4

Chapter Four: Potential Technologies for Industrialization in the Current Home Building Industry: An Assessment

The industrialization of residential construction requires major strides forward in information management, production processes, organization of production, and use of new materials and technologies. If the housing industry is to make a reasonably rapid transition from its current, craft-based production system to an industrialized production system, participants in the industry need to better understand the relationships among information, labor, resources, and production. This chapter develops strategies for integration and industrialization of the home building industry.

Information integration appears to provide the key to the technological, methodological, and management issues in the industrialization of the home building industry. Information integration is deeply rooted in the four other types of integration discussed in chapter three. To highlight the importance of information integration, this chapter develops overall information schema for bringing integration and industrialization to the residential construction industry. In addition, this chapter develops both an implementation path and plan based upon information integration and management.

Acknowledging that the home building industry is diverse and that strategies for one sector may be inappropriate for other sectors, this chapter continues by classifying the residential construction industry into four different sectors. These sectors aid in not only the discussion of integration and industrialization but also the development of implementation strategies and priorities throughout the chapter.

Strategies for integration and industrialization in the home building industry are needed to make a transition away from current, craft-based production.

AN OVERALL SCHEMA FOR INDUSTRIALIZATION

To create a complete industry model, the overall schema for the residential construction industry must be studied historically. One approach to this task is to focus on improving the performance of the residential construction industry as a whole by developing a cohesive, integrated information system spanning housing design, production, and operation. This seamless flow of information at, to, and from the construction site has been identified in early research as an initial obstacle preventing the industrialization of the residential construction industry. In the end, seamless and integrated information flow will enable change in the current, craft-based concept of housing from an unplanned mixture of components to an "integrated housing system." The integrated system approach will yield a higher-quality, more cost-effective housing product that, in turn, will increase end-user satisfaction.

Origins of Proposed Concept

The concept of integrated information management is not a new one to the residential construction industry. In 1850, housing design and construction fell within the sole domain of the master builder. Communication between the builder and the owner was as clear as could be between two adults (see Figure 4.1). The model, as illustrated, enabled full information and technology communication to be contained within the house concept of the master builder, and the house performance was considered from the builder's holistic standpoint.

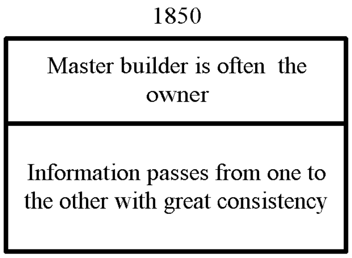

Figure 4.1: Typical information exchange for residential construction in 1850.

Today, the information exchange model for residential construction often results in the isolation of information within each technical trade or technology involved in the building process, resulting in compartmentalized components and subsystems being optimized without regard to the effects on the overall performance of the house. Conflicts among technologies, subcontractors, and subsystems are inherent to the final product. Figure 4.2 illustrates the current system for information exchange within the residential construction industry.

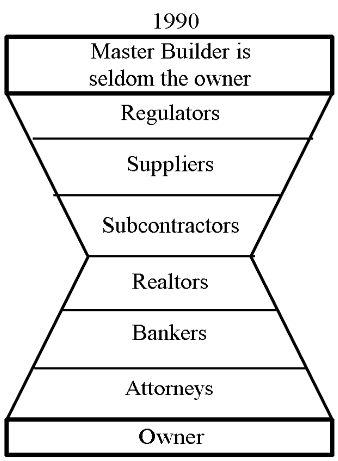

Figure 4.2: Information exchange within the current residential construction industry.

The proposed model, which helps to create an environment favorable to industrialization of the residential construction industry, returns to a holistic design philosophy. The proposed system is similar to that of the master builder, but with a memory equal to the computing power of the computer server handling the data warehouse. Design, construction, and training tools developed to enable this change will provide a medium for seamless information exchange in a real-time, collaborative environment. This medium would enable the various parties involved in the design, construction, and eventual decommissioning of a house to work together in improving overall quality and end-user satisfaction. These improvements will come via reducing waste, eliminating interference problems and incompatibilities between various subsystems in the building, providing guidance on ramifications of design/construction decisions, reducing the need for a highly specialized and skilled labor force, providing better more usable information to the construction labor force and streamlining the regulatory approval process. These tools will also improve the conceptualization communication among owners, designers, functionality of the home meet all expectations. Figure 4.3 is a proposed diagram of this integrated system.

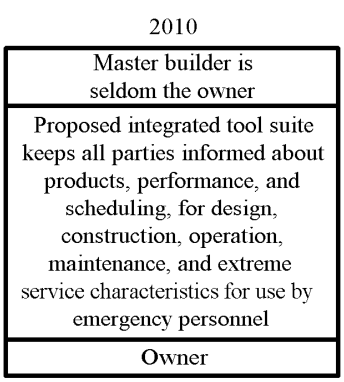

Figure 4.3: Integrated system for information exchange proposed for the residential construction industry.

