MEETING CLIENT NEEDS

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INDUSTRIALISING RESIDENTIAL CONSTRUCTION FOR SMALL TO MEDIUM SIZE US HOME BUILDERS

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ABSTRACT

In an effort to transfer academic research to a broader constituency, the Department of Housing and Urban Development (HUD), the major US homebuilding research funding agency, is pursuing strategies intended to move research into practice. Previous research by the authors has identified that a unified integration of information, physical, performance, production, and operation influences can become a primary contributor toward transforming current site-based residential construction practices into effective away from the workface industrialized process. The work also identified enterprise resource planning (ERP), object oriented CAD (OO CAD), Just-in-Time (JIT) supply management, design for manufacturing and assembly (DFMA), and virtual prototyping as the more promising techniques to affect an immediate impact in industry efforts to industrialize the residential construction process.

This paper introduces ongoing research that intents to; 1) create a self-assessed transfer guide that allows a builder to gauge their own or another's level of industrialization, 2) propose a strategy for accessing and transferring current industrialization opportunities from research to practice and if followed guide the builder in optimizing their current homebuilding processes through higher levels of industrialization, and 3) move research into practice.

Keywords: Housing Industrialization, Process Transformation, Industrial Transfer

1.0 US RESIDENTIAL CONSTRUCTION

The US Department of Housing and Development (HUD) is charged with the overall goals of increasing US homeownership, supporting community development, and increasing access to affordable housing free from discrimination. This is a huge charge impacted by an industry that in 2005 will put over $621 billion (US) of residential construction into place. According to the US Census Bureau (2005) approximately ninety five percent (95%) or 1.5 million residential units will be site-built. This from a homebuilding industry that essentially builds homes in the same manner as it did 175 years ago. Within the US homebuilding industry, small (<20 homes/year) and medium size builders (<100 homes/year) typically account for approximately 60% of all new single family US starts (US Census Bureau, 2000). Therefore any industry breakthroughs that are transferred to small and medium size builders will impact a majority of housing starts and subsequent a larger percentage of homeowners.

Traditionally residential construction relies on new product innovations to advance any performance breakthroughs. This is approached conservatively while the efforts to incorporate higher level manufacturing processes into homebuilding are all but nonexistent. To this end the US government through HUD has initiated a significant research effort involving a public-private Partnership for Advancing Technology in Housing (PATH). PATH (2005) 'is dedicated to accelerating the development and use of technologies that radically improve the quality, durability, energy efficiency, environmental performance, and affordability of America's housing' with a major goal to transfer current housing research to industry.

Toward this effort current HUD/PATH research is directed at finding transfer mechanisms to commercialize or transfer previously completed research. This paper is based on Industrializing the Residential Construction Site, Phase I, II, and III and explores the content and techniques to transfer previous research on the enterprise wide industrialization of residential construction into useful application. Other prominent research efforts that HUD/PATH has engaged are 'Tech Transfer Plus,' 'Commercialization Tools for Manufacture's,' and 'Diffusion of Innovation' (PATH, 2005). These projects have the same aim of transferring homebuilding research to homebuilders.

1.1 HUD/PATH RESEARCH ENVIRONMENT

PATH was launched in 1998 with a specific objective to accelerate the adoption of innovative housing technologies. PATH (2005) promotes innovation through key strategies of identifying and reducing barriers that impede innovation; disseminating information to speed the development and adoption; and by encouraging broader diffusion of innovations. Within the PATH website are numerous research reports that address innovative technologies, processes, and techniques. One of HUD's funded research projects *'Industrializing the Residential Construction Site'* (HUD, 2000) has resulted in examining the homebuilding industry from a non-product based industrialization approach to an approach that identifies process redefinition as the key to effecting industrialization of the whole home building industry.

1.2 INDUSTRIALIZING US RESIDENTIAL CONSTRUCTION

In this work the emphasis on 'industrialization' as an innovative residential construction process modifier is purposefully targeted at the evolution and interface of current office/field practices. The intent being to gain efficiencies and reduce errors through more intentional process designs that focus on optimizing productivity of the whole process rather than on discrete subcontracts. The authors propose that