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Technology Assessment of Automation Trends in the Modular Home Industry

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Abstract

This report provides an assessment of technology used in manufacturing modular homes in the United States, and that used in the German prefabricated wooden home industry. It is the first step toward identifying the research needs in automation and manufacturing methods that will facilitate mass customization in the home manufacturing industry. Within the United States, a relatively low level of technology was found in domestic modular home manufacturers. Raw material transportation was mostly manual; manually operated saws sized raw materials; cranes were used to move subassemblies, and modules were pushed by hand or with a battery-powered pusher. German prefabricated home manufacturers used closed panels to construct walls, roofs, and floors rather than modular construction. Three levels of automation were identified: manual, semi-automated, and fully automated. Manual production methods were similar to those found in the United States. In semi-automated factories, automated machinery was used, but an operator was required to manually load, unload, and start the machine. The fully automated factories had equipment capable of machining and transferring panel components and placing and fastening components together. Such investment in automation is risky in the cyclic housing industry. The modular factory has elevated homebuilding from a craft to mass production, but flexibility is reduced and significant customization is difficult. Future research should examine the cost effectiveness of using high levels of automation, software, and equipment in the U.S. homebuilding industry and whether it can profitably provide the manufacturing flexibility for mass customization. Alternatively, the use of lean manufacturing in modular home factories to realize the same benefits needs to be examined.

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Technology Assessment of Automation Trends in the Modular Home Industry

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Introduction

Traditionally, American homes have been constructed on site in a method known as “stick built,” meaning that components are connected at the location where the house will remain. In contrast, modular homes have major components built in a factory and are transported to the building site and then assembled into the final house. In 2008, *Automated Builder* reported that approximately 200 modular home manufacturers in the United States make assembled sections of housing (Traynor 2009). Modular units are constructed in factories and produced in complete, box-like sections that are delivered to the home site. Multiple-section units and stack-on units are also commonly produced. Modular homes are 80% to 95% complete when they leave the factory.

Potential advantages of modular home construction compared with conventional site built homes include the following:

- Builders are currently experiencing a shortage of skilled workers, and population demographics suggest that the labor pool of available construction workers will likely shrink even more.
- Modular home construction takes place in a controlled environment under a factory roof, which prevents weather damage.
- Results are of better quality, as labor is performed in a comfortable environment, and modular manufacturers are more likely to have a quality-control program.
- Building can continue without weather interruptions.
- Reduced construction time results in a shorter period of capital outlay for the builder.
- Materials can be used more efficiently with the help of computerized optimization.
- Different components can be manufactured concurrently.
- Use of specialized equipment is possible in the factory.
- Inventory can be controlled and materials managed better.

Traynor (2009) estimated that of the industrial housing industry (which accounts for 95% of new home production), the modular home industry has provided between 6.2% and 7.6% of new home construction during 2004–2008. Future projections range from a high of 90% within a decade to a more conservative estimate of 90% in 20 years (O’Connell 2003, Coates and others 1996). Regardless of which projection is correct, this industry has successfully become a force in the homebuilding industry and appears poised to grow.

Objectives

Our long-term goal is to develop a program that will investigate applicable technologies, methods, and approaches to factory home production. Future research needs related to industrial home manufacturing include applications of automation and optimization equipment and manufacturing methods that will facilitate mass customization and examining new wood-based materials specifically developed for factory-built homes. The first step is to conduct a technology assessment of the processes and equipment currently used in modular home construction.

The purpose of the study is to provide an assessment of technology used in the production of modular homes. As objectives, this assessment will address questions such as the following:

- What components (which will define the organization framework used in this study) of modular housing are typically constructed as stand-alone fabrication?
- For each component, what equipment (and process) is available and used in its construction?
- For major process tasks, what is the state of the technology of major equipment items compared to competing technologies?

Methods

Our approach was to examine the modular home industry primarily through plant site visits to (1) identify major processes in modular home construction; (2) identify equipment, supply vendors, and manufacturers used in each process; (3) understand the use, application, and

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capabilities of equipment supplied or available to the modular home industry. Seven domestic modular manufacturers and two component manufacturers were visited. Because we anticipated that the implementation of technology and equipment used in factory home manufacturing would be more advanced in European countries, we visited 10 German factory home manufacturers.

This paper summarizes our observations from modular home plant visits and visits and consultations with equipment manufacturers.

Overview of American Modular Home Construction Industry

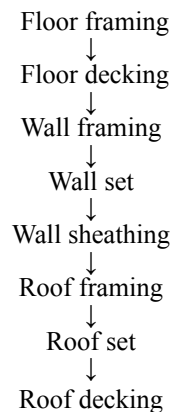
This section of the paper summarizes our assessment of the current level of technology implementation in the American modular home industry relevant to the utilization and processing of wood or wood components. This section presents an overview of technology in the modular home industry as found in our plant visits during summer 2004.

Trip reports summarizing visits to American plants can be found in Appendix A.

Manufacturing Process

Modular home factories are generally designed in one of two basic flow patterns. In side-saddle flow factories, the modules move through sideways in a single line. In contrast, modules are arranged end-to-end with dual lines in the typical shotgun-flow pattern. Both flow patterns are most often in a straight line, although other configurations have advantages and disadvantages. Other variations include the use of mezzanines and the spacing provided between dual lines.

Modular home construction involves many processes outside the realm of wood construction. However, focusing on those processes that involve wood products, the major steps are as follows:



Our study is focused on the major structural ingredients of home building: floor, walls, and roof. Other major steps in the modular home factory include installation of electrical and plumbing systems, insulation, interior dry wall, siding, painting, and more.

Technology Assessment

Our technology assessment goal focused mainly on the movement of materials, the sizing of components, and how components were connected. We asked four questions at each of the processes that primarily used wood:

1. How is the raw material transported?
2. How is the raw material sized?
3. How are the components fastened?
4. How is the finished product moved?

As shown in Table 1, the level of technology found throughout our representative sample of factory visits was basic.

We did not find the advanced levels of automation that we thought might exist (at least in some factories). Raw material transportation was manual in almost all cases with a joist transport cart (sometimes called a joist dealer) occasionally assisting. Similarly, raw material sizing of studs, joists, and sheathing was generally done with a manually operated circular, cut-off, or panel saw. Manual nail guns and pneumatic screw drivers were prevalent throughout these factories. Cranes were often used to move subassemblies, while the in-process modules were pushed by either a battery-powered line pusher or human hands, assisted by rollers, tracks, or air pads.

A more detailed table listing technologies found in each of the seven domestic modular home factories visited can be found in Appendix B.

Overview of the German Prefabricated Home Industry

Wooden homes account for approximately 14% of new homes built in Germany; 84% of these wooden homes are prefabricated off-site as closed-wall panels and then transported to the home site where the panels are assembled to construct the house (Personal communication between Russell Hurst and Oswald Alexander of the Bundesverband Deutscher Fertigbau on March 21, 2007).

In June 2005, we toured 10 prefabricated home manufacturers in Germany. This report provides an overview of the German method of home manufacturing, including the automation levels employed at the factories we toured.

The German method of closed-panel prefabrication differs greatly from most present-day American methods of home prefabrication. In German home prefabrication, the wall panels typically have doors, windows, insulation, and conduits for electrical wiring, moisture barriers, OSB (oriented strandboard), and drywall already installed when they leave the factory. Exterior siding is also often installed on the wall panels. At some factories, interior finishes are even applied to the panel.

On-site construction of these closed-wall panels requires setting the panels with a crane, fastening the panels to one

Table 1—Summary of wood processing technology found in modular home industry in floor wall and roof build processes

	Technology used			
	Raw material transportation	Raw material sizing	Component fastening	Finished product transportation
Floor framing	Manual	Cut off saw	Manual nail gun	Crane
	Manual w/ joist dealer	Precision-end trim saw		Crane to track Rollers
Floor decking	Manual	Circular saw	Manual nail gun	Crane to track
				Crane to rollers
				Air pads
Wall framing	Manual	Cut off saw	Manual nail gun	Crane
Wall sheathing	Manual	Circular saw	Manual nail gun	Not applicable
Wall set	Crane	Not applicable	Manual pneumatic screwdriver	Not applicable
Roof framing	-----Outside purchase of trusses ^a -----			
	Manual	Cut off saw	Manually connected Pressed plate	Manual to cart
Roof assembly	Manual	Not applicable	Manual nail gun	Crane
Roof decking	Manual	Circular saw	Manual nail gun	Not applicable
Roof set	Crane	Not applicable	Manual pneumatic screwdriver	Not applicable

^a Some plants purchase roof trusses from outside sources.

another, connecting the electrical wiring between panels, and installing plumbing lines. Middle floors (the floor between the first and second story) and roofs are also built as panels in the German prefabricated method. These floor panels are typically built with OSB decking on one side of the joists, insulation installed between joists, moisture barriers installed on both sides of the floor panel, and furring strips nailed to the bottom of the floor element. The ceiling drywall is hung onto these furring strips once the home has been wired in the field. The roof panels are comparable to the floor panels except the furring strips are on the outside of the panel and OSB and drywall are on the inside.

For increased energy efficiency, moisture barriers are installed on both sides of the wall, floor, and roof panels. Manufacturers told us that with such airtight construction, homes had to be manually or mechanically vented to prevent moisture build-up. None of the manufacturers we toured, however, installed air-conditioning in their homes.

Trip reports summarizing visits to German plants can be found in Appendix C.

Manufacturing Process

Because walls, floors, and roofs are all constructed as panels, the manufacturing processes were very similar for these components. The first process in panel construction was sizing the OSB panels, drywall panels, and studs and

joists used in the wall, floor, or roof panels. After sizing, elements for a panel are transferred to a jig table where the individual wall, floor, or roof panel is built. After framing, exterior sheathing is installed and the panel flipped. Insulation, conduit, and moisture barriers are then installed and the interior of the panel sheathed. Closed panels are then hung vertically for installing exterior and interior finishes. Windows and doors are installed at either station, depending on manufacturer preference. Panels are then loaded onto a trailer for transport to the home site; at none of the toured German factories did we see large inventories of finished panels (houses) waiting to be delivered.

Classifying Levels of Automation

We observed three distinct levels of automation in production, which we classified as manual, semi-automated, or fully automated. The manual German plants processed their components in similar fashion to American methods. In semi-automated factories, automated machinery is used at some workstations. These workstations, however, are not inter-connected and require an operator to manually load, unload, and start the machine. The fully automated factories we visited had equipment capable of machining almost all components for the panels, transferring the cut components to other machinery, and inserting or placing and fastening the components onto the panel. The fully automated factories did have operators on the production floor, although

Table 2—Average machine capabilities for three levels of automation

Job	Machines used		
	Manual production	Semi-automated production	Fully automated production
Sizing OSB ^a and drywall	Table saw	Table saw or CNC ^b router	CNC router
Sizing studs and joists	Saw	CNC saw/joinery machine	CNC saw/joinery machine
Transferring sized components	Carts	Carts	Conveyor system
Affixing studs or joists to frame panel	Manual nailgun	Manual or CNC nailgun	Multi-function CNC machine
Placing OSB and drywall onto panel	Manual	Manual	Multi-function CNC machine
Nailing OSB and drywall onto panel	Manual nailgun	Manual or nailgun bridge	Multi-function CNC machine
Flipping panel	Butterfly table or crane	Butterfly table	Butterfly table
Inserting components into panel	Manual	Manual	Mostly manual
Manufacturing stairs	Manual or CNC router	CNC router	CNC router

^a Oriented strandboard.^b Computer numerical controlled.

these operators were typically there to clear any errors in the machinery and to manually insert components such as insulation, doors, windows, and exterior/interior finishes into the panels.

Although each factory toured had a unique production set-up, Table 2 summarizes typical machine capabilities for each of the three levels of automation.

In semi-automated manufacturing, we saw a variety of computer-numerical-controlled (CNC) routers used for panel sizing; these CNC routers were typically wired into the factory's network, allowing the operator to download the program onto the router without leaving the workstation. Almost all factories used CNC saw/joinery machinery to cut the beam or joist to length, drill holes through which cables or plumbing would be run, and notch the beam or joist where necessary. This machinery consistently produced accurate cuts and appeared to be significantly faster than comparable manual operations. The fully automated factory we toured was truly impressive with its extensive automated machinery, material handling systems, and capacity to produce 1,000 homes annually. In this factory, after being sized, elements of the wall panel were transferred onto a conveyor system that temporarily stored them in a queuing rack until the elements were needed by other machinery. As impressive as the automated factory was, it was only producing at approximately one-third of its capacity, leading us to question the practicality of such a large capital investment given the dependence of future profitability upon the typically cyclic housing market.

German Wood Frame Homes

German wooden houses had few major differences compared with wooden houses in the United States. On average, German homes are smaller than American homes. Germans seem to place greater emphasis on design and quality of the home than size. As more than one German manufacturer told us, homes (both wood and brick) in Germany are “built for more than one generation.” Most German home manufacturers offered significantly longer performance guarantees on their new prefabricated home compared with new homes in the United States. Typically, the wooden homes had a 30-year structural guarantee (including roof leakage).

One key selling point of wooden homes in Germany is their high insulation value. This focus on energy efficiency is due to higher energy costs, public emphasis on and perception about energy efficiency and conservation, and tax deductions available for low-energy homes.

We did not see trusses being used in construction of single-family residential houses. Rafters are still favored, and attic space is typically used as living space in the home. The home manufacturers we toured sheathed walls with OSB or plywood on both the inside and outside of the wall, again emphasizing energy efficiency. Drywall was installed over the interior OSB. Vapor barriers were installed on all sides of walls, ceiling and floors, and roofs. With such air-tight construction, we were told that homes had to be manually or mechanically vented to prevent moisture build-up. None of the manufacturers we toured, however, installed air-conditioning in their homes.

German basements were typically pre-cast concrete panels. The basement floor is poured on site after the wall panels have been set. Wood is used to make floor, wall, and roof elements. Some manufacturers reinforced floor sections with steel I-beams for large spans. We did not see the use of engineered wood products such as wooden I-beam floor joists, truss floor joists, or roof trusses. We also did not see glulam beams. Typical wood products used were OSB for inside and outside wall sheathing and fingerjointed wooden posts for walls, floors/ceilings, and rafters. We were very impressed with the quality of lumber we saw being used.

German manufacturers typically marketed and produced three classes of homes: completely custom, semi-custom, and standardized. The completely custom homes were designed specifically for the client by either an independent or in-house architect and had very few limitations on design.

Manufacturers also offered their semi-custom homes. These were homes designed by the manufacturer (the plans belonged to the manufacturer) that customers could customize to fit their needs. We called these homes “Dell homes” because customers could add features for set prices, similar to how a customer specifies options when purchasing a Dell computer (Dell, Inc., Round Rock, Texas). Typically, this line of home had one or two base floor plans. Often, one or two walls were (re)movable. Bay windows or built-in (winter) gardens are common additions to the floor plans. These semi-custom model homes had specific options for flooring (limited selection), doors, wall treatments, window types (wooden or vinyl), and heating equipment. Extra insulation and exterior siding were also options. We found the options presented in this line of homes very comparable with tract-built homes in the United States.

Manufacturers also typically offered their line of standardized homes. This line of homes had very few choices for the customer to make. The advantage for the customer was the lower cost per square meter of the home. Options in this category would be door color (wooden or white for example) and exterior home color.