The proposed model for housing design/construction is an enterprise wide model that considers the multiple issues associated with housing from conceptualization to decommissioning, including the costs associated with all phases of the building's life. Essentially, this model of information flow and integrated tool suite would enable an accurate optimization of the holistic performance of housing from a life cycle cost analysis. These parameters are a significant expansion of those typically associated with optimization of housing design, but they are all included in the costs associated with home ownership. Since the end result of this effort is to provide the homeowner with a better-built, better-performing house at a lower overall cost, all of these pertinent factors should be considered in the work towards industrialization of the residential construction industry as a whole. Figure 4.4 is a graphical version of this systematic, all-inclusive design concept.

APPLYING INFORMATION INTEGRATION IN THE CURRENT HOME BUILDING INDUSTRY

The home building industry is far from homogenous. The industry is made up of numerous sectors and markets and the majority of product is built by small volume craft-based builders. Each sector has different structures, different access to capital and capital equipment and different supply chains. Universal implementation of any information integration strategy is likely to be problematic unless the strategy is designed appropriately for the industry sectors in question. For this reason, we divide homebuilders into four groups:

- small-volume residential builders—building fewer than 20 homes per year;
- medium-volume builders—building up to several hundred homes per year in regional markets;
- high-volume builders—building more than 1000 homes per year, utilizing on-site construction methods, with a regional or national presence; and
- production builders—using off-site fabrication including modular, manu-factured (HUD code), and factory-based panelizers, undertaking the majority of their work in a factory environment, and delivering consolidated materials to sites in fewer than 10 deliveries from a single factory.

This grouping will be used in the following sections to develop strategies and priorities that are applicable to each sector of the industry.

Implementation Paths and Plans

The implementation of integration and industrialization in the home building industry rests on the understanding of information flows and usage throughout each of the previously identified home building industry sectors. The first step in developing this understanding is to undertake an information mapping study for each sector of the industry.

Information Mapping and Analysis: The First Step

Information mapping of the industry is an essential first step in implementing an integrated approach to information management in the home building industry. The mapping process needs to look at how information is generated and used in the home building industry sectors. Information use by current industry participants (e.g. customers, designers, builders, subcontractors, subsystem suppliers, materials suppliers, financial institutions, and regulatory authorities) needs to be mapped and understood. This mapping will determine information requirements of current industry participants and currently used construction methods. A comprehensive information model for each industry sector can then be developed that will provide the information requirements for implementation of integration and industrialization strategies.

Small-Volume Home Builders: Appropriate Technologies And Implementation Priorities

Small-volume homebuilders make up a large and important sector of the residential construction industry. The fact that these builders have limited operating finance and capital support represents a considerable challenge for this sector, as many of the integration and industrialization technologies require capital investment that is likely to be beyond their capacity. These builders also lack the supply chain influence that can force a change in the way the industry currently operates. As one of many small customers of large suppliers, small-volume homebuilders often deal with intermediate distributors of building products. For this reason, the adoption of industrial technologies in this sector is likely to be driven by either large suppliers, intermediate distributors, or agents who have an interest in selling product to builders and consumers.

The small-volume builder personally performs the information management of the building task. For example, the builder himself orders materials; schedules subcontractors; supervises the workforce; arranges permits and inspections; and deals with design issues, home purchasers, financing, and accounting. Managing this complex information web is a difficult and nontrivial task. In addition, the manual systems used by small-volume homebuilders perpetuate the fragmented, craft-based approach in this industry sector. The manual systems can also limit productivity and profitability.

Industrialization of this sector could be led by a builders' supply group that provides builders with an integrated information management package that enables input of the design using an object-oriented CAD system and provides for input of the construction schedule. The schedule-linked, object-oriented CAD model would enable the builder to specify the delivery dates of the components to be used in the building. The information management package would then link with the supplier using the World Wide Web or wireless technology and schedule the required materials, subcontractors, payments, and inspections for the construction of the house. Componentization and modularization have made inroads into this sector of the industry with the use roof trusses, wall panels, structural insulated panels (SIPs), windows, and doors, but ordering and delivering are essentially manual processes, as is scheduling of subcontractors and inspectors. A CAD based information system will provide opportunities for further physical and production integration in this sector.

