extensive experience working with AutoCad r12 to produce construction documents. I have also produced several marketing packages, RFPs, interview packets and presentations, and design development packages using Adobe Photoshop, Microsoft Power Point, and word processing packets. Many of our clients require full color renderings, and I have been responsible for the production of both computer generated renderings and hand drawn renderings. I have had limited exposure to two specification systems: Master Spec and HDH's Technical Specification System. I have also been the field architect for a large structural upgrade at the Virginia Tech Campus, from May 1996 - December 1996. I have also had the opportunity to follow several other projects through the construction phase from pre-bid conference through close-out.

Valerie A Hrabel P.E./ P.P./ Civil Engineer /Kinnelon, New Jersey
April 1989 - June 1989/Draftsman
In my short time with Valerie Hrabel, I learned a significant amount of practical skills. While my main duty was hand drafting of construction documents, I also learned how to run prints, and prepare conceptual presentation drawings.

Computer Skills	AutoCAD r12	Microsoft Office Pro
	Suretrack / Primavera Project Planner (P3)	Microsoft Project
	Microsoft Power Point	Adobe Photoshop
	Aldus Pagemaker	HTML Construction

Architectural Interests	Prefabrication of Building Components & Their Use
	Prefabricated Housing
	Adaptive Reuse of Existing Facilities
	Historical Preservation
	Renovations of Education Facilities