German manufacturers often offer their homes at various levels of completeness. The majority of homes are built “turn-key,” although it is not uncommon for the home manufacturer to close in the home and leave finishing to the customer. This is entirely based on customer demand. One of the largest manufacturers we toured offered an interesting line of semi-custom homes. In this line of homes, the customer selected the options for their home (windows, doors, siding, floor-plan, roof style) from a list of options, and then selected one of the five levels of completion: turn-key and levels one through four. Each successive level offered more steps for the customer to finish.

Summary

We were surprised (and somewhat disappointed) at the relatively low level of technology found in domestic modular home manufacturers. Although factory home manufacturing offers many potential benefits, too often these were not being taken advantage of or were overridden by other issues. For example, although the potential for cut-up optimization exists because equipment systems are available in the factory that would improve material efficiency, modular homes actually consume more wood than stick-built in order to resist racking forces when modules are lifted by cranes.

Our trip to Germany and tour of 10 wooden-home prefabrication factories did provide us with a firsthand look at how automation can be incorporated into factory home production. Whereas all the manufacturers we toured were producing high-quality homes, it became apparent that the home manufacturers using CNC automation were more consistently producing accurately sized and squared components resulting in homes that fit together easily and tightly. But we also realized the risk of spending too much on automation in an industry dependent on the cyclic nature of the housing market. In the United States, such a high investment by private companies in the face of a market downturn would likely prove ruinous and we therefore reject this option as a prohibitive risk.

Future Challenges and Direction

The domestic modular home factory of today resembles Henry Ford’s early automobile assembly lines. Whereas the modular factory is elevating homebuilding from a craft to mass production as did Ford’s early assembly lines, flexibility is reduced and significant customization is difficult. The challenge facing the modular industry is to develop those processes and techniques that will allow easy and economical customization to occur along the production line.

The issues and challenges that the factory-built home industry faces also define future research needs of factory-built housing research programs:

- Would a home-producing factory using high levels of automation, software, and equipment technology be cost-effective in the United States and provide the manufacturing flexibility required for mass customization?
- Can lean manufacturing strategies be incorporated effectively into current modular home factories, and would the change dramatically improve flexibility and profitability?
- What are the appropriate levels of outsourced subcomponents compared with building them in-house?

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Appendix A—Trip Reports Summarizing U.S. Modular Home Plants

Plant A

Contact: Sales Manager
June 2, 2004

Key Points

- Plant A will produce custom homes.
- The company is small but looking to grow.

Company Description

Company A is a wholly owned subsidiary of the Larger Company. The Larger Company originated as stick-built apartment builders; the company got into modular home construction with Company A.

Production

This plant produces about three to four modules per day (three to four floors per day), with a home on average being about three modules. They build standard models typically, but are willing to customize standard models, or even take a non-modular floor plan and consider converting it to modular. Plant A can build up to a 69-ft-(21-m-) long module. Plant A made some Cape Cod model homes with separate roof/room modules. Most simply had the flip/prop-up roof sections with knee walls (a short or partial support wall) in the attic. Plant A could allow for the roof sections to flip up from any side of the module (Fig. A1). The flip-up wall has a drop-down knee wall (Fig. A2).

Based on estimated Company A sales and 150 employees, we estimate Plant A's productivity to be \$94,666 per person year.

Process Description

The factory has three subcomponent lines: floors, walls, and roofs. The main line brings all three subcomponents together. Company A purchases roof trusses from an outside company. In terms of wood products, they use southern yellow pine (SYP) for floor joists and bands and roof rafters, spruce-pine-fir (SPF) for studs and engineered joists (Open Joist 2000, Trois-Rivières, Quebec, Canada (Fig. A3)). Laminated veneer lumber beams are used for long spans including sliding glass door openings and open living space. They do use 2 by 3s in marriage walls (walls between modules). Relam, a fingerjointed stud from Lamco Forest Products (Lamco Forest Products Inc., St-Félicien, Québec, Canada), was used in the bathroom and kitchen because according to the plant manager, "they are straighter."

We did not observe much impressive technology in this plant. Floors are built on a pneumatically adjustable jig that was not working at the time of our visit (Fig. A4). Overhead cranes lift and move subsystems (floor, walls, roof) so they

can be connected. Floors are placed on heavy duty rollers on metal tracks and are pushed down the production line. They had a total of 26 modules on the floor (almost nine days of product, assuming they produce three modules per day). They employ pneumatic technology for nail guns and screw drivers. Material is cut according to print drawings from the engineering department. A floor plan and quality control (QC) check-sheet are attached to each module, which is numbered and lettered according to the job (e.g., 1854C) on the end band.

Layout of joists and studs appeared to be done by hand, and nailing accuracy was judged by eye. Some nailing appeared excessive, which we also saw in other manufacturing facilities. Wiring and hole-drilling was also totally done by hand in the factory. The walls were constructed on a table (Fig. A5); the drywall extended to the edge of the wall, so when the walls were assembled on the floor, the drywall extended to the outside corner of the wall (Fig. A6). All wall seams (drywall, outlets, drywall to stud) were sprayed with foam for insulation (air movement) and to prevent cracking of the drywall seam (Fig. A7).

Company A notches wall studs to insert a T-strip diagonally along walls to strengthen the house during transport. This T-strip was stated to be exclusive to Plant A, although we have seen it in other facilities. Galvanized nail protectors were only used on the outer side of studs, which seems to be the accepted industry standard. This would prevent factory workers from puncturing wires while sheathing the module; however, it would not stop the homeowner from puncturing a wire with a nail from inside the home.

Once the modules had been completely assembled, they were lifted onto delivery trailers with "the crab," a converted boat lifter. The sales manager said that Company A brings large items (such as bathtubs) into the modules before enclosing them; he stated this can be a costly mistake if any re-work is necessary.

Other Impressions

Overall quality was generally good. The sales manager noted the difficulty in precisely joining the top floor to the lower floor, especially in terms of common walls lining up, as along staircases. Plant A allowed for up to 1 in. (2.5 cm) between the modules once they were set on the foundation. After visiting other manufacturing plants, this seems to be an accepted standard. The model home (3,300 ft²) we toured was nice; however, it had some soft spots in the floor. The house also had visible and noticeable bulges in the wall, especially around where the upper and lower modules met. The model house had a specialized central vacuum system add-on. The sales manager estimated that the typically sub-contracted foundation is a problem about 10% of the time when setting a modular home.

When asked, the sales manager said factory-direct sales to homeowners would be "a nightmare" because the numerous

details that must be obtained prior to manufacture. When discussing transportation costs, the sales manager said that transportation to Atlanta, Georgia, (roughly 400 miles) would be about \$2,400 per module (\$6/mile/module).

Figure A8 shows the floor plan of this plant.



Figure A1. Module end showing flip roof.



Figure A2. Example of fall-down knee wall in attic. Note that the metal connector plate is hinged.



Figure A3. Floor made with Open Joist 2000.



Figure A4. Floor being assembled on non-functioning adjustable jig. These men are constructing a floor section on a floor jig, the metal framework that the wood floor is resting on. Wheels on the jig base allow the overall frame to move.



Figure A5. Inventory and construction table for wall assembly.



Figure A6. Corner of module showing drywall coming to end of wall section (see arrow).



Figure A7. Foam spray sealing drywall gaps from rear and adhering to studs.

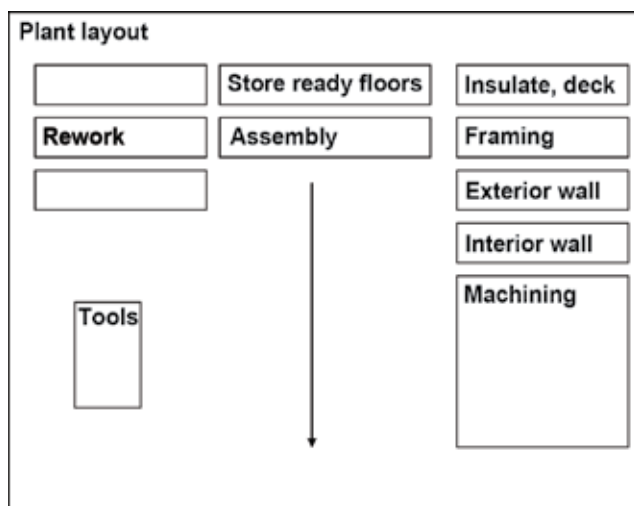


Figure A8. Floor plan of plant.

Plant B

Contact: Sales Manager

June 3, 2004

Key Points

- Modules are mass produced.
- Exterior walls are built with 2- by 6-in. lumber for energy conservation.
- Plant B builds many subcomponents (roof trusses, stairs, window frames) onsite.
- The customer can choose from selection of brand name floors, cabinets, and carpets.

Company Description

Plant B is the largest system builder of single family homes in the United States, with multiple facilities. The sales manager suggested that because modular built homes can be confused with other terms, he likes to call it “systems-built housing.”

Production

This 10-year-old factory produces 600 homes per year, with a target of 29 floors per week. Their average home has about 2.8 modules. It takes 4-1/2 days for a floor to move through the 35 stations or steps in this factory. This plant employs a total of 225 people, with 165 of them working on the floor. The estimated productivity is $600 \text{ homes} \times \$50,000 / 225 = \$133,333$ per person. Plant B seemed to target the middle range of modular housing. This estimate of \$30 million in sales for this plant fits within the sales range published by the 2004 Harris Infosource Selectory of North Carolina Business (Harris Infosource, a division of Dun and Bradstreet, Twinsburg, Ohio).

Process Description

The layout of the plant was good, with separate areas for (1) floor systems; (2) exterior walls built with 2 by 6s, which differentiates Plant B homes from other modular homes; (3) marriage walls using 2 by 3 studs; (4) interior walls using 2 by 4s. Housekeeping was fair to good, with an air-pad system used to move the modules as they are built. Plant B also manufactures many components of the home, such as roof trusses, window frames, and stair systems (Fig. B1). These components were manufactured in cells along the assembly line. These cells were adjacent to where the components should enter the house, which allowed for good material flow. The sales manager stated that whenever a module was being problematic (especially because it was a custom job), the assembly line schedule would be delayed, causing the component cells production schedule to no longer align with the modules in the assembly line. There were 35 stations along the assembly line, although not that many modules were on the floor.

Plant B used two floor jigs, one to build the floor frame and the other to glue the oriented strandboard (OSB) decking to the floor frame (Fig. B2). The framing station was an adjustable jig, though the sales manager indicated that they use it for only two widths (13 feet, 9 in. and 12 feet). The jig adjusts in width and has lay-up fingers to position the joists (Fig B3). However, this joist jig was designed for 16-in. on-center 2 by 10s and could not be adjusted (neither spacing between joists nor the width of the joists) to accommodate the Open Joist 2000 type of floor joists, which allow 19-1/2 in. on center spacing, or their approximately 3-in. widths. Because the Open Joist 2000 joists did not fit in the jig fingers, the Open Joists were set on top of the jig (not in the jig fingers) and then affixed to the 2 by 10 frame.

As a side-note: An average 60-ft module needs 45 joists at 16-in. on-center spacing. That same module with 19.5-in. on-center spacing needs only 37 joists. By not using the Open Joist 2000s at their correct 19.5-in. on-center spacing, on a 60-ft module, Plant B would use 8 excess joists.

We saw the following standard products being used:

- Fingerjointed spruce-pine-fir (SPF) 2 by 4 studs for interior walls
- Fingerjointed SPF 2 by 6 studs for exterior walls
- Southern yellow pine 2-in. by 10-in. floor joists and bands (Fig. B2)
- Open Joist 2000 made of SPF 2-in. by 3-in. lumber

Spruce-pine-fir roof trusses were made on site, surprisingly.

The sales manager commented that he preferred using relam for either interior or exterior wall studs because of the straightness of these fingerjointed studs. In addition, Plant B uses Trus Joist TimberStrand (a thick oriented strandboard (OSB)) structural member, (Weyerhaeuser Company, Federal Way, Washington) as a 6-in. stud behind kitchen and bathroom walls behind vanities. This was due to the straightness of the strand lumber, which reduced manufacturing time.

The sales manager also mentioned the Chief Architect design and drafting software (Chief Architect, Inc., Coeur d'Alene, Idaho) that has 3-D capability, but indicated that Plant B's engineered drawings were done with AutoCad (Autodesk, Inc., San Rafael, California). On the floor, workers only have access to the floor-plan drawing, not a side elevation view. For machining components of the house (window frames, headers, door frames, etc.), employees looked at the floor plan of the home. In addition to the above-mentioned components was a code that correlated to a second sheet of paper at each station. On the second sheet, the code was deciphered for the component (width, height, thickness). The components used seemed very standardized.

The sales manager explained four ways to identify a modular home:

1. The modular home must have an ID code somewhere within, indicating that it has been manufactured to code. Plant B stamps inside the electrical panel.
2. The roof trusses often have some type of a flip installed. A cap may be on top of the two roof sides.
3. A marriage wall will likely be inside the house. Older modular homes had thick marriage walls (two 2 by 4s mated together), but with the use of 2 by 3s, the marriage wall is not as thick.
4. Mating of modules (including plumbing and electrical) is generally visible in the crawlspace.

The plant can be divided into six major build process areas:

1. Roof build
2. Sub-component build
3. Wall storage
4. Floor build
5. Home assembly
6. Home finishing

These can be subdivided into 35 separate stations that encompass the major process steps:

- Floor build (Stations 0–5)
- Floor decking and wall build (1–6)
- Wall set and roof jig (3–8)
- Roof set (5–10)
- Electrical bottom (5–10)
- Plumbing and electrical top (7–12)
- Electrical test (8–13)
- Underlayment (9–14)
- Hang and tape (10–15)
- Insulation (11–16)
- First and second coat/wall sheathing (1–16)
- Third coat (12–17)
- Ceilings/windows and doors (13–18)
- Deck and load (13–18)
- Roof sheathing (15–20)
- Sanding (16–21)
- Shingles (18–23)
- Siding (18–23)

- Painting (18–23)
- Rough cleaning (20–25)
- Cabinets (21–26)
- Shelves and specials/doors and window trim (21–26)
- Basetrims/rework (21–26)
- Plumbing and electrical (22–27)
- Pitched roof (23–28)
- Wrap (25–30)
- Shiploose (small items not attached until home is sited and closed in) (26–31)
- Clear/final clean/under plumbing (27–32)
- Quality assurance sales inspections (28–33)
- Cleared/load and lab (34)

Other Impressions

Our impression was that although the sales manager said Plant B would customize, overall this plant would prefer not to because their goal is volume production. When asked about future challenges, the sales manager suggested that the challenge that might prevent plant automation would be the need to customize. He seemed unaware of existing technology in the modular housing industry.



Figure B1. Plant B built its staircases and roof trusses in-house.



Figure B2. Floor frame constructed on jig table.



Figure B3. Open Joist 2000 floor joists were used but could not fit into the positioning fingers shown.



Figure B4. Walls and floors are moved with overhead cranes (top left and top right); modules in process are moved using pneumatic air pads (bottom left); completed modules are loaded onto trailer for delivery using boat transporter (bottom right).



Figure B5. Modular home techniques include use of foam adhesive to fasten ceiling (left), attic modules with folding trusses (center), and engineered floor joists such as Open Joist 2000 product (right).

Plant C

Contact: Vice President, Manufacturing
June 16, 2004

Key Points

- This plant uses a team-based management approach.
- They are interested in technology and are looking to modernize.