This system would provide for increased predictability and decreased variation in the supply chain. This first stage of industrialization is not as difficult a step as it may seem. Many intermediate distributors and hardware suppliers already use software-based systems supplied by component manufacturers to order kitchen cabinets, doors, and panelized frame components. In addition, the suppliers schedule deliveries of component subsystems using the same systems. This first stage of implementation of an integrated information system requires various systems to be brought together and placed in the hands of the builder. The information management system in this case would enable further parts of the home builder's operation to be industrialized as the system is adopted. For example, increased componentization and modularization would be possible if orders were placed earlier with suppliers. There would also be increased impetus for integration of systems in this case.

It should be emphasized that for industrialization to occur in this sector of the building industry, the capital investment must be provided by some party or coalition other than the builder.

Implementation Priorities for Small-Volume Builders:

- Development of ordering scheduling and site production systems to help reduce fragmentation in this sector

- Introduction of object oriented CAD systems as a linkage between customer orders, suppliers, materials purchasers, subcontractors, payments and inspections, as a stepping stone to physical integration and production integration

Medium-Volume Homebuilders: Appropriate Technologies and Implementation Priorities

Medium-volume builders are generally in a better position than smaller-volume builders to respond to the challenges of industrialization. They generally have access to larger financial resources and can make capital investment in equipment, systems, and training. Medium-volume builders are also likely to have supply chain influence, especially if they are a large regional player. For this reason, it is not uncommon to find builders in this market sector encouraging their suppliers of framing materials to make the step towards providing complete panelized sections of the home rather than individual framing members. This is an initial step in industrialization. Builders in this sector are also likely to have in place a company-wide accounting and procurement system that is familiar to company personnel. This will ease the implementation of an information management tool because people in the organization are familiar with systemized approaches to information management. The challenge in this sector of the industry is to broaden information integration from accounting and cost control to include pre-construction and construction activities.

Integrated providers of information systems, which are now offering linked accounting and procurement systems in a Web-based format, may serve information management needs for this sector of industry. The missing link in these systems is the design, production simulation modeling, and field construction information tools necessary to form an enterprise resource planning (ERP) tool for the builder.

Implementation Priorities for Medium-Volume Builders:

- Introduction of object oriented CAD systems linked to existing purchasing and accounting systems to provide integrated information ERP for customers, suppliers, materials purchasers, subcontrators, payments and inspections. This is a stepping stone to physical integration and production integration

- Use of supply chain influence and ERP to move to Just-In-Time (JIT) operation

- Develop integrated information systems for, resource management, scheduling and construction progress reporting

- Develop tools for field staff for onsite use of the information systems

- Access production modeling and simulation systems for further refinement of existing field processes and development and analysis of new processes.

High-Volume Home Builders: Appropriate Technologies And Implementation Priorities

There are a significant number of national high-volume builders who use predominately on-site construction methods while also utilizing industrialized techniques such as panelization in the form of roof trusses, panelized stud walls, and SIPs. These builders have a significant national presence and considerable supply chain influence, which they use to leverage prices for raw materials and components via long-term, national supply contracts. In general, they have sophisticated information management systems at both the national and regional levels that are used to manage finance, procurement, sales, and marketing.

It is unusual for the sophisticated information management system to extend to the site construction of the house. In fact, in many respects the site construction methods used in this sector do not differ substantially from those used by the medium-volume builder. The scheduling, ordering, and production scheduling are done by a field superintendent, who is responsible for the construction of 10–20 houses. While CAD systems are used in the design, very little use is made of the potentially available embedded information in scheduling, ordering, and supervision phases of the work.

In this production system, the site superintendent can be seen as a missing link in the information chain. Feedback to and from the field is a significant obstacle to further industrialization of the process. An information management tool for superintendents would not only highlight bottlenecks in the process by providing updated schedule information to suppliers, subcontractors, and inspectors but also provide production information to regional offices for sales, ordering, and production planning. The field information would be linked back to the head office for schedule updating as well as cost and financial information. It is anticipated that making this final link in the information chain will have considerable effect on the implementation of other industrial technologies. Once good production information is collected and analyzed, builders will have the opportunity to analyze the field production process similar to other industrialized manufacturers. This analysis is likely to lead to the development of new assembly procedures, use of new materials, and production processes that in turn should yield the long-sought-after benefits of industrialization to the residential construction industry.

Implementation Priorities for High-Volume Builders:

- Extend current use of CAD to embed resource management, scheduling, ordering, and supervision information and link to existing purchasing and accounting systems to provide integrated information ERP for customers, suppliers, materials purchasers, subcontractors, payments and inspections. This is a stepping stone to physical integration, production integration, and operations integration

- Develop tools for superintendents, subcontractors, and other field staff to enable onsite use and appropriate updating of the integrated information (ERP) system data.

- Use design for manufacture (DFMA) and other production modeling, analysis and simulation systems for further refinement of existing field processes

- Develop advanced production methods using new systems and materials

Production Home Builders: Appropriate Technologies And Implementation Priorities

By their very nature, production homebuilders tend to use industrialized production methods in construction of houses or house modules. The builders' off-site factories use assembly-line construction processes with multiple workstations. However, much of the information handling in these organizations is manual. For example, change orders are often processed manually for each house. Exchange of information in the production process uses paper drawings and lists, and very little use is made of numerically controlled production equipment.

Production builders tend to have considerable influence on their supply chain, and several of the production builders visited as part of this study make use of just-in-time (JIT) manufacturing with little inventory of major components held at the plant at any time. These operations are very sophisticated in terms of inventory management, and several of the production builders use materials requirements planning (MRP) systems within the factory environment.

What is surprising about this sector of the industry is that the actual construction methods used in both modular and manufactured housing appear to differ little from those used in site-built construction. Construction is still typically of wood, with some panelization of floor, wall, and roof systems and prefabrication of some home components. It appears that the application of the industrial technique known as "design for assembly" and the increased use of currently available new materials could yield substantial improvements in this sector of the industry.

The sector should consider applying integrated information management throughout the entire design and construction process. This integrated system would include initial design and planning, receipt of orders (including special and change orders), the production process, and delivery of the final product to the site. Establishing such an information chain would enable the enterprise to plan and schedule the resources for production. It would also enable suppliers to look into the information system to move all component supply to a JIT delivery method throughout the production system. This change would result in a reduction of many associated inventory costs.

Implementation Priorities for Production Home Builders

- Extend current use of MRP for factory production to ERP for the whole house production from order to closing. Use the ERP for interaction with customers, suppliers, materials purchasers, factory workers, subcontrac-tors, payments, building code approvals and code officials' inspections.

- Develop tools for superintendents, subcontractors, and other field staff to enable onsite use and appropriate updating of the integrated informa-tion (ERP) system data.

- Implement design for manufacture (DFMA) and other production model-ing and simulation systems for further refinement of existing manufac-turing and field processes

- Develop advanced production methods using new systems and materials

CONCLUSIONS

Information integration provides the key to the industrialization of the home building industry. This chapter develops an overall information schema for integration and industrialization. Four sectors are identified within the housing industry to enable a comprehensive plan for implementation for industrialization and integration to be developed. The first step in implementation requires the mapping and analysis of information flows through the four identified sectors of the home building industry. The results of the information mapping will provide a basis for proceeding to the next stages of integration and industrialization within each sector.

The industrialization of residential construction requires the industry to implement information management, new production processes, better organization of production, and use of new materials and technologies. The characteristics of each industry sector with respect to supply chain influence, currently utilized technologies, information management, and building methods require sector specific implementation plans and priorities for implementation. Implementation of these plans will begin to move the housing industry from its current, craft-based production system to an industrialized production system, resulting in improvements in productivity, efficiency, and quality.

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Chapter Five: Concluding Remarks on Industrializing the Residential Construction Site

This report examines the means and methods available for integrating and industrializing the housing construction site and industry. Chapter 2 reviews current and past U.S. efforts in industrialization of housing including Building America, PATH, and Operation Breakthrough. International efforts in this area are also discussed. Chapter 2 identifies means and methods of industrialization that have been useful to other industries, mainly in the manufacturing sector, to move to a higher level of industrialization. The techniques identified as most promising are: resource and material planning systems known as enterprise resource planning systems (ERP), object oriented CAD, Just-in-Time supply, design for manufacture and assembly (DFMA), and other prototyping and analysis tools.

Chapter 3 looks at systems integration as an essential element in industrialization. Five types of integrations are identified: information, physical, production, performance, and operation integration. Information integration is identified as the key enabler of the other integrations in the goal of holistic systems integration. Attention to information integration will ensure the availability of key information for all elements of the enterprise. Production integration will result from information integration as participants in the industry become aware of improvements that can be made in componentization and modularization.

The key to industrializing the construction site is to have appropriate information available to each participant.

Chapter 4 sets out plans for bringing integration and industrialization to the home building industry. It begins by developing a strategy for information integration across the industry which is seen as the first essential step in the process. Subsequent plans for implementation are developed as a sector-by-sector basis for the industry. Plans are presented that are appropriate to the degree of capitalization and resources available in each sector. The degree of industrialization already present in each sector was also taken into account in the development of each sector plan.

The plans outlined in this report, when implemented, will begin moving the home building industry from its current fragmented craft-based approach to an industrialized integrated and productive industry. The plans generally use existing technology either already available in other sectors of the construction industry or the manufacturing industry to bring about industrialization. It is envisaged that implementation of the plans will deliver to the industry a platform from which to develop new materials and processes for housing construction. The key to industrializing the industry is to have appropriate information available to each participant. This requires not only collection and capture of the information, but also efficient filtering and representation so that the information is available and accessible. The ability to identify problems and areas from improvement delivered by the information integration will not only help eliminate fragmentation in the construction process but has the potential to deliver a new view of housing performance and operation. Designers will be able to develop design and analysis tools that give comprehensive consideration to life cycle performance issues, in-house design, as well as production performance.