Company Description

Plant C began in 1972 as a manufactured (mobile) home plant, but today makes mostly modular housing. The homes constructed in this plant today are all already sold. Twenty percent of their homes are on-frame (HUD code 1% or on-frame modular 19%) and 80% are off-frame modular. The plant layout overall was good (Fig. C1), but plant house-keeping suffered.

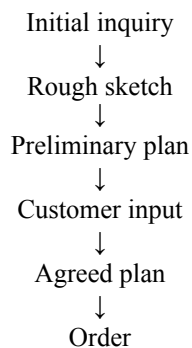
Production

The plant employs 250 production employees working four 10-hour days per week. Employees construct nine floors per day four days per week, or 36 total per week. The Vice President says these 36 modules build 14 to 18 homes per week.

Every 56 minutes, the line will shift down to the next station, and there are 30 stations in the plant. They can build a house in three days once the order is entered into the system, and the homes spend two days in the yard for repair. We observed many homes in the yard awaiting delivery.

Process Description

Drafting is done with DataCAD (DATACAD, LLC, Avon, Connecticut). The engineering process is as follows:



Plant C has its own metalworking shop to build frames upon which all floors are built, and upon which the “on-frame” homes remain. They are capable of building up to 60 frames per week.

The floor area was in a different building from the wall and roof area. In the floor “department,” the flow of process was as follows:

1. Construct wooden frame on flipper jig
2. Insulate between stringers
3. Install black plastic insulation retainer

4. Attach metal frame with wheels (Fig. C2)
5. Screw the assembly to the flipper jig
6. Flip the assembly
7. Roll to next station on low-profile wheels (Fig. C3)
8. Run ductwork, plumbing (PEX tubing), electrical
9. Glue (and nail) tongue and groove OSB to 2 by 10 frame
10. Cut holes for plumbing, electrical, air ducts, flush trim OSB edge, sand floor
11. Mark floor with chalk lines for placement of interior walls
12. Lay plastic sheeting for floor protection

Floors were 13 ft, 8 in. standard width, with a maximum length of 72 feet (average length is 56 feet, according to the vice president). If exterior wall construction is with 2 by 6, width is 13 feet, 10 in.

Finished kitchen and bathroom cabinets manufactured in-house (Fig. C4) were placed on top of the floor section for later installation. Interior cabinet door panels are purchased from outside. Plant C also purchases trusses and floor joists outside.

The houses had three wall lines: short walls that could be for angled ceilings or flat ceilings (run perpendicular to length of module); long walls that run the length of the floor (Fig. C5); and the marriage wall line (Fig. C6). The first wall line mentioned above employed a movable saw (moved by hand) with an adjustable carriage to select the angle needed (Fig. C7). Studs were loaded onto the saw uncut; the saw would cut all studs to the correct length, at the correct angle.

Once framed and drywalled, wall sections were moved to the floors by crane with wall sections being clamped by visegrips. Wall sections were connected to floors with 3-in. screws.

Roofs and ceilings were constructed in the upstairs loft (Fig. C8). While we were there, Plant C workers were constructing an interior ceiling with a 12-in. wide band to have room for the interior heating/cooling duct. As we have commonly seen, no screws or nails held ceiling drywall to the trusses. Instead, adhesive foam was used. These sections were moved by crane to the floor and wall assembly (Fig. C9).

Other Impressions

The vice president seemed excited that we were researching technology, stating that he hopes to modernize the manufacturing process at Plant C. The vice president also said that he had sent off for information on an automated panel production machine; however, no one had contacted him with information.

The vice president's managerial style was very "independent." He has encouraged workers to come up with solutions to their own issues on the shop floor. Numerous times he stated that he had "the best guys" working for him. The vice president explained that he let the employees decide on the four-day week. He also explained that Plant C always has a few extra employees on the shop floor to substitute in for anyone who does not come in to work. Plant C has relaxed their attendance policy over the last years to keep quality workers. Plant C's vice president says that with the team approach of the factory, team members do not tolerate other team members being excessively absent, because it causes the team to be behind schedule. A few times during the tour, he said, "Do everything that you can do well."

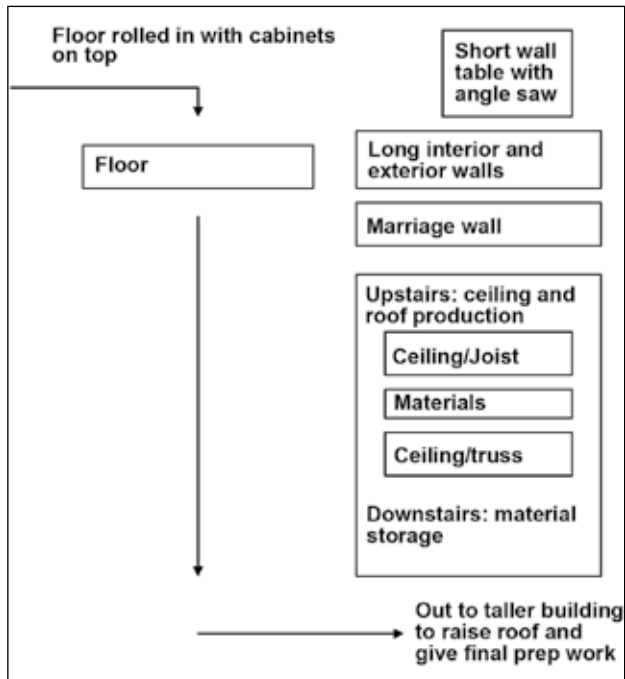


Figure C1. Floor plan of Plant C.



Figure C2. Metal frame with wheels being attached to constructed floor frame.



Figure C3. Metal frame is placed on top of low-profile wheels.



Figure C4. Plant C constructs kitchen and bathroom cabinets.



Figure C5. Long wall tables with completed walls standing to the side.



Figure C6. Marriage wall characterized by lack of insulation and a gasket seal. Note the small drywall panels providing additional support.



Figure C8. Roofs constructed in the upstairs loft were moved by overhead cranes.



Figure C7. An adjustable carriage was used to select the angle required to saw the wall for angled ceilings.



Figure C9. This ceiling (middle floor) section shows adhesive foam used to attach drywall to ceiling joists. Note the metal bracket and chain used by a crane to hoist the ceiling section.

Plant D

Contacts: President, Engineer
June 16, 2004

Key Points

- This plant handled material well.
- Plant D focuses on customization.
- Their assembly line is clean.
- Plant D maintains a low inventory throughout, as they practice “lean” techniques.

Company Description

Plant D is an independent manufacturer of modular homes that sells directly to builders. The company started in 1970 as a manufacturer of mobile homes, which they made for a year or so. They had a \$2–\$3 million investment and expansion three years ago, and the president said that they were trying to make the investment pay for itself. Three years ago they employed 100 people; now they have 180 employees. Plant D now focuses on mass customization, contrasted with their former production-process focus (i.e., standard modules). With the rising prices of steel and wood, they are facing challenges to remain profitable.

Production

Basically, the manufacturing floor has 23 stations and produces five floors per day with 180 employees. We were told that the average module produced by Plant D is 12 feet wide and 36 to 44 feet long. The president said that the average Plant D home is two to three modules. It takes one week for the house to get through the manufacturing process.

One floor plan had four modules and their factory cost was \$69,000 base price. Assume that with options, it works out to \$20,000 per module, or \$100,000 per day production sales (five floors or modules per day). If they work 225 days per year, then their total sales is \$22,500,000. Per person (total of 180), their productivity is \$125,000 per person.

Process Description

Basic process areas (Fig. D1) were about the same as found in the three previous plants we had toured:

1. Dormers (shipped separately) are built.
2. Rafters are constructed in the millroom. (Other manufacturers have used truss systems, instead of the rafter system used at Plant D.)
3. Walls are built on tables, including the exterior wall table and interior wall table. The maximum wall length was 66 feet. A simple cart was pushed along-side the wall table for the workers to unload the studs onto the table.
4. Floors are framed on a table including a joist dealer or carriage that had been end-trimmed with a precision end-trim (PET) saw, and then flipped on the floor (Fig. D2). Floor frame construction used a band consisting of laminated veneer lumber (LVL) on the inside and spruce rails

on the outside, with I-beam floor joists made with 2 by 3 cords and OSB web. In the Plant D plant, small wheels were attached to the flooring as it traveled down the line. To move through the stations, two employees used motorized pullers (or tugs) to pull on the sides of the modules.

5. Floors were decked with plywood.

6. Electrical and plumbing are installed, and drywall is erected and mudded.

7. The roof is constructed.

In the millroom, we saw a chop saw that was capable of swiveling to different angles set to preset stops, used to cut parts for rafters (Fig. D3).

One thing we noticed was that OSB sheathing was nailed to the wall after the wall was erected on the floor. We believe that this is standard operating procedure for all the previously visited factories and that we just had not noticed this earlier. This allows wiring to be done once the wall frame (with drywall attached) was connected to the floor. With Plant D, the exterior OSB sheathing was one solid piece vertically.

Our Plant D contacts told us they are experimenting with a new software system that will allow their builders to directly price, option, and order homes, much as an online car-builder would work. The system is known as the Home Base Program, made by Base 3 Technologies (Base 3 Technologies, Greenwood, Delaware). Base 3 Technology, “specifically designed for the Modular Home Industry, this software supports a 3 tier information pipeline where information coming from the manufacturer is immediately available to the Builder/Dealer as well as the Sales Professional (Base 3 Technologies 2008).” Plant D is the second or third user of this software we observed. Again, the program would control (1) sales entry, eliminating a sales representative, as the builder will price the house; (2) pricing with options for special items; and (3) orders. This will enable the user to follow the order from beginning to end; ensure that the order matches prints; include drafting and production; and provides a “stop changes” function that prevents further changes and hence finalizes the order.

Plant D had many modules in their yard waiting to be delivered; however, they said they have spoken with their builders about staggering their orders so Plant D could avoid holding a finished module. This problem would be remedied with the new ordering program.

Plant D placed a large emphasis on lean manufacturing. When walking through the plant, little excess material was lying around waiting to be used. We were told that Plant D focused on the production process in the past, but that they now focus on mass customization. We were told that 95% of their homes are a customized product.

We saw good organization of raw material. For example, each window or door had an order number that correlated

with the order number of the module. This was the first time we had seen such material handling/lean warehousing.

Other Impressions

Their product seemed to be high quality. The engineer noted that they tried to build a product that they would not have to service in the field. Some of the quality points we noticed included their use of plywood for floors and over-building of studs around doors and windows. Plant D was also using seat-belt straps to strap their exterior walls to the floors, in addition to screws to provide extra wall stability.

This was a good plant in terms of flow and housekeeping and low inventory of raw materials. We noted that the operation was done well, but potential improvements could be in the areas of production planning, delivery scheduling, and in-house data flow. They currently employ six to seven draftsmen who use Cadsoft software (Cadsoft Corporation, Guelph, Ontario, Canada).

As has been a common theme with all modular manufacturers, we were told that builders want to do less and less, meaning they want more complete modules shipped to the site. This may be a major reason for the increasing popularity of modular housing.

Reference

Base 3 Technologies. 2008. HOMEBase+ modular home builder software. Greenwood, DE: Base 3 Technologies. <http://www.base3tech.com/HOMEBase+/00.htm>. Accessed Jul 1, 2009.



Figure D2. Precision end trim (PET) saw used to trim lengths (left) and joist dealer carriage (right).



Figure D3. In the mill room, chop saw used to cut different angles on rafters.

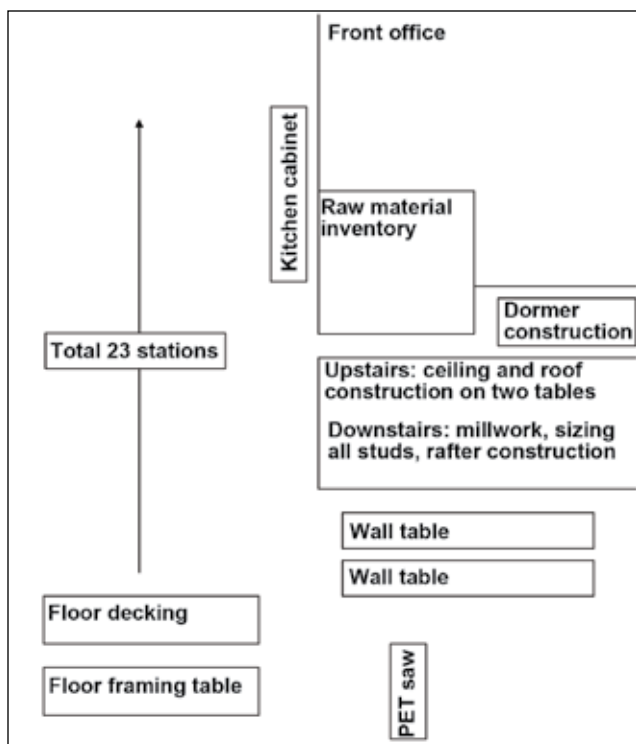


Figure D1. Plant D floor plan.

Plant E

(no photos allowed)

Contacts: President, Engineer

June 30, 2004

Key Points

- Plant E builds mostly custom homes.
- They keep a very large materials inventory by buying in bulk.
- Their housekeeping is poor.

Company Description

Plant E is a 4- to 5-year-old subsidiary of Company E producing both modular and Housing and Urban Development (HUD) code homes (Note: Plant E is not producing HUD units (a cross between a manufactured home and a custom modular home)).

Plant E can produce up to 72-feet-long floors, with the average being 54 to 62 feet. The engineer estimated that the average Plant E home is three or four modules. Standard floor widths were 13 feet, 9 in. and 11 feet (the latter for the center of a triple wide); however, different floor widths could be accommodated.

Production

Plant E produces 22 floors per week; 15 or 16 modules were on the shop floor during our visit. The engineer said 15 stations are on the line, and four to five line moves per day (four to five line moves per day = 16 to 20 floors per week). Plant E employs 160 total people. We did not see good housekeeping: screws, nails, and bolts were on the floor along the assembly line.

Process Description

Five drafters worked in engineering. Plant E uses AutoCAD 2000 Architect for their drafting. We were shown the drawings that are sent to the shop floor. In AutoCAD, the drafters had standardized blocks, essentially pre-drawn components that could be lifted into another drawing.

At the floor station, the joists were set on a table and nailed to the lumber bands; the floor was then craned over to the assembly line and set on rollers on steel tracks. Unique numbers are spray painted onto the ends of the floors. Plant E uses 3/4-in. tongue and groove OSB for flooring, 1/2-in. OSB for siding, and 5/8-in. OSB for roofing.

All exterior walls were 2 by 6 Southern Pine and were held onto the floor with 4-in. screws; the exterior walls had a gasket between the wall and OSB sub-flooring. On exterior sheathing, Plant E set a moisture barrier at OSB joints (behind top OSB sheet, in front of bottom OSB sheet). Plant E used 2 by 3s sheathed in OSB for the marriage wall. The engineer did not know if this internal void would be sealed by the builder. As with other manufacturers, we saw signs of overbuilding by Plant E; for example, triple 2 by 4s were used as headers over doors. Once the module was at the end of the assembly line, it was transferred onto different roll-

ers and rolled out of the factory to where it was transferred (again) onto a trailer.

As the floor assembly made its way down the assembly line (see flow diagram in Fig. E1), the roof was craned onto the module. Plant E purchases trusses for their homes. Cranes in the Plant E factory were split between the left and right side of the factory. By aligning a crane track from each side, loads could be transferred (unlike at Plant D where loads could only transfer at certain stations). Plant E made some three unit roof sections (for covering a triple-wide).

One interesting specialized tool we saw was a large dormer jig. This was basically two large steel tables that were angled (one side lifted into the air) to simulate a roofline. This allowed Plant E to build its dormers by simulating the angle of the roof of the in-place home. Pegs on the jig tables allow easier placement of the lumber.

The machining department was divided into stations for the dormer, stairs, and wall/floor. Carts were used to move material and finished goods around in the factory.

In addition to the typical vinyl siding, Plant E offered Hardiplank siding and window trim (James Hardie Industries, Amsterdam, The Netherlands). Plant E installed brand-name cabinets. We were told that Plant E buys in bulk to save money. We saw a *large* amount of inventory sitting around the factory. Plant E is presently building extra storage buildings on their property. Material handling did not seem to be as efficient as possible.

Other Impressions

- The engineer emphasized that Plant E only produces HUD code homes for one builder.
- The engineer was against the production of HUD homes.
- The engineer said that on average, a site-built home costs \$100 per square foot, compared with \$75 per square foot for a modular home.

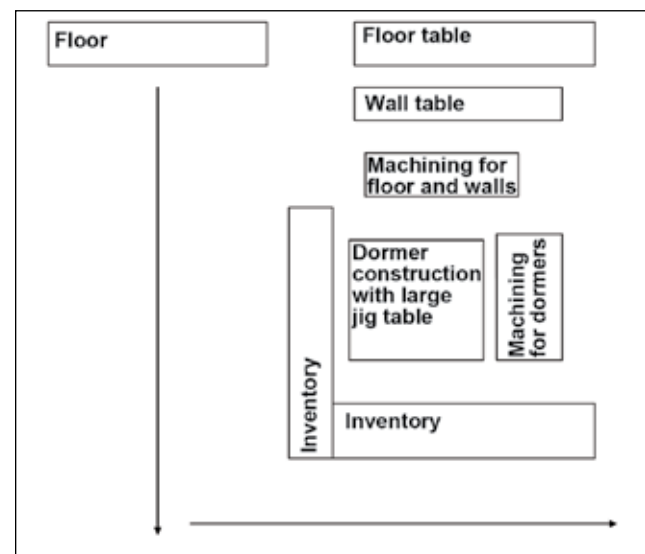


Figure E1. Plant E floor plan.

Plant F

Contact: Vice President
July 1, 2004

Key Points

- Plant F has a shotgun layout.
- They practice very good housekeeping.
- Parts cut and subassemblies are built away from the main production line, allowing the assembly line to focus on module assembly.

Company Description

The original plant was constructed in the 1950s. Today at least four manufacturing buildings are on site, with a total of 400 employees. Plant F is owned by Company F, which has other manufacturing facilities in the region. The Plant F site produces an average of three modules per day and emphasized recycling scrap cutoffs.

Production

As noted, this factory produces three modules per day. Assuming \$20,000 per module (based on an estimate from another producer), 245 days per year, the first approximation of its annual productivity is (only) \$36,750.

Process Description

Although the facility was stated to be space-constrained, we found that Plant F was well organized in terms of process, labor, and layout. As with previous plants, we did not see much in the way of computer technology being used on the floor. The module assembly line at Plant F is a “shotgun” layout, meaning that all modules move down the line lengthwise, as opposed to all other plants we have seen in which the modules move down the line sideways (Fig. F1).

The first section of floor assembly at Plant F starts on a flooring table with three floor stations beside the table where interior walls are set on the floor (Fig. F2)). The floors are constructed with spruce-pine-fir (SPF) joists or engineered laminated trusses (depending on the price class of the module) and Southern Pine lumber bands. They use a lumber buggy over the floor to distribute the joists. At the floor stations (normal floor widths of 12, 14, and 16 feet, none narrower than 10 feet), either $\frac{3}{4}$ -in. OSB or $\frac{1}{2}$ -in. plywood flooring is nailed, heating registers cut out, a layer of plastic is placed on the floor for protection, and the walls are placed. They have two wall tables (Fig. F3); long walls (maximum of 64 feet) are drywalled on the table and then lifted in place with a crane (at the flooring station). A short wall table was used for interior and end walls. Spruce-pine-fir wall studs were used and were predrilled by supplier for electrical (Fig. F4). They also build folding roof (and drywall ceiling) rafter systems on the factory floor (Figs. F5 and F6) (as opposed to trusses) and use the crane to lift these onto the modules. Necessary attic work must be done in the rough end of the module building because this newer part

of the plant has adequate height. They use a floor pit for sub-floor plumbing and electrical work.

After plumbing, the module is moved to the cross-over area and essentially the two-line process becomes a three-line process. It is important to note that modules move through the production process end to end, rather than crosswise. After inspection and exterior wall insulation, the module is sheathed with $\frac{3}{8}$ -in. pine plywood. The vice president pointed out to us that only QC folks use red markers to note deficiencies that must be corrected (Fig. F7, which is also a good example that missed staples occur even in factory production). Mud and spackling of dry wall is not begun until the module is totally sheathed in plywood (Fig. F8). They also use plywood sheathing on marriage walls because the marriage wall is load bearing. For interior finishing, two coats of paint are rolled. The vice president said the builder could leave this second coat as the finish coat. In bathrooms, Plant F offers three paint colors.

Other Impressions

Plant F takes pride in producing a customized product and classifies each job according to the level of customization: 1 is standard, 2 is changes required, and 3 is complete custom special. The vice president pointed out that the details of customization limit the amount of computer technology that can be incorporated into the process. Stated otherwise, standard, repeated products are easier to automate with computerized systems. Plant F also takes pride in being the upper end of the price point (quality) scale for modular homes.

Housekeeping was excellent throughout this plant. Notable was its philosophy of having the production line focus on assembly, and having its on-site component plant cut and prepare parts (Figs. F9 and F10). As the vice president told us, their goal is for the assembly plant to be an assembly plant (using line workers) and not to modify any material (for example, not cutting 2 by 4 or sheathing plywood). He stressed that, “The assembly line workers should pick up and install components and parts.” The component plant produced rafters, doors, doorframes, cut countertops, and ripped wall panels. The plant used a second story area to inventory kitchen cabinets, commodes, sinks, insulation, and flooring (all goods going into houses). The vice president says the doors are made in-house to better control inventory. The vice president said Plant F has just enough inventory to meet orders immediately, although we observed what appeared to be large quantities of inventoried materials. For example, lights come into the factory on a per-house basis. To bring material to the manufacturing (assembly) line, a per-house buggy of inventory is assembled and delivered to the line.

The vice president discussed the daily complication of a builder not being ready to accept that day’s delivery of a module. He stated that the delivery process generally requires two weeks to plan/execute (a few days to process the Department of Transportation wide-load permit delivery application, and then one week already scheduled).

For drafting purposes, the vice president said Plant F uses AutoCad (year not known). The vice president also said Plant F had purchased and experimented with a drafting system to create the parts list and materials purchasing list; however, he said that the software did not meet expectations, so Plant F now again does this manually.

The vice president told us that a pilot car (as is sometimes necessary for overlength modules on highway) costs \$2.10 per mile. One unique feature was that Plant F sets all of its homes rather than relying on either builders (the purchasers) or outside contractors. The set crews target setting two homes per week (each a 2-day set). The builder only assists the set crew.



Figure F1. Looking down the “shotgun” manufacturing line toward the cross-over area.

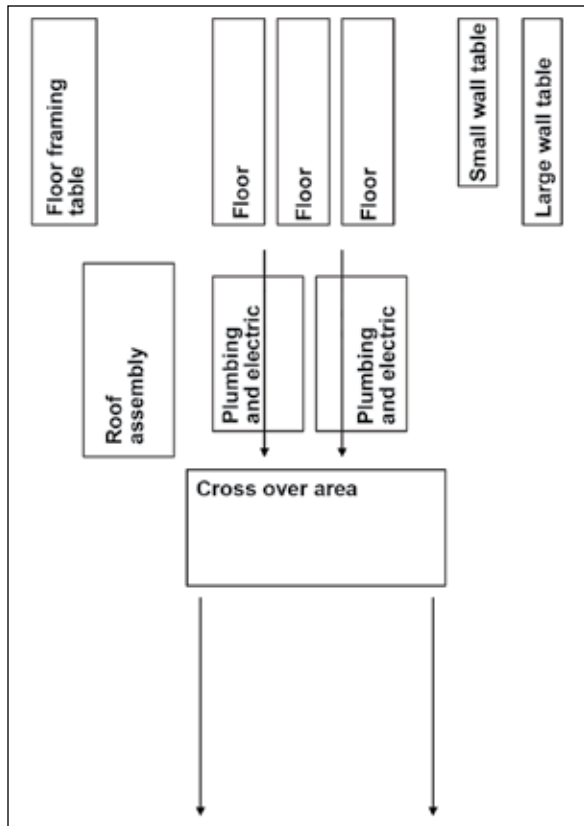


Figure F2. Manufacturing flow at Plant F Homes.



Figure F3. Joists installed at floor framing table.



Figure F4. Wall construction (left), and use of predrilled spruce-pine-fir (SPF) wall studs (right).



Figure F5. Installing rafters on ceiling drywall.



Figure F6. Installed rafters and knee brace in attic module.



Figure F7. Quality control uses red markers to visibly flag problems.



Figure F8. Plant F typically uses 3/8 in. pine plywood wall sheathing.



Figure F9. Component plant produced rafters, doors, doorframes, cut countertops, and inventoried purchased items such as cabinets, commodes, sinks, insulation, and flooring.



Figure F10. Rafters being built in component plant (top). Constructed dormers (center) and component parts assembled in kits by module (bottom).

Plant G

Contact: Truss design manager
August 11, 2004

Key Points

- Plant G is a truss and wall panel manufacturer.
- This plant had four truss assembly areas (two lines, each with two stations).
- The wall panel used two lines.

Company Description

Plant G is part of a larger company that makes doors and supplies lumber. The truss plant is five years old, whereas the wall panel plant is three months old. This new building is 80 ft by 120 ft and has two wall-panel lines. Five years ago, three truss designers were employed; today, 10 truss designers are employed. Plant G has \$6 million in sales (with about \$1 million of that being walls). They have been making wall panels for three years. Plant G is in the process of opening a new truss operation elsewhere in the state. Plant G ship trusses as far as 120 miles.

Production

We spent a lot of time with the truss design manager looking at the Mitek software (MiTek Australia Ltd., Melbourne, Victoria) that is used to design trusses. This was obviously where the truss design manager is more comfortable (as opposed to being out on the floor), and it was the first time we had toured and visited a truss operation. The truss design manager explained that the MiTek software has two major functions: layout, where the truss is designed, and engineering, where the design is evaluated based on load. The software then lets the designer know whether the truss design meets design loads. Designs typically assume a 40-pound per square-foot load. Different lumber grades are purchased and their specifics are entered into the software. Southern Pine is often used in girder trusses because of its high strength. They sometimes use piggy-back trusses as the crown of large trusses, but sometimes use hinged joints to accomplish this.

Process Description

This company requires a two-week lead time to produce normal trusses. Complex trusses may take three weeks just to draft. The MiTek software is complex; the truss design manager said that it might take a new designer two to three months to learn how to do a simple design, even though the designer is proficient with AutoCad. It might take a new designer a year to be able to perform a moderate design. The truss design manager said that a large house (10,000 ft²) that might have a 7,000 ft² roof and require \$32,000 in roof trusses.

Other Impressions

The wall panel plant has two lines, which were not running because it was the end of the shift. One line was the interior wall line while the other was the exterior wall line and used Panels Plus equipment (Panels Plus, Albert Lea, Minnesota). These simple lines needed three people each approximately. The exterior walls were sheathed on one side with OSB. No drywall was used, and thus these were not closed-wall panels. We noted that the jigs at the framing station were not being used. These simple lines consisted of a framing station with manual nail guns, a panel station with panels loaded manually, and a stationary bank of nail guns.

Plant H

Contact: Operations Manager
August 11, 2004

Key Points

- Plant H produces seven to eight modules per day.
- The plant has a two-line shotgun layout.
- Housekeeping is poor.

Company Description

Plant H produces both modular and a “united frame” HUD/modular on-frame model for “land-lease” situations. Plant H produces on average seven modules per day, again applying the mass-production mentality. Our contact told us that Plant H would also produce completely custom modular homes. Plant H employs 300 people, with about 280 in production and five in engineering/drafting. Housekeeping seemed to be a low priority in the factory. The factory was built several years ago; an addition was made to the original factory in 1997.

Production

Floors were assembled in a building separate from the main assembly line. The floors were assembled directly on the castors on which they rode down the line (attaching castors is an extra step). The employees manually pulled the floors down their line. Before the floors were transported to the main assembly line, plumbing, insulation, and wiring were run. Felt-back vinyl flooring was also installed to prevent tearing due to racking caused by transportation and setting. Our contact explained to us that for two-story homes, the floors were assembled one on top of the other to ensure that the floors were the same size (a problem we have seen with marriage walls in other manufactured homes). Alongside the final assembly line were the four tables used to assemble walls. One large table with a plastic top was used to assemble the long walls (both exterior and interior) with a maximum length of 70 ft (average 60 ft). Three shorter tables were used to assemble smaller interior and gable

walls. Exterior walls were standard 2 by 6, and interior walls were 2 by 4. We were told that a module takes four days to move down the assembly line from start to finish. Our contact estimated that there are 30 stations along the assembly line. Our contact stated that Plant H presently has a 14- to 15-week backlog for home orders.

Process Description

Plant H uses 14-foot sheets of 0.5-in. drywall for interior walls and 14-foot sheets of 5/8-in. drywall on the ceilings. Plant H mixes its own interior paint. Plant H buys the trusses for its homes.

Other Impressions

This visit raised a question: is ordering a modular home really faster for the consumer? Plant H has a 14- to 15-week backlog now. Then, assuming the builder is ready, delivering the home takes a week. Our contact said that to make the modular home “turn-key,” builders often need another 60 days (8 weeks) after the modules have been set.

Plant I

Contact: Operations Manager
August 12, 2004

Key Points

- Plant I produces between 3,000 and 3,500 ft of wall panel per day on the two wall-panel lines.
- They use Mitek truss software and truss equipment (Mitek Industries Inc., Columbia, MO).
- They use Intelligent Building Systems (IBS) (Intelligent Building Systems, Arlington, TX) wall panel software and equipment.

Company Description

Plant I produces roof trusses, floor trusses, and wall panels. The roots of Plant I are around 150 years old; however, Plant I was officially started in 1975 (according to the Web site). Overall, we were impressed with the equipment and operation. The wall panel line at Plant I is semi-automated. Plant I is producing a minimum of 3,000 feet of wall panel per day; our contact told us that up to 3,500 feet per day is normal. The wall-panel line area showed good housekeeping. The wall panel assembly lines were two and three years old.

Production

Eight-foot tall wall panels are normally 12 feet wide, whereas Plant I panels greater than eight feet high are eight feet wide. Our contact said this size weighs less and is advantageous for transportation and panel-placement reasons. The panels over eight feet high were manually assembled/sheathed on a special table in the truss building (probably manually framed). Plant I also made some special “enclosed

wall panels” for surrounding fireplaces. These were also manually sheathed (and probably manually framed) on the special table.