The plans outlined in this report represent a first step in moving the residential construction industry forward using integration industrialized systems to deliver an affordable product with improved performance and operation.

Appendix A: Supply Chain Management Case Examples

SUPPLY CHAIN MANAGEMENT IN THE TEXTILE INDUSTRY

One of the obstacles to supply chain management is enabling different parties to speak the same language. The apparel manufacturing industry has virtually overcome this communication problem. The Textile Apparel Linkage Council (TALC) was formed in May of 1986. Its objectives were to develop industry standards for both the apparel and textile industries. TALC's efforts were widely accepted by virtually all members of the American Textile Manufactures Institute (ATMI) and the American Apparel Manufacturers Association (AAMA) (Hunter 1990). In fact, TALC helped institute several key electronic data interchange (EDI) standards in it first two years of operation. The following is an adapted list from Hunter's (1990) work.

- *EDI Format.* TALC has endorsed the use of ANSI X12 standard formats. ANSI X12 are the American National Standards Institute's standard for the electronic transmission of data for such business transactions as purchase orders and invoices. The communication link between trading partners may take the form either of a direct connection between their computers or via a third party networking service.

- *Roll Identification.* Each roll of fabric shipped by the textile producer will be uniquely identified by means of a 15-character identifier, consisting of a 6-digit producer number followed by a 9-digit alphanumeric produce assigned number. The roll identification number is to be represented in both human and Universal Product Code (UPC) bar code readable forms on a hang tag or pressure sensitive label accompanying the roll. A recommendation has also been approved for the layout of the information on the ticket.

- *Width/Length Measurement.* By obtaining accurate dimensional information in standard form, the apparel manufacturer is in a position to reduce costs and improve efficiency through better fabric utilization, elimination of duplicated measurements, and speeding up the marker making and cutting processes. The standards call for widths to be expressed in ¼" increments, rounded down; the length is to be given in 0.1 yard increments.

- *Shade Measurements.* To eliminate duplicate measurements of fabric shade, the standard calls for each roll to be identified with either delta values or the 5-5-5 shade-sorting convention agreed to by the trading partners.

- *Identification and Flagging of Fabric Defects.* Based upon buyer/seller agreement, defects to be flagged by the producer have been established for four categories: Critical, Denim, Standard, and No Flagging Required. The principal method for flagging defects for automated detection is the use of metallic stick-on devices, but several textile companies are using more sophisticated mappings of defects that record the distance of the fault from the edge of the fabric.

- *Order Status.* The items of information necessary for the seller/buyer interfaces on delivery data relative to order status are provided by this standard. Communications on delivery non-conformance are also being reviewed.

In addition to the items developed by the TALC effort, the committee is also involved in product forecasting. “A committee is examining ways to define the items of information and their timing, to be transmitted by manufacturers to textile supporters projecting future demand. This is a subject of great importance to the textile producer because of long lead times associated with fabric manufacture (Hunter 1990, pg. 71).”

SUPPLY CHAIN MANAGEMENT IN PRODUCT DISTRIBUTION NETWORKS

Examining a supply chain management solution more closely related to the residential construction industry would be the Hardware Wholesalers Inc. case study presented at the 1997 Washington, DC APICS convention (Palevich 1997). Hardware Wholesalers Inc. (HWI) is a distributor of hardware products, building materials, and lumber. With over a 62,000 items stocking list, HWI has combined supply chain management with logistics to create a partnership with their business affiliates. HWI strives to bring distribution, manufacturing, transportation, and customers closer together.

According to Palevich, HWI Inc. had been working in a universe where supply warehouses, transportation companies, and manufacturing plants were not inline with customers’ needs. HWI Inc.’s improvement initiative, as a distributor, was to connect vendors and transportation companies directly to the customers. Implementation of a comprehensive computer-based system has allowed inventory control, purchasing, distribution, traffic, accounting, and pricing to be centralized. In addition, HWI Inc.’s supply chain management and logistics system has reduced the company’s operating costs, improved asset productivity, and compressed order cycle times (Palevich 1997).

Specific programs that have been reengineered around easing the supply chain process include purchase orders, invoicing, scheduling, credit authorization, advanced shipping notices, electronic pricing, and warehouse management. In fact, one of the most important factors in the success of these programs has been the implementation an electronic data interchange. Order lead times, data entry errors, and vendor based order forecasting have all been positively influenced by the exchange of common electronic data.

Another item of particular interest is HWI Inc.’s certification and compliance program. “Certification allows us [HWI Inc.] to work on common technologies together with our business partners. We are working on verification of bar code quality. Product packaging, type of pallets, and timing of delivery are also part of our certification program (Palevich 1997, pg. 3)." Vendors and suppliers to HWI Inc. must meet these standards or face monetary fines or the potential loss of business. In particular, bar code quality is a critical item of interest because of its application in the warehouse management system.

The warehouse management system (WMS) controls, "the flow of inventory, warehouse operating functions, information processing, transportation decisions, and order placement (Palevich 1997, pg. 4)." Additionally, the WMS works with in-place bar code information labels to allow for information retrieval from many aspects of the warehouse process. First, the receiving process is automated through scanning serial shipping containers. This digitized receiving procedure allows HWI Inc. to

- Verify freight bill piece counts
- Automate the purchase order matching function
- Reduce or eliminate the checking function
- Prioritize receipts for stocking
- Improve the payment process.

Next, forklift operators scan the bar code strip on each stock item in the receiving are and transmit data via radio frequency data communications (RFDC) to the mainframe. Storage stack area data and any additional important information is relayed back to the forklift operators. The materials are then carried to a designated area within the warehouse with the exact location being scanned and sent to the mainframe once the operator has made final placement.

Finally, when shipments are ready to leave the warehouse orders are assembled and scanned once again in the shipping department. The WMS creates a label with important information that includes the part numbers, the MSDS information, and quantities. Additionally, a bill of lading is printed once the final shipment is aboard the truck. All of this information is then passed onto the customer via E.D.I. or paper copies depending on the customer's sophistication.

At the time of this publication, HWI Inc. had planned to extend this system to the World Wide Web. Customers could then place orders and monitor prices on a real-time basis. Currently, HWI Inc.'s retail Website is http://doitbest.com. Product availability, alternatives, specification, images, and prices can all be found on this Website.

Appendix B: How Many People Make A House?

Number of people	Trade/subcontractor	Task
2	surveyor	lot layout
2	Realtor	lot purchase
1	appraiser	lot appraisal
2	Banker	lot loan process
2	Attorney	title check
2	architect	house design
1	structural engineer	structural design
1	mechanical engineer	plumbing, heating
1	electrical engineer	power lighting
1	civil engineer	storm water
1	town planner	plan review
1	Building inspector	plan review, general
1	plumbing inspector	plan review, plumbing
1	electrical inspector	plan review, electrical
1	contractor estimator	assembles estimates
1	excavation estimator	estimates excavation
1	footing estimator	estimates footing
1	foundation estimator	estimates foundation
1	dampproof estimator	estimates dampproofing
1	Framing estimator	estimates framing
1	insulation estimator	estimates insulation
1	roofing estimator	estimates roofing
1	doors/windows est.	estimates doors/windows
1	siding estimator	estimates siding
1	gutter/downspout est.	estimates gutters/downspouts
1	drywall estimator	estimates drywall
1	Painting estimator	estimates interior paint
1	Cabinets/millwork est.	estimates cabinets/millwork
1	appliances estimator	estimates appliances
1	floor finishes estimator	estimates floor finishes
1	landscape estimator	estimates landscape/irrigation
1	electrical estimator	estimates electrical
1	mechanical estimator	estimates mechanical
1	cable TV installer	cable underground
3	natural gas installer	natural gas underground
3	water installer	water underground
3	sewer installer	sewer underground
3	electrical installer	service underground
2	phone line installer	service underground
1	deliver temporary toilet	
1	deliver temporary dumpster	
2	order/ship stone/gravel	
2	order/ship block	
2	order/ship foundation drains	
2	order/ship concrete	

2	order/ship framing	
2	order/ship plumbing	
2	order/ship mechanical	
2	order/ship electrical	
2	order/ship drywall	
2	order/ship cabinets	
2	order/ship appliances	
2	Surveyor	building layout
2	excavator	footing excavation
3	Concrete subcontractor	footing formwork/pour
3	Masonry subcontractor	foundation
1	dampproofing sub.	installs dampproofing
4	framing crew	framing/sheathing/doors
4	roofing crew	installs roofing
3	insulation crew	installs insulation
2	electrical crew	roughs in electric
2	Plumber	roughs in plumbing
2	mechanical subcontractor	roughs in gas/mechanical
4	drywall installer	installs drywall
2	cabinet installer	installs cabinets
3	flooring installer	installs floor finishes
3	Painter	interior paint
2	gutter/downspout inst.	installs gutter/downspout
2	Millwork and trim installer	installs millwork and trim
3	final grade/landscape inst.	final grading/landscape
1	building inspection dep.	footing inspection
1	building inspection dep.	framing inspection
1	building inspection dep.	electrical inspection
1	building inspection dep.	curb cut/apron inspection
1	building inspection dep.	plumbing inspection
1	building inspection dep.	final inspection
2	Banker	converts to permanent financing
1	appraiser	appraises for permanent financing
1	Attorney	closing
1	insurance agent	insurance

135 TOTAL

Appendix C: School Construction System Design (SCSD)--A Physical Integration Success Story

In a white paper presented to this project's advisory board in August 1999, master's degree candidate Chris Vandenbrock described the open system approach to physical integration promoted by Ezra Ehrenkranz and others. The open system is a "building system whose subsystems are interchangeable with other subsystems. Open systems are usually produced in response to bidding conditions requiring each subsystem to be compatible with two or more subsystems at each interface (thus assuring virtually universal interchangeability)." (Educational Facilities Laboratory 1967) The School Construction Systems Development (SCSD) program, the most successful effort at promoting modularity, allowed diverse manufacturers and suppliers of subsystems such as lighting, ceiling panels, enclosure, and partitions to freely bid and supply product to over 400 schools in California. The open system plays a similar role in Canada and some Scandinavian countries, allowing diverse suppliers while providing contractors with known production rates and owners with known durability. In the wood frame house as currently practiced, the modularity of the sheet panel product is the closest practice to the open system. Insulation, window, and skylight manufacturers also recognize the primacy of the structural panel module, but for the majority of housing subsystems, suppliers (mechanical, plumbing, lighting) make no effort at modular coordination at the scale of the whole system.

A longtime proponent of building systems integration, Ezra Ehrenkranz led a team of school district superintendents, material suppliers, labor unions, builders, sociologists, and financial executives in developing the SCSD, established in 1961. SCSD employed a rigorous systems approach to the design and construction of schools, stressing the need for compatibility, durability, and meeting user-specified performance criteria for the various building components. SCSD components made up approximately half of the cost of the school construction, enabling local designers and school districts to personalize and make regional adjustments to the system. Project specifications required general contractors to utilize the manufacturers of these components (who had previously won competitive bids to produce the components) as subcontractors.

The components were designed for one- and two-story school buildings but were utilized up to three stories. School sizes ranged 30,000–200,000 square feet. Components were designed and specified by the SCSD advisory committee to provide the highest performance in a school setting for the lowest cost. The end result was a system of over 300 components which could be specified by local designers and installed by local contractors.

The SCSD approach stressed end user flexibility. The prime factor for the adoption of this innovation by the school boards was spatial reconfiguration, supported by 70-foot column-free spans, demountable partitions, and reconfigurable air conditioning systems. Performance features such as increased lighting levels, salt air corrosion resistance, and glare-reducing concrete were a standard part of the system.

Another key factor in adoption of the SCSD system was cost competitiveness. At the time of adoption, the system approach was within 6¢ per square foot of traditional school construction having fixed partitions.

Physical integration thinking began with the SCSD planning modules. A 5-foot by 5-foot by 2-foot-deep structural module gave local design architects significant flexibility in customizing the school. All subsystems were required to be able to accommodate the 4-inch by 4-inch partition planning module. This 4-inch module also enabled the incorporation of plumbing within the partition thickness. SCSD's approach to physical systems integration depended on a 36-inch-deep "service sandwich" residing within the depth of the steel trusses making up the roof structure. This space contained structure, mechanical, electrical, lighting, communications, and ceiling finish.

The SCSD approach to performance was tied to a life-cycle cost basis for systems and components. Code minimums were the basis for structural design and life safety design, while the following client-generated performance criteria for the SCSD systems were established to guide manufacturers in the development system components:

sound transmission through assemblies	28 decibels
heat gain through exterior wall	6,000 BTUs per hour per 200 square feet
ventilation air	minimum 8 cubic feet per minute per person
total air supply	minimum 30 cubic feet per minute per person
air velocity at sitting height	20–50 feet per minute
mechanical zoning	minimum 3,600 square feet
mechanical service	minimum bid 5 years
lighting	minimum 70 footcandles
minimum illumination on work plane	within 25 per cent of average illumination level
maximum brightness in direct glare zone	350 footlamberts
lighting module	5 feet by 5 feet
demountble partition facings	must be independently replaceable
demountable partition reconfiguration	must be by school maintenance personnel
demountable partition service integration	must accept vertical and horizontal services

Production integration was considered in the design and specification of demountable partitions, lighting coffers, and the superstructure, which required compatibility with the planning module and flexibility by specifying school district personnel as the maximum skill level necessary to reconfigure. The predominant SCSD superstructure was a steel truss integrated with steel deck as its top chord. This connection was made through a heavy, hinged element, which enabled a higher number of components to be stacked on each truck. These large-scale (up to 70-foot-long and 6-foot-wide) prefabricated structural elements made for quick support and enclosure of the roof plane compared to a series of smaller, site-assembled components.

Glossary of Terms

customer-integrated decision-making (CIDM): a process that enables customer input into many aspects of the manufacturing industry

dependent-demand inventories: those materials whose quantities are directly related to the needs of an independent-demand item and not to the marketplace

design-for-assembly: a method of designing in which a part or series of parts are designed from the point of view of how they will by assembled and manufactured

electronic data interchange: an interchange of structured data according to agreed message standards between computer systems, by electronic means

enterprise resource planning (ERP): a powerful database with broad data format translation capabilities, within which are linked a series of supporting applications specifically addressing the various functions of an enterprise

enterprisewide business support systems: a plan which integrates information management with corporate goals

expert systems: computer programs based on knowledge developed from consulatation with experts on a problem, and the processing and/or formalizing of this knowledge using these programs in such a manner that the problems may be solved

fail-safe design: a design approach in which parts are manufactured that cannot be improperly assembled

floor jacking method: innovative high-rise construction technique which begins by constructing a staging platform composing the top floor of the building. The staging platform is jacked up story by story as the floors are completed.

HUD code housing: also known as "manufactured housing"

independent-demand inventories: those items which are subject to market conditions and are hence independent of operations

information integration: a computing system that seeks to eliminate the traditional linear flow of information and allows all involved a free exchange of information

insulating concrete form (ICF): a concrete form system which combines the formwork, internal insulation, plates, and studs to attach finish materials into one process

just-in-time manufacturing: a manufacturing approach which seeks to eliminate waste by providing the right part, at the right place, and at the right time

knowledge based engineering: a software system that uses relationships and rules developed by manuals, data-sheets, the memories of key engineers, manages, and suppliers to help in the design and analysis of manufacturing products

knowledge based systems: a system which catalogues expert information to advise users

lean manufacturing: a systems-view of an organization that is centered on the notion of customer-defined value. It aims at eliminating all the steps in the production of a good or service that do not add value to the final customer

manufactured housing: a specific term used to define a particular type of factory built home construction in which one or more units will be transported to the site and usually installed on nonpermanent foundations

manufacturing resourse planning: an information system used to plan and control inventory, capacity, cash, personnel, facilities, and capital equipment. It utilizes a feedback loop between in-process orders and the master schedule to adjust for production capacity availability.

materials requirements planning: an inventory control system which releases manufacturing and purchase orders for the right quantities at the right times to support a master schedule

modular housing: factory built homes of one or more units which typically use platform frame construction

operations integration: making the many subsystems of a building (HVAC, lighting, power, irrigation, security) function together as one

optimum value engineering: a planning technique that seeks to reduce construction material waste by working to modular dimensions of materials and modifying traditional framing practices with engineering based designs for the spacing and dimensions of framing elements

panelized housing: a classification of manufactured housing which consists of factory-built housing components, transported to the site, assembled, and secured to a permanent foundation

performance integration: making the many systems of a building perform as one

performance based specification system: a specification that requires certain standards of performance from the building system in question

physical integration: making the many parts fit together as one

platform framing: evolving from a technique known as “balloon framing”, which dates from the 1830’s, this construction system uses single-story, wood 2x members connected by wire nails and is constructed by first building a floor system (platform) on which to construct the story walls. Each succeeding story is constructed in the same manner.

production integration: conducting the many operations in the construction or manufacturing process as one

precut housing: a classification of manufactured housing which consists of factory built kits that have been cut at the plant, with components assembled for shipping, and then shipped to the site for assembly on a permanent foundation

quality function deployment (QFD): extends integration into the product development phase by bringing together product designers, engineers, process planners, and production planners at the time the customers are being surveyed

structural insulated panels (SIPs): mass produced composite wall panels that are manufactured with structural panel products (OSB, plywood) on one or two faces, with foam plastic insulation bonded to the structural panels

supply chain management: a management system that seeks to monitor and control all aspects of production

systems integration: a process which seeks to incorporate multiple building systems (HVAC, structure, electrical, etc.) into efficienct building design

task characterization: the accurate description of resource and information imputs; inventory of parameters for decision making; documentation of alternative methods for task completion; inventory of resource, product, and information outputs for each task of a larger process

total building commissioning: generally on the commercial scale of construction, this process involves third party certification of building performance, consumption, and maintainability

total quality management: a system-wide strategy for change that focuses on improvement of products, processes and people using tools, techniques, and philosophies to better meet customer requirements

value-engineering: a technique by which a project's value is increased, namely by increasing a project's worth while decreasing a project's cost

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