Process Description

Wall panels were designed using Intelligent Building Systems’ software. As we have seen with the Mitek truss software, this software automatically inserted studs where they belong, seemingly shortening drafting time. This file was then sent to the wall panel supervisor, who then decided on which line the panels would be made. Once the supervisor had decided which line to use, the operators would see the panel visually displayed on their monitor.

A schematic of Plant I wall panel lines is shown in Figure 11. The employees involved with the wall panels were sawyer, part assembly (parts included decks, ladders, jacks, Ts, corners), component assembly, and assembly line. An employee pre-cut the sheathing to go on the framed wall panel. After parts were made in part assembly, they were carried to the component assembly table, which fed directly into the assembly line. The two operators on the framing section of the assembly line viewed a line drawing of the wall they were making on a monitor. Jig fingers could be used for standard dimension walls; however, whenever components were set into the wall, the jig fingers were often useless and the tape measure printed on the table was used.

The workers then squared the wall panels on the table, and the semi-automated nail gun was pulled along the framed wall panel. The wall panel then went to sheathing where two employees set the pre-cut wall skin on the frame. The semi-automatic nail station only was used where there was uninterrupted wall section; i.e., not around windows and door openings. Around these openings, the operators manually nailed the sheathing. At the time we visited, only a type of fiberboard was being run as sheathing. Staples were used for the sheathing, and the staples did not seem to consistently penetrate the panel skin. The wall panel also exhibited visual deflection whenever the nail gun row was lowered onto the panel. There was a router station after the skin section; however, we did not see this station being used. The router station was again semi-automated. Once finished, panels were lifted off of the assembly line and stacked according to a stack sheet. Here an operator used a crane to lift and set the panels.

Other Impressions

We saw nine employees per assembly line; however, a total of 27 employees worked in the wall panel section of the plant during the day. Fourteen employees worked the wall panel section during the night. These extra positions include forklift driver, lumber puller, supervisor, the panel pre-cut employee (as mentioned above), and the extra person outside the building to stack the interior panels from the right side assembly line.

Each assembly line cost approximately \$150,000. Our contact said the average employee in the panel department is paid \$10.50 per hour, plus medical and dental insurance and a 401K-plan option.

Our contact explained to us that most component plants (truss and wall panels) will do about \$3–\$5 million in business every year; meaning that manufacturers tend to be “mom and pop” shops that have developed over the years. As for homeowners’ move-in time, we were told that the panelized homes from Plant I typically have a 120-day move-in time. Our contact stated that Plant I used to have one of the first CAD/CAM wall panel assembly lines installed in 1994 ; however, eventually their operational requirements outgrew this system.

Appendix B—Technology Assessment of U.S. Modular Home Plants

In the following table, four questions are answered for each major process. These answers are a guide to the level of technology employed at each of these processes.

We asked four questions:

- How is the raw material transported?
- How is the raw material sized?
- How are the components fastened?
- How is the finished product moved?

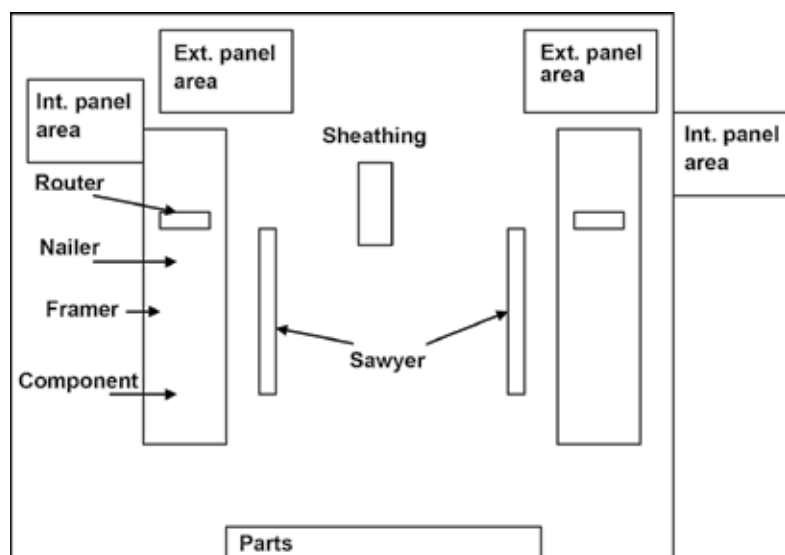


Figure I1. Plant I floor plan.

Table 1—Technology assessment

Process/Technology	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F	Plant H
Customer input	Standard or custom	Standard with options	Standard or custom	Standard or custom	Standard or custom	Standard or custom	Standard or custom
Plant design	—	AutoCad	DataCAD	CADSoft ^a	AutoCAD 2000 Architecture	AutoCAD ^b	—
Plant plans	Printed	Printed	Printed	Printed	Printed	Printed	Printed
Floor framing	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/ frame-flipped ^c	Manual with joist dealer/PET saw/manual nail gun/crane-flipped	Manual/cut-off saw/ manual nail gun/ crane to track ^d	Manual with joist dealer/cut-off saw/ manual nail gun/ crane to track	Manual/cut-off saw/ manual nail gun/rollers
Floor decking	Manual/circular saw/ manual nail gun/ crane to track	Manual/circular saw/ manual nail gun/ air pads	Manual/circular saw/ manual nail gun/ frame on rollers	Manual/circular saw/ manual nail gun/ crane to rollers	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA
Floor infill ^e	Manual	Manual	Manual ^f	Manual	Manual	Manual ^g	Manual
Wall framing ^h	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/manual nail gun/crane ⁱ	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/crane	Manual/cut-off saw/ manual nail gun/crane
Wall sheathing (OSB or plywood)	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA	Manual/circular saw/ manual nail gun/ NA
Wall set	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA
Wall infill	Manual	Manual	Manual	Manual	Manual	Manual ^j	Manual
Roof framing	OSP of trusses	Manual/cut-off saw/ plate press/ manual to cart	OSP of trusses	Manual/cut-off saw/ manual connected/ manual to cart	OSP of trusses	Manual/cut-off saw/ manual connected/ manual to cart	OSP of trusses
Roof assembly	Manual/NA/ manual nail gun/ crane ^k	Manual/NA/ manual nail gun/ crane ^l	Manual/NA/ manual nail gun/ crane	Manual/NA/ manual nail gun/ crane	Manual/NA/ manual nail gun/ crane	Manual/NA/ manual nail gun/ crane ^m	Manual/NA/ manual nail gun/ crane
Roof decking	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA	Manual/circular saw/ manual nail gun/NA
Roof set	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA	Crane/NA/manual pneumatic screw/NA
Roof infill	Manual	Manual	Manual	Manual	Manual	Manual	Manual

^a Plant is in the process of implementing Base 3 Technology's Home Base Program (Base 3 Technologies, Greenwood, DE).

^b Plant bought software for a parts list and materials purchasing list, but found the software problematic.

^c Floor is attached to transport frame and then flipped.

^d At the end of the assembly line, modules are lifted onto a different set of rollers that are perpendicular to main assembly line. The modules are rolled out of the plant and transferred onto a trailer.

^e Floor, wall, or roof infill—plumbing, wiring, duct work, and insulation.

^f Floor infill begins on framing table, before being flipped.

^g Floor pit used for sub-floor plumbing and electrical work.

^h Sheetrock was attached to wall framing on the framing table at all manufacturers.

ⁱ Special cut-off saw table for short wall sections.

^j Plant F used studs with a predrilled hole about 30 in. from one end.

^k Ceiling sheetrock not attached at roof assembly.

^l Ceiling sheetrock was attached at roof assembly.

^m Unlike other manufacturers, Plant F installed infill while roof was on the floor.

Appendix C—Trip Reports Summarizing German Modular Home Plants

Plant GA

Contact: Technical Manager

June 15, 2005

We were told that Plant GA (Fig. GA1) was one of the top 10 factory home builders in Germany, reputable for building a high-quality though expensive home. They manufacture 95% custom homes and 5% Teuton (no options). They sell through free agents that use one of their 20 demo houses built throughout Germany. They do engage the customer directly and use their on-site home and option display for the customer to use and finalize plans (and flooring, doors, and windows and such) after the architecture plan has been finalized.

Plant GA does not use laminated beams in its homes. Instead, they use solid timber beams. In situations where large open rooms are designed without support walls or columns, steel I-beams are used to support the wood timbers.

After plans are finalized, the house can be completed in 8 to 12 weeks. Once transported to the building site, the house is finished in one day. They use three different software programs in the process of selling, designing, and producing a house:

1. Sales drawing (light-duty CAD (computer-aided design))
2. Architectural drawings, which are again made by a 2-D program. This program can use some of the information from the sales drawing which is a dxf file, a data format developed by Autodesk used for CAD vector image files, such as AutoCAD documents.
3. The 3-D construction program CADWORK (Cadwork Informatik CI AG, Basel, Switzerland) is supposed to extrude the 2-D file written; however, the technical manager states that the extrusion is seldom correct, and therefore this option is not often used.

Plant GA employs 200 people, 100 in production and 100 in the office. They manufacture 200 complete homes, known in German as *schlüsselfertig* (turn-key) per year, and about 100–150 Aus-Bau Homes (customers complete the inside or a part of the inside).

In Germany, 15% of the housing is timber frame (wooden) homes, and 85% is traditional cement and stone. The German housing market share for timber frame houses is down, and many factories closed in 1995. These were factories built in East Germany that failed because of the lack of demand (lack of money) in East Germany after the fall of the wall. Typically, a German customer builds only one house in his lifetime.

Process Description

Timber frame processing—According to the technical manager, “the heart” of the Plant GA factory is two machines, the Hundegger CNC timber frame processor (Hundegger GmbH, Hawangen, Germany) (Figs. GA2 and GA3) and a Giben automated (CNC) panel processor (Giben International S.p.A., Pianoro (Bo), Italy) (Fig. GA4). At the time of our visit, the timbers being worked on were fingerjointed spruce 5 cm by 10 cm (this was the minimum size timber used by Plant GA). The Hundegger station notched timbers and drilled holes for the connectors (lag or normal bolts) and cut the timbers to length with angles other than 90 degrees as needed (Fig. GA5). The infeed had at least six groups of differently sized timbers, which were automatically preloaded into the machine (Fig. GA6). Selection and machining of timbers was done by the computer program. The timber processing machine was located between the wall table and the roof table to easily feed both processes. The automated timber loader was a Weinmann timber loader (Weinmann Holzbausystemtechnik GmbH, St. Johann-Lonsingen, Germany). For short timbers, a manual cut-off saw was used at a separate station (Fig. GA7).

Panel processing—A very large Giben automated (CNC) panel processor was used to cut OSB, particleboard, or plywood panels to size (Figs. GA8 and GA9). In combination with the Hundegger timber frame processor, these form “the heart” of the factory. Only those panels that need trimming are cut here, such as those that will not fit into a standard 4 by 8 space (Note: panels were not measured to ensure that standard European size is indeed 4 by 8).

Wall table processing—This operation constructed the timber frame as a wall, placed sheathing (plywood or OSB), and laid down batts of insulation (Figs. GA10, GA11, and GA12). Wall studs were fastened with a nail gun, as were panels to the wall frame. After sheathing one side, the wall panel is flipped with a crane. Electrical conduits and insulation are then installed (Fig. GA13), and final sheathing is done. This outer sheathing may be OSB or it may be foam insulation if the house will be bricked on site. Windows were also installed on this line. All void spaces (including those around insulation) were filled with expanding foam (Fig. GA14). Wiring conduits were routed up the wall to a channel at the top of the panel (Fig. GA15) and connects to the adjoining panel via this channel. Wires were then run through the conduit, with coiled wire left hanging off of the panels (Fig. GA16).

Floor/ceiling table (middle floor)—This station used an automatic board dealer and automatic nail gun to fasten furring strips to larger beams (Fig. GA17). Drywall ceiling or flooring panel can then be attached to these strips; the strips function as support for the ceiling or flooring. A flipper finishes the other side of this component (Fig. GA18).

Roof table/line—Furring strips were manually attached to larger beams using a nail gun. Plastic water proofing sheet was attached to the construction. Tile shingles were installed at the construction site, after the entire wall/floor/roof panels have been set and the space under the walls filled with concrete (Figs. GA19, GA20, and GA21).

Finished panels were oriented vertically by crane and loaded onto a metal platform, which in turn was hydraulically lifted and placed on a truck bed for transport (Fig. GA22). The technical manager stated that window breakage because of transport is so seldom a problem (one broken window per year) that it is not even considered.

Plant GA also has a stair-production line manufacturing 30 staircases per week, mainly of beech with some oak. These stairs are customized products for more than just Plant GA's houses. Target moisture content for this raw material was 6%–9%. With these staircases, glued hardwood panels are bought in different thicknesses, widths, and lengths and CNC-machined to the needed size/shape (Fig. GA23).



Figure GA1. Plant G-A manufactured home facility in Germany.



Figure GA2. Infeed side of Hundegger timber processor.



Figure GA3. Shielded sawing and notching area of the Hundegger K2. The red clamps are feeding a timber to the cutting heads.



Figure GA4. Giben computer numerical controlled (CNC) panel processor.



Figure GA5. Example of timber cuts made by Hundegger K2.



Figure GA6. Weinmann automated timber loader selected and picked up timbers from the infeed bays using screws.



Figure GA9. Giben infeed with many panels available for vacuum lift.



Figure GA7. Manual cut-off saw used for short timbers (infeed bays for the Hundegger shown in background).



Figure GA10. Nailing sheathing to the timber frame at the wall table station.



Figure GA8. Large Giben computer numerical controlled (CNC) panel processor cut oriented strandboard (OSB), particleboard, and plywood.



Figure GA11. Timber frame showing red electrical conduits, mineral wool insulation, and exterior window shade.



Figure GA12. Stud member fitting into notched gable roof. Note mineral wool insulation.



Figure GA13. Framed and drywalled wall showing bats of mineral wool and plastic electrical conduit.



Figure GA14. Expanding foam used to fill voids and completely insulate wall panels.



Figure GA15. Top of wall panel shows channel developed for electrical conduit placement.



Figure GA16. Wiring conduits exiting wall panel with wiring.



Figure GA17. Automatic board dealer and automatic nail gun fastens furring strips to joists at the middle floor station (floor and ceiling).



Figure GA18. Butterfly table flips the middle floor construction so other side can be worked on.

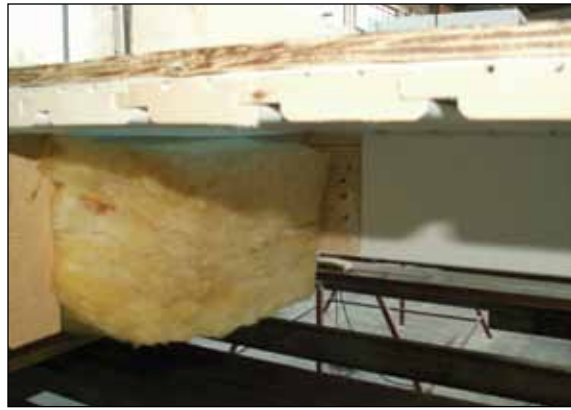


Figure GA21. Edge view of roof showing exposed beam (right), insulation bat (left).



Figure GA19. Roof table showing furring strips for tile shingles (installed on site), blue plastic water proofing, and painted exposed joist.



Figure GA22. Finished wall sections are oriented vertically and loaded onto a metal platform, which is placed on truck bed for transport.



Figure GA20. Roof table showing furring strips and sheet of plastic water proofing.



Figure GA23. Beech stair stringer machined with computer numerically controlled (CNC) router.

Plant GB

Contact: Engineer

No photos were allowed in factory, but photos were allowed in showcase homes on site.

June 17, 2005

Plant GB is one of the premier home builders in Germany. The company has been in existence since 1912. In 1972, they began building post and beam homes designed by architect Manfred Adams. These homes are very open in design and have large glass windows. They use laminated beams throughout made of Scandinavian spruce (Fig. GB1).

The architect works with customers to design the completely custom floor plan. All Plant GB homes have open floor, open wall, and open roof sections; this is the Plant GB architectural style (Fig. GB2).

Plant GB builds about 125–135 houses per year, and employs 300 employees total: 100 in production; 100 in “building science” (CAD design, planning and scheduling); and 100 in administration and in other cities (example houses). They work five days per week with four weeks holiday per year. They have show houses throughout Germany and Europe (Fig. GB3). The average Plant GB home in Germany is 200 m². In Great Britain, the average Plant GB home is 300 m².

Processes

Plant GB has two main buildings, Carpentry Hall and Assembly Hall. In the Carpentry Hall, their main piece of equipment was the Fezer CNC machine.

This machine was approximately 40 m (120 feet) long, but the plant is limited by what length they can haul on their trailers (limit is 11.66 m overall length). Their new Fezer can saw, drill holes, make grooves for the beams to interlock, and produce sloped horizontal surfaces by sawing. Timbers are grouped by the job. They also use their older, more manual Fezer machine to process shorter beams.

All hand tools in the Plant GB factory were Festool (Festool Germany, TTS Tooltechnic Systems AG & Co. KG, Wendlingen, Germany).

The beams then enter a QC area where visible, loose knots or other defects (such as sap pockets) are removed and plugs inserted. The beams are then sanded using a three-head buffering sander, stained (five coats for exposed sections and three coats for interior beams), and then air dried. Not all exterior stains are applied at this time, however.

Also in the Carpentry Hall is an IMA HullHorst CNC (IMA Klessmann GmbH, Lubbecke, Germany) which cuts, drills, grooves, and sands stairway parts—stringers and rails. This two-table CNC uses a pod system.

The Assembly Hall had eight work areas:

- Roof table
- Angled roof table for roof sections with large windows (no automatic angle setting)
- Wall table—triple-glaze windows are built into exterior wall sections. Cranes load these wall sections onto trucks vertically.
- Wet wall area—a separate wall for bathroom plumbing that goes in front of the regular wall
- Interior floor area
- External first floor wall section
- Interior first floor wall area—cranes are used to move interior walls, which are 16 cm thick
- Interior second floor wall

At the roof table, they first work on the ceiling. The layers, starting with the layer visible by the customer (looking up at the ceiling) are the following:

- Tongue and groove paneling (installed manually) or drywall
- OSB
- Lathe
- Plastic membrane
- Insulation between beams
- Beams

After the tongue and groove is installed, the roof section is flipped by crane, and layered with two thick layers of mineral wool, a breathable membrane, and a lathe for the roof tile, which is installed at the building site. The roof sections are then placed on transport trailer.

Note: The actual sequence of roof construction layers may not be totally correct, but do correctly show the detail involved.

Our contact stated that Plant GB tried to maximize the level of panel completion in the factory to minimize required work at the construction site. Many Plant GB homes are shipped each year to Britain. Our contact referred to Plant GB as “the Mercedes of homes,” saying that she knew of no other home manufacturer in Germany with higher quality homes.



Figure GB1. Painted laminated beams are used throughout Plant GB homes.



Figure GB2. Plant GB homes are characterized by an open architectural style.



Figure GB3. Plant GB model home located on site.

Plant GC

Contact: Construction Engineer
June 17, 2005

Plant GC is a custom-build homebuilder, with 150 employees (30% are in the office and the remainder are in production and assembly). This plant sells its houses directly to the customer through a dealer network, using example houses throughout Germany to help customers determine options (Fig. GC1). Their office staff makes building plans and manages construction paperwork to meet government paperwork. Their construction plans are drafted using Nemetschek software (Nemetschek AG, Munich, Germany), which is similar to AutoCad. Our contact noted that one advantage of *Fertigbau* (prefabricated construction) homes is the guaranteed pricing of a new home. Plant GC sells 150 homes per year.

Plant GC is currently operating on one shift. Last year they ran two shifts, as the housing market was boosted by a 2-year government program to provide loans at a 4%, 10-year adjustable rate mortgage for certain income brackets. Plant GC buyers are typically young families that purchase unfinished (do-it-yourself) homes. A 20% down payment for the home is typical.

Our contact mentioned that home manufacturers discussed timber size requirements with sawmills so they could have the desired dimensions and quality provided (these were fingerjointed timbers from Germany, but they were not laminated (Fig. GC2)). Standard height of interior walls was 2 m, 50 cm. The studs used for interior walls were standardized (cut to length) to accommodate this height requirement. Our contact said that Plant GC produced custom homes, so any interior wall height could be accommodated; however, Plant GC would have to wait on their manufacturer to custom cut the longer timbers/studs for taller walls. Walls are limited by truck length to 15 m long. The maximum allowable height for wall panels is 4 m.

Processes

In the Plant GC home manufacturing process, walls and floor sections (called wall and floor elements by most in Europe) were built using specialized tables (Figs. GC3–GC8). Roof trusses and gable ends were also cut and constructed (Fig. GC9 and GC10); however, roof elements were not assembled in the factory. Plant GC ran the conduit for the wires of the home to be placed in; however, the home was wired on site. The home was also plumbed on site, but major plumbing apparatuses (the connections to the toilet and showers) were installed in the factory. In the wall sections where plumbing would be run, the drywall was simply screwed to the wall framing so it (the drywall) could be easily removed and re-installed on the construction site.

Typical dimensions for their solid wood members were 6 by 8 cm for interior studs and either 8 by 14 cm for

exterior walls or 10 by 14 or 14 by 14 cm for joists or other main structural members. This plant's typical exterior wall layered construction (Fig. GC11) from the outside, would be stucco board, particleboard, 14-cm thick stud with insulation, particleboard, moisture barrier, and interior drywall.

At the factory, elements (components) of the home are built, such as interior and exterior walls, wooden part of the middle floor (5 cm of concrete is poured on site over each completed floor). These wall and floor components were transported by truck to the site (Fig. GC12), electrical wiring and plumbing was installed on site, and roofs were assembled on site, the rafters being cut and painted at the factory (Fig. GC13). Plant GC also manufactured the concrete panels to be used in the construction of the basement of its homes. These concrete panels were placed/set at the home site and a cement slab would be poured at the home site. For all interior wall elements that would have any angle on their upper corner (walls on the second floor), the wall elements would be constructed on a jig made by building one of the gable end walls on the factory floor. This would ensure that all walls, rafters, and gable ends lined up when being assembled at the construction site.

Our contact stated that Plant GC was in the top one-third of wooden home quality in Germany, and that the price of a Plant GC home was about average (the 50th percentile). Our contact said that all Plant GC homes have a 4-year, all inclusive warranty, and a 20-year structural–construction warranty.

Our contact stated that most customers of Plant GC homes said that they needed approximately 1,700 liters of oil to heat the home and the hot water for an average home size of 150 m². This works out to be 447.4 gallons of oil to heat (house and hot water) 1,614 ft² of home (equates to 0.2772 gallons of heating oil per square foot) for an entire year.



Figure GC1. An example of a typical Plant GC showcase home.



Figure GC2. Fingerjointed exterior walls are 14 cm thick.



Figure GC3. Frame table with air-activated cylinders to clamp and hold frame.



Figure GC4. Wall-build table showing stops used to position wall-frame elements.



Figure GC5. Specialized wall table clamp that can retract into table to remove trip hazard.



Figure GC8. Elevated cart for worker access to vertical wall.



Figure GC6. Stop bracket on wall table used to position wall frame elements.



Figure GC9. Gable walls are built one on top of the other to ensure symmetry.



Figure GC7. Light curtain reflector at wall table used to protect workers during clamping by halting clamping operations if workers break the light perimeter.

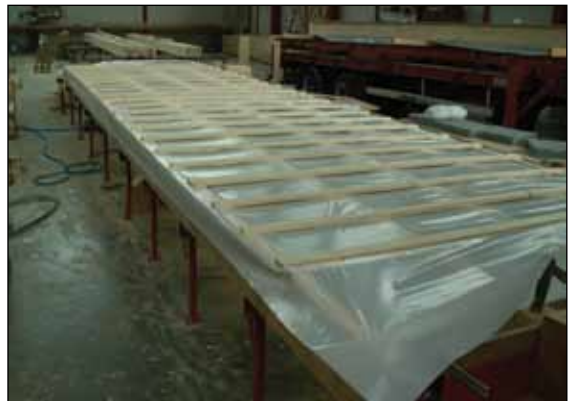


Figure GC10. Roof element on transporting platform.



Figure GC11. Exterior wall construction from left: stucco board, particleboard, 14-cm stud, particleboard, moisture barrier, drywall.



Figure GC12. Wall components are fastened in a rack on the transport trailer.



Figure GC13. Roof rafters are cut and painted at the factory but assembled on-site.

Plant GD

Contacts: Draftsman, Technical Leader
June 20, 2005

Plant GD produces high-quality homes and stated that they were in third or fourth place in quality in Germany. They rank Plant GE higher. Plant GD has been in business for 75 years, and the factory we toured was 12 years old. Over the 75 years of business, Plant GD has produced over 28,000 homes. They market their homes in Germany, Austria, Switzerland, France, Spain, Great Britain, and Ireland. They have six example homes on site. Their maximum wall dimensions are 13 m (length) by 3 m (height).

Processes

Plant GD was unique in its wall-production method. They produce standardized elements (one example element was 1.55 by 2.5 m) and combine these standardized elements to produce full-size wall panels. We were told that combining standardized size elements allows Plant GD to automate production (assembly) of 85% of its needed wall panels. The remaining 15% of wall panels are produced on another wall table in a manner similar to wall panel construction typically seen in Germany. The 15% of walls produced without using standardized elements was stated to mostly be wall sections with gable ends; this prevented excess waste. We do not know how many standardized wall element sizes exist. These standardized wall elements are further unique in that they are entirely glued together; nails are only used to affix wall elements to one another. These standardized wall elements already have insulation installed, and internal studs in the elements have a square notch cut in one side of them to allow cables to be run. We did not see the production of these standardized wall elements.

The Plant GD wall-panel production process begins with elements being picked from a buffer (Fig. GD1) and delivered to a staging table (Fig. GD2). The standardized elements are delivered in the order in which they need to be affixed to produce the wall panel. After being delivered to the assembly table, workers manually staple and nail the standardized elements together (Fig. GD3) using nail guns. After being affixed, the wall panel was moved down the assembly line (Fig. GD4) and a plastic moisture barrier was installed over the OSB (Fig. GD5).

Plant GD constructs with mostly German spruce timbers (both fingerjointed segments and laminated beams) and some pine. They use sanded OSB and (pine) plywood: 15-mm OSB for walls and 18-mm for ceilings.

Plant GD employs about 300 people; 80–90 in production; 90 administration; and 90 in construction. They employ about 20 draftsmen who use AutoCad with specialized Plant GD elements that are standard sizes; custom sizes to all components can be entered (constructed), too. Plant GD manufactures its own windows, staircases, and front doors.

Customers often have their own architects and supply their own plans. Plant GD focuses on building a truly customized home with standardized building elements.

They produce an average of two houses per day, about 350 to 400 per year. Their average home size is 150 m². Our contact told us that the average Plant GD home costs about 1,000 euros/m², excluding the basement. Converted to square feet, these homes cost about 93 euros/ft².

Some of the technology we saw in the factory included a 3Tec software system used to pick elements and place them in the wall assembly line. The HELO TEC machine (HELO TEC Automation GmbH & Co.KG, Bueren, Germany) bored holes for electrical switches and outlets (Fig. GD6). These holes were bored after the wall panels were vertical, just before the wall panels were moved into the vertical storage racks (Figs. GD7–GD8). The LeWecke machine (Lewecke Maschinenbau GmbH, Blomberg, Germany) was used to build roof sections and included automatic lathe dealers and nail guns for panels (Figs. GD9, GD10). The Hundegger CNC drilled, sawed to length and angle, and notched, as we have seen in other factories. This Hundegger was used to size pieces for roof and floor–ceiling elements.

Plant GD is currently running a backlog of orders, so it takes six months to get your house. Normally, three months would be the expected turnaround time if the foundations and plans were ready. It takes about one week to produce and four to six weeks to erect.

The production manager told us that approximately 35% of the operating cost for the factory is for electricity. As with most other manufacturers, Plant GD built wet walls with internal plumbing; these wet walls are set in front of the regular house walls. The technical leader stated numerous times that one of the best features of their factory is the linear flow through the assembly line (production). Plant GD sells the homes with a 5-year all inclusive guarantee and a 30-year structural guarantee.



Figure GD1. Wall-panel elements stored in buffer area prior to starting the process.



Figure GD2. Staging area into which wall panel elements are correctly sequenced.



Figure GD3. Assembly table workers manually connecting standardized elements together.



Figure GD4. View along the length of the assembly table.



Figure GD5. Plastic moisture barrier installed over wall panel.



Figure GD6. The HELO TEC machine bored holes in walls for electrical switches and outlets.



Figure GD7. Wall sections hung on vertical storage racks.



Figure GD8. View of walls vertically hung beyond the HELO TEC borer.



Figure GD9. LeWecke machine nailing panels onto roof section.



Figure GD10. View of LeWecke machine capable of dealing lathe and automatic nailing.

Plant GE

Germany

Contact: Visitor Guide

June 21, 2005

Our contact has been working at Plant GE for 23 years. Its two product lines were Plant GE and Twin Home, home lines with the same quality but different target customers (see Figs. GE1 and GE2 for model home). Plant GE homes can be completely customized, whereas the twin homes are much more preplanned. Next to the factory was the company founder's original wood home built in 1963. As we walked toward wood storage, we walked past the painting booths. Plant GE paints doors and windows and has winter gardens and certain special elements.

Plant GE has a total of 1,000 employees working in two factories. In the factory we toured, 160 work in production on two shifts. About 260 employees work in the office, and about 240 employees work in erection on site. About 240 people work at the second factory with approximately 110–120 in sales.

Plant GE has a total of about 50 apprentices throughout the company. Plant GE makes finished roof or ceiling elements, though we did not see this. Last year, Plant GE produced 870 houses. They also have a second factory in Germany. Plant GE has erecting crews at both factory locations.

Processes

Following wood storage, the next section was the metal-working area. Employees were working with copper- and titanium-zinc-coated steel for gutters and flashing. Stainless steel was also fabricated. The metal came in on coils and was straightened and clipped to length. Wood jigs were used for shaping metal pieces, welding, and building flashing around windows and gable ends. Metal part seams were bent rather than welded to allow for expansion and contraction of the metal. Timber painting was also done in this area. Exposed wood timbers must be painted; the rest is optional. If the final paint color is white, the final coat of paint is applied in the field after the home has been constructed. Otherwise, the final paint coat is applied in the factory. Plant GE also makes roof elements that are 2.4 to 2.5 m wide.

Next, in lumber and panel storage, the wall studs are pre-cut to their length for wall height when delivered to the production floor (Fig. GE3). The studs are dried to 12%–15% moisture content at a low temperature so the wood will not twist. In the winter, studs are staged in the factory to allow them to equalize with the assembly line environment. The particleboard used contains polyurethane glue, and example pieces illustrated how little the particleboard swells when soaked in water. The drywall they use is moisture-resistant (also called greenboard and typically used in bathrooms). Plant GE, however, uses it throughout its whole house, as they place an emphasis on using high-quality materials.

Plant GE does much research and development and quality control on its houses. The example our contact gave was, “What if it is raining on the day of your construction? Your walls need to be of the best material.” Our contact stated that many competitors use cheaper materials, which is why their price is lower. Within the first day of construction of the house on site, it is rainproof. If any water gets into the house, the walls allow moisture out. Plant GE uses three suppliers of windows, all local producers.

Machines

All machines seen in the production line were Weinmann. Table one was for the outside wall; however, when the frame was built on the table, the top of the wall is the interior (Fig. GE4). The wall was framed, the moisture barrier installed, and then particleboard and drywall were attached. The holes were drilled for electrical outlets and switches using a Weinmann multifunction bridge (Fig. GE5), which nails or staples the panel to the frame and then cuts rough openings and trims panel edges. The wall was then flipped using a butterfly table (Fig. GE6). The electrical conduit was then run, insulation installed in the wall, and then another moisture-diffusible barrier was installed and sheathed with cement-bound particleboard. This cement board is 90-minute fire-resistant and appeared to be approximately 3.8 cm thick. Barrier strips were manually installed along the outer edge of the wall panel, and a machine automatically spread plaster 1.5 cm thick. On the exterior of the building, the support net for the stucco was installed on the building site and wrapped around the entire building so there would be no joints (Fig. GE7). After being wrapped, the building is spackled, again on site.

Housekeeping was medium to better than medium—but better than any modular factory in the United States we have seen. The doors and windows were installed after the walls were hung vertically (Figs. GE8–10). The doors were specially noted to be 9.6 cm thick—the guide mentioned how the doors and windows used contribute to the homeowner's feeling of security.

In the factory, only conduit was run for wires and then the wires were installed at the construction site. We asked the guide why the wires were not run in the factory, and the guide responded that this factory was “yesterday's technology.” Further, Plant GE had worked with its supplier to develop electrical, plumbing, and bus connectors that would automatically connect when the wall was set into place. These houses were called “three-day houses” since that is the estimated length of time to assemble components and have plumbing and electrical connections completed. Some of these houses have been built to prove the connection technology. The guide said that at this time the connectors are simply too expensive to use on a mass-production scale.

The rolladen rolling exterior shades (rolladen is German for shutters) are built into the wall while vertical. Plant GE

differentiated itself by building these shades totally into the wall so that they were flush with the exterior wall. Dry-wall was then manually cut and fit to cover the hole where the rolling shade was installed (on the interior). Window choices for the houses were plastic, wood, or wood and aluminum.

In the factory, tile was already put on the wall. Also, special protectors were put on passageways that were not doors, and then removed once the house was finished on site. This prevented damage to passageways during erection and construction.

Even though greenboard was used, the shower area was painted with a layer of liquid rubber. The foam used for insulation was EPS (expanded polystyrene). When processing the large timbers, all four sides of the timber can be processed in the same step. They had a four-headed processor.

Plant GE mostly used beech in its stair production. The Maka CNC machine used fixtures to hold stair parts. They used a hand router to rounding the corner of the stairs. We noted that the CNC router was capable of drilling vertically, then rotated and drilled horizontally (Figs. GE11 and GE12).

The staircase was built in the factory and then shrink-wrapped. Components for winter gardens were also built in



Figure GE1. Model home at Plant GE.



Figure GE2. Kitchen typical of quality and amenities.



Figure GE3. Infeed timber buffer for Hundegger processor.



Figure GE4. Outside wall lay-up with insulation, moisture barrier, and particleboard.



Figure GE5. Multifunction bridge station for wall panels.



Figure GE8. Troublesome components, such as this gable, can be pulled offline. Note eyehooks used for vertical hanging.



Figure GE6. Butterfly table used to flip wall panels as they move down the line (background).



Figure GE9. Butterfly transfer table raises wall panel for vertical hanging onto line (to right).



Figure GE7. Detail showing many layers of the exterior wall.



Figure GE10. Note electrical conduits, interior window shade, and installed doors and windows.



Figure GE11. Maka CNC machine used vacuum pods to hold stock used to produce beech stair parts.



Figure GE12. Staircase assembly.

the stair-production area.

Plant GF

Contact: Engineer

Wednesday, June 22, 2005

Plant GF, a privately owned company, has been in business since 1881. According to the engineer, they are in the middle top range for quality and price. The engineer stated that some companies in Germany are more prefabricated than Plant GF, but many are less. Plant GF has 220 to 230 employees, most located at the building site. In 2004, they built 206 houses; in 2005, 197–198. Its sales radius is 300–400 km, which is mostly in Germany around Stuttgart but includes Switzerland as well. A model home at the plant site is shown in Figure GF1.

Processes

This operation was housed in several buildings. Our overall impression was that the operations were space constrained (i.e., crowded). Separate buildings housed sequential operations, specifically the Hundeggers that pass components to either walls or roof building areas in different buildings, which seemed inefficient. Overall housekeeping was not good.

Joinery area—construction of front doors and stairs. Plant GF builds 90% the front doors for houses. Ninety-five percent of the stairs are built by Plant GF; the engineer stated that stair fabrication required a lot of hand work. An example of an installed finished staircase is shown in Figure GF2. A Maku CNC router was the “heart” of the joinery (Fig. GF3). They cut parts for doors and stairs on this pod-based CNC. Stock material for much of this process was 1-m by 5-m wide beech panels, *Verleimt Holzplatten* (edge-glued panel) (Fig. GF4). This Maku CNC is also used to cut out the holes required in particleboard panels for toilet connections.

Component preparation—Plant GF has two Hundegger CNC machines. The first is in the preparation area for wall components (Fig. GF5). It prepares (bores, notches, routs holes, and applies metal plates) wall sill plates and top plates. Many of these openings were for electrical and plumbing. Electrical wire and final stucco coat are applied at the building site, while rough plumbing is run in the factory. Particleboard wall panels in plumbing areas are removed on the building site to allow plumbing completion. The Hundegger used for wall component preparation starts with 4.9-m-long lumber that it cuts to required lengths. The metal plate capability allows them to use short parts. The Hundeggers are run by a German CNC control software program, SEMA Timber Construction Software (SEMA GmbH, Wildpoldsried, Germany).

Exterior wall and partition wall area—(Fig. GF6).

Hall 1 was in a separate area of the same building as where the components are made. They use a standard wall height

for their homes. Interior walls are 6.5 or 9.5 cm thick. Exterior walls use timbers 6.5 by 18.4 cm (2.5 in. by 7.2 in.). Both sides are sheathed with 14-mm particleboard. A polyethylene vapor barrier is followed by drywall on the inside. Long walls are made in this area using a butterfly table to flip the wall. The outside roll shades are installed on the inside of the wall. Electrical holes are drilled on the side, 4-cm polystyrene applied, and the first layer of stucco applied adjacent to the wall table. The two layers of stucco applied in factory are 5 mm in thickness. Plant GF tries to ship each house on three trucks: wall truck; roof truck; ceiling truck (Fig. GF7).

Hall 2. The same type of production tables were used for gables and eaves. Workers were spraying stucco while we passed through, using fiberglass mesh as a base (Fig. GF8). The engineer commented that they use (true) fir for studs, sills, and top plates. They use normal studs for rafters and glulams for purlins.

Hall 3. Three programmers worked in an upstairs office in this hall downloading the Spirit (software similar to Auto-Cad from STI International, Inc., Concord, New Hampshire) architectural drawings in a dxf format and converting the drawings with SEMA software, which writes the code to control the two Hundeggers. Hundegger is the big name for beams and rafter processing, and they make tenons in addition to the other things. Normal dimensions for the joists are 8 cm by 22 cm. The floor elements have 12-cm-thick insulation between joists. The particleboard used for flooring is 22 mm thick. The roof windows are installed at the site; however, the moisture barrier and roof insulation are installed at the factory. The rafters are typically 8 by 20 cm; however, all these sizes can be customized. The roof insulation is 20 cm thick. Roof insulation is more flexible than what is used in the walls, as the latter would slide down during transport if it were not stiff. Roofs are shipped laying down (Figs. GF9, GF10, and GF11).

Hall 4. Short partition walls not made in Hall 1 were made here. They use a shipping truck out of Hall 4 that is shorter than that used in Hall 1. The engineer explained that Plant GF also set a wet wall in front of regular walls for toilets. All tables used in production were butterfly tables.

Hall 5. Balconies and metal working, exterior handrails, and chimney parts were done. The balconies we saw were attached to a header joist for a ceiling, and the balconies were built of wood and covered with sheet-metal.

Plant GF employs two architects and three civil engineers, and seven draftsmen work in the main office with the purchasing people. Plant GF homes are always customized; they do not have standard plans. The software program Spirit is used to make floor plans and blueprints, apply for building permits, and show the customer the final blueprints.

Plant GF pours cement over floors for noise reduction, and the poured cement floor must dry for four weeks before be-

ing covered with carpet. Plant GF also builds basements out of precast concrete panels. Our contact's role in the company is to be in charge of the time plan until the project starts. Metals used for balconies and gutters were either titan zinc or copper. The company makes front doors and buys its internal doors and windows. Basement walls are 20 cm thick, and the first floor is 18 cm thick. Our contact estimates that 80% to 90% of houses built have a basement. The outside walls generally have conduit run in the factory while the inside walls do not. The 3-D program to make the sales rendering is called ARCON 3D Architect (Eleco Visualisation Software, Surrey, UK) Ten percent of the houses have whole house ventilation systems (heat exchanger with fresh air), and none of the houses have air conditioning.



Figure GF1. Model home at Plant GF.



Figure GF2. High-quality beech staircases were the norm in German prefab houses.



Figure GF3. Maku computer-numerical-controlled (CNC) router used to machine door and stair components.



Figure GF4. Edge-glued and fingerjointed beech panels were common stock for stairs.



Figure GF5. Hundegger computer-numerical-controlled (CNC) timber processor used for wall components.



Figure GF6. Exterior wall and partition wall tables in Hall 1.



Figure GF7. Wall components loaded onto truck for delivery to building site.



Figure GF8. Stucco being sprayed onto wall panels using fiberglass mesh.



Figure GF9. Roof table using pneumatic jigs to place and hold rafters.



Figure GF10. Roof table area.



Figure GF11. Stacked roof sections with insulation.

Plant GG

Contact: Production Manager

June 23, 2005

Plant GG employs 200 people; 60 in drafting, sales, architecture, managers here and on site, subcontractors; 70 in construction on site; 70 in production. Our guide estimated that 95% of employees are skilled (have completed an apprenticeship for their occupation). Employees have target production goals per day and if they beat target production, they are given additional pay; implementation of this pay system has boosted production by 10%. Plant GG also has a commercial sales division of 15 people that includes four architects.

Sales volume is 28 million euros per year. Plant GG sells an equivalent of 160 to 180 houses per year. The average home is 145 m² of living area and without the basement, and it sells for 160,000 euros (1100E/m²) (Figs. GG1, GG2, GG3). Commercial cost is about 800 E/m². Plant GG offers three lines of houses: 1) individual (an example size of 9 m by 12 m was given (108 m² or 1160 ft²)), 2) platform housing system, where you can choose options like a garage or balcony; 3) no options—customers choose a standard package from a plan book.

Plant GG, however, produces only 80 to 100 homes per year and the balance is in commercial buildings, office buildings, or kindergartens. Factory capacity is 300–350 homes on three shifts. About 50% of production is housing and 50% is businesses and other. Currently Plant GG is operating one and a half shifts. If Plant GG were only producing commercial buildings, we were told they could meet production in only one shift; with houses Plant GG would need two shifts.

Processes

Plant GG's total production time for a house is 20 days. This includes the time needed to produce the wooden windows for its houses. We were told that because different production processes take different amounts of time, it is extremely important to begin the different operations at the correct time so all components of the house are ready to be shipped at the same time. Plant GG's bottleneck was production throughput at the older Weinmann machine, which (among other functions), nailed furring strips to the roof element rafters.

Presently Plant GG uses two computer programs. AutoCad is used to do the floor plan, and SEMA draws each wall as a component and then writes the machine language for framing and panel stations. Within the next year, they hope to eliminate the AutoCad and only use SEMA. An additional computer program was used to schedule production for line balancing. Our contact stated that this scheduling program was not necessary for a company as small as Plant GG.

From 1980–1996, Plant GG produced walls based on standard elements (such as is done by Plant GD today). Today

its Weinmann precutting machine (Figs. GG4, GG5) processes all panels—50,000 sheets per year of gypsum and particleboard—one sheet every 40 seconds. This machine was built for the furniture industry, and on a 2.5-m long panel had 0.5-mm tolerance. It sizes the panels, drills holes for outlets and sockets, and drills holes for attaching the walls. The Weinmann panel processor also cuts a place for metal bracket to hold walls to floor. Plant GG produces three wall heights: 2.66 m for housing only; 3.1 m for commercial only, and 2.8 m for both. Internal walls are 9 cm thick, external walls are 16.5 cm thick.

Plant equipment requires 100–150 houses per year to justify the investment. Our contact repeatedly stated that if you are paying for the machine, you need to be able to reduce the number of employees in that area of production.

It took Plant GG three years to reach the takt time (the maximum time per unit allowed to produce a product in order to meet demand) promised by Weinmann. Plant GG purchased its Weinmann equipment in 2000. In 2001, the takt time was 50 minutes; today the Bumeck (European equipment no longer made) has a takt time of 30 minutes per wall. The multifunction bridges now have new staplers that staple 10 staples per second. Eighty percent of all walls go through the Bumeck wall machine. Fifteen percent run through the short or gable wall table, and 5% run through the special wall area (wet walls included). At the Bumeck, as the first stud was inserted, lag bolts were manually inserted into the stud for future connection to the adjacent wall. The Bumeck machine-sizes studs when a non-standard size stud is needed. The Bumeck can also notch into top and bottom plates for electrical connections. We were told the Bumeck can be used to make walls with angled corners (second-story wall) by making the full wall square and then cutting the corner off of the wall (Figs. GG6, GG7).

Coming out of the Bumeck, the interior of the wall is face up; a paper moisture barrier is then laid down (Fig. GG8). Precut sheathing is laid on the wall and it then goes through the automated stapler (Fig. GG9). Some holes were manually cut in the moisture barrier for attaching the walls.

The old fiberglass-batt insulation weighed 17 kg/m³. New insulation made of wood fibers and 5% polyethylene weighs 55 kg/m³. The insulated value is the same, but the thermal mass of the newer insulation slows heat transfer (Fig. GG10). Ecological construction techniques are popular in Germany, and this type of product change gives customers an opportunity to use a green product (wood-based insulation).

Other Observations

Plant GG is producing 24,000 linear m of wall per year. This depends on amount of commercial compared with residential homes.

- Plant GG homes featured continuously circulating hot water (through the pipes) so home occupants do not have to wait for hot water. No toilets were placed on exterior walls; a special wet wall would be used if placement in front of external wall was needed.
- Seven types of wood were offered in 30 colors of water-based paint for wood siding. The other siding offered was stucco, which has a base of 20-mm-thick polyurethane sheathing with mesh reinforcement. Stucco is then applied in the factory over the polyurethane/mesh. A one-hour application of stucco in the factory would take four hours on site. The exterior walls with stucco finish have a 45 degree angle along its corners (edges); when erected on site there should be no more than a 2- to 3-mm gap between walls. After siding was attached, the wall transporter stood the walls vertically and took the walls from production to wall storage.
- The automated machines that produce the windows are 15 years old. We did not see them.
- The windows were installed on vertically hung walls. 2,500 wood windows are made per year. Plant GG machines a V groove into the drywall to allow it to be folded 90 degrees around the window case.
- Plant GG has 1,000 m of wall storage (GG11), or about five houses. The average house fits on four trucks. Doors are installed in the house on site.
- For commercial buildings, trusses were built in house, though our contact classified them as a C product, meaning that they were not built too often.
- Its 1996 Weinmann bridge was the prototype (Fig. GG12). Our contact recommended never buying the first production unit of equipment. He identified this as the bottleneck. The two tables wait on the multifunction bridge, which lays down furring strips and staples or nails the strips.
- Plant GG also had a Hundegger K-1 beam processor for the roof and floor elements. Our contact stated that with a Hundegger machine, you plug in air and electric and it is ready to go—the machines have no problem.
- Our contact thought it was important to contract with machine vendors concerning future upgrades of the computer hardware and software—hardware may only cost 2,000 euros but software programs may cost 40,000 euros.



Figure GG1. Model home at Plant GG.



Figure GG4. Weinmann panel processor cuts gypsum and particleboard panels.



Figure GG 2. Kitchen area highlights wood paneling in this prefab house.



Figure GG5. Weinmann panel processor cuts 150 thousand sheets per year.

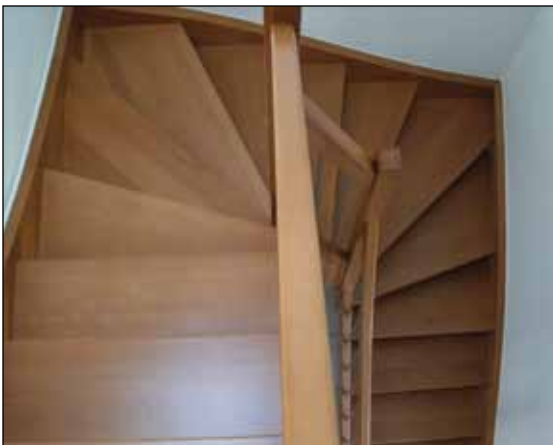


Figure GG3. Beech stairways were typically found in German prefab model homes.



Figure GG6. The Burmeck wall machine area. Note infeed staging area on right.



Figure GG7. Burmeck wall machine requires many manual actions.



Figure GG8. Paper moisture barrier placed on wall panel section.



Figure GG9. Automated stapler is used to fasten moisture barrier.



Figure GG10. New wood-based (5% polyethelene) insulation.



Figure GG11. Wall section hung vertically: Note cut out areas used to connect adjacent walls at building site.



Figure GG12. Older model Weinmann multifunction bridge lays and nails furring strips.

Plant GH

Contact: Manager

June 23, 2005

Plant GH is a large conglomerate with operations in Germany, Romania, Czech Republic, Croatia, England, France, and Spain. They own and operate sawmills, dry kilns, laminated beam plants, and window and door plants (many of these millwork products with their sister company). The entire Corporation had gross sales of 400 million euros. The company started 37 years ago with two men and now has a total of 3,600 employees.

Processes

This plant manufactures laminated beams up to 215 m long (Fig. GH1). This includes grading and trimming the lumber, fingerjointing, laminating, and surfacing. The large laminated beams are mostly used for commercial buildings. They also make stables, barns, homes, and offices. We were told that this laminated beam plant manufactures 60,000 m³ of wood per year. The planer used on the large laminated beams had an infeed table that was 2.50 m wide.

Floor area: After seeing many other things, we got to the house factory. We started with the middle floor construction. In this area, they had two Hundegger beam processors. The older one was a prototype and dates to 1973. The newer one was used for floors and roofs (Fig. GH2). Data for the home are electronically sent to the Hundegger beam processor. The operator only selects the program and runs it. Butterfly tables were used and the ceiling was worked on first. On cheap floors that use particleboard for sheathing, drywall is installed on site and not in the factory, most likely for wiring. Special noise protection (low-density fiberboard) was sheathed on floors. Some roof elements are cut here. Special roofs are assembled at building site.

Roof and ceiling area (Figs. GH3 and GH4). Ceiling boards were painted/stained one of four standard colors by a machine in this area. Special colors require hand painting unless very large. There is a butterfly table in this area to allow fastening of external and internal strips, sheathing, or paneling.

It takes two or three hours to erect the roof during the one day it takes to waterproof the house. The roof is lag-bolted in from the top onto the walls. When the plant releases a blueprint for a job, everyone involved in the job (factory manufacturers and construction crew) gets the same one. This single blueprint covers all aspects of the floor plan/job, from manufacturing specifications to special instructions for installation. By having one single blueprint, Plant GH prevents confusion when discussing the plans.

Plant GH still manufactures roof trusses, which started early in Plant GH history. Trusses are now a small part of the business: offices, stables, supermarkets, and inexpensive

houses. As a picture shows, the equipment used for building the trusses was very simple and outdated (Fig. GH5).

Wall fabrication area. Most toilets are constructed in a separate wet wall that will be placed in front of the regular wall (Fig. GH6). These toilet walls have a drywall and particleboard panel that will need to be removed to connect the installed plumbing. On those sections of particleboard and drywall that need to be removed for connection of plumbing, we have often seen the drywall and particleboard held in place with a few screws.

Lag screws are built into the connecting walls for easy connection in the field during construction. These lag screws are pre-inserted as the wall is being framed and reached via a pre-cut access hole in the drywall and particleboard (Fig. GH7). These screws have grease on the tip to assist in threading into the adjacent wall section. Our contact said that a special wrench is used to turn these screws easily. The normal wall construction is with 140-mm-thick studs and 40 mm of foam. Plant GH has the ability to manufacture using 200-mm-thick studs and 100-mm-thick foam. Maximum wall height is 3.13 m. Shipping length restrictions limit them to 12.5 m (Fig. GH8). Electrical conduit is run in the factory and wire is installed at the building site. The window shade pocket is installed from the interior.

At the framing station, two sets of butterfly tables were used. A cut-off saw located in the mezzanine cut studs to length and the operator marked top and bottom plates from the plan, according to what the carpenters below should do (Figs. GH9 and GH10). Note that this operator marked studs, headers, and bottom plates, and he worked on an elevated platform, sending the cut wood down to the butterfly assembly table (Fig. GH11).

The operator used special markings to illustrate where cut studs were to be placed and affixed. By using these universal signs/markings, building workers did not need to look at a floor plan to locate the studs in the wall during assembly. The walls are numbered according to the order of erection at the site. Two men are needed to retrieve the studs and plates from the overhead rack. These men also staple the particleboard onto the frame, and cover it with breathable moisture barrier (Fig. GH12). Particleboard and drywall stock are manually cut to size on a table saw that electronically adjusts cutting width according to information entered by the operator. The wall is then flipped with the butterfly table, and at least two (maybe three) people attach the moisture barrier and staple drywall to this side of the frame.

At the time of our visit, Plant GH was working on 87 houses for the 2006 Olympic Games in Turin, Italy. We were told that Plant GH manufactures 900 houses per year at four different factory locations. The factory we visited was said to manufacture approximately 350 houses per year.



Figure GH1. Laminated beams in process at Plant GH.



Figure GH4. Tables used in the ceiling and roof building area.



Figure GH2. Newer Hundegger beam processor used for floor and roof components.



Figure GH5. Older truss-building equipment.



Figure GH3. Ceiling being constructed.



Figure GH6. Wet wall used for toilet contains installed plumbing.



Figure GH7. Lag screw used to connect wall panels accessed by precut hole.



Figure GH10. Sawyer marks component placement on bottom plate.



Figure GH8. Vertical wall hanging area.



Figure GH11. Butterfly table flips wall section after one side is sheathed.



Figure GH9. Wall components are cut in upstairs mezzanine and carpenters reach for them.



Figure GH12. Other side of wall panel has moisture barrier and sheathing attached.

Plant GI

Contact: Project Engineer

We were not allowed to take photographs, but were given Weinmann (equipment company) videos that have scenes filmed in this plant.

June 24, 2005

Plant GI is part of a very large corporation. Portions of the factory were built in 1997, and the equipment is six years old. According to our contact, the factory is “the most modern production plant of Europe,” which is approximately 17,000 m² (183,000 ft² or 4.2 acres). The equipment consists of computer-controlled production lines whose machines were developed particularly for Plant G-I, and that are served also with in-house software. The initial investment (in 1999) was 24 million Deutschmarks or approximately 12 million euros. We noted that the large factory floor expanse was lit by skylights and that no electric lights were turned on at the time of visit. Our guide said that lights are turned on during the winter months whenever there is not enough natural light.

The equipment reportedly is capable of producing 1,000 houses per year on a single shift, and at one time the factory was producing 2,000 houses per year with two shifts. Currently, however, the factory only produces about 300 homes per year because of poor market and management conditions. Factory lay out and equipment seemed logical, but we wondered about making such a large investment only to have the market drop. Our guide suggested that Plant G-I has many problems, mostly managerial, and the company has changed hands at least once, in addition to having marketing problems. Our guide stated that factory operation has not been a problem. Some of the systems originally designed into the building are no longer being used, however. For example, there was an elaborate insulation delivery system that transported insulation all around the factory. This insulation delivery system was no longer in use, as it caused too much dust in the factory. Insulation is now manually delivered to the stations needing it.

Processes

Plant GI had six different process stations: beam cutting, panel cutting, framing station, framing completion, moisture barrier, drywall table, and multifunction bridge

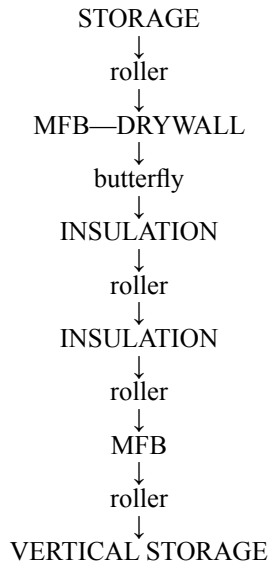
1. Beam cutting. Two Hundegger systems process beams. One Hundegger is used for roof and ceiling beams and is fed manually. Outfeed, however, is by conveyor and automatic lift. The conveyor then transported the sized beams through a sander or planer. The other Hundegger is used to process wall beams and is fed beams with a screw lift from 18 bays. Processed beams are passed downstream by conveyor. The one Hundegger that we could view could saw angled cuts (end of roof beams, for example), angle horizontal notches, vertical notches, small drill, and large drill. Although the Hundegger wall beam processor had

the capability to perform all the above functions, the wall beams were processed again (by a separate notcher) as they were about to enter the wall framing station.

2. Panel processing. Two Eima CNC MultiCenter 54s (EiMa Maschinenbau GmbH, Frickenhausen, Germany) are fed sheet stock (OSB or drywall) from five lines of raw materials via vacuum lift and chains. The outfeed product is conveyed to a vacuum lift pick-up point that moves the cut panel to an elevated (above the floor about 30 feet) conveyor which carries it to one of four storage tray bins (buffers). These four storage bins were arranged according to what type of wall they served. The two storage bins on the right were for wall sections and the two bins on the left were for gable ends. For both bin groups (walls and gable ends) one bin was for the first side of the wall, the other bin for the second side of the wall.
3. Framing station. This wall-framing station required one man to operate. The top and bottom wall plates were automatically placed, and studs were automatically placed and nailed to the top and bottom plates. Plates were also notched here, though we do not understand the difference between notching here and at the Hundegger initially used in beam sizing/cutting. The wall-framing station also had the capability to size studs (cut to length). We did not understand why this would need to be done at the wall-framing station. While we watched, we witnessed a problem with a stud being fed. It hung up in the lugs and the operator had to climb up to wrestle it free. The operator then manually placed the stud in the wall machine, and over-rode the machine so it would nail the stud. The machine then carried out the next stud placement (the empty lug) while the operator waited. Studs were stored in an elevated mezzanine and were retrieved automatically by a robot clamp feeder that placed the pieces onto a lug ladder that carried the stud down to placement and nailing area. We noted that the operation of the framing station seemed slower than what he had witnessed in the video. The elevated mezzanine (as previously mentioned for stud storage) was also the area where window and door modules were assembled and placed into a buffering rack. We did not see one of the door or window modules being placed/positioned into the wall.
4. Framing completion. Shorter pieces (bracing, etc.) are added manually using a mallet and nail gun.
5. Moisture barrier. An auto-roller was used to lay down the plastic sheeting, but it was manually stapled (though the promotional video from Weinmann showed it done automatically).
6. Sheathing and drywall table with multifunction bridge. Pre-cut drywall is placed by the multifunction bridge and then nailed into place. While we were watching the placement and nailing of sheathing onto the wall frame, we saw one of the operators disconnect the trigger on the nail gun

of the multifunction bridge and use a manual nail gun to nail the sheathing to the framing. After one side of a wall panel was sheathed, the butterfly table would flip the wall panel.

The following schematic shows the flow and function between the different tables in this area of wall construction.



A roof line and a ceiling line were downstream from the Hundegger, which was cutting roof and ceiling beams. On the roof table there were stops to guide beam placement, and the cross beams were manually stapled or nailed. On the ceiling line, lathe was nailed by the MFB, which also used a saw to trim the drywall and make cut-outs. The roof and ceiling lines contained the exact same machinery.

Plant GI uses two trailers per house, one for the walls and one for roof and ceiling.

Plant GJ

Contact: Project Engineer

No photographs were allowed.

June 24, 2005

We visited Plant GJ with our guide after visiting the Plant GI factory. Unfortunately, we arrived at Plant GJ after production had ended for the day. Our tour was given, but we were only allowed to see the Weinmann manufacturing line. Our guide could tell us very little about the manufacturing process; essentially we looked at a large line of Weinmann machinery that was idle.

The Weinmann line was in a U shape with the panels started at one end of the U and was totally finished at the other end. A total of seven wall panel tables comprised the manufacturing line; two Weinmann multifunction bridges were on the manufacturing line. The two multifunction bridges were capable of traveling down the arms of the U. Workers could use vacuum-assisted lifts while placing sheathing on the wall frame.

The manufacturing line produced “multi-walls;” these wall sections are essentially multiple smaller walls built together as one and then separated (cut apart) at the end of the manufacturing process.

On table 1 the wall was framed and windows and doors were installed. These windows and doors were already framed in, making window and door modules. This method had also been seen at Plant GI. Insulation was inserted at table 4, the table at the top of the U between the two U arms. Table 4 was a part of a butterfly table that flipped the wall sections.

We were told that Plant GJ manufactures 200 houses per year, there are 200 employees at Plant GJ, and seven operators are needed for the Weinmann manufacturing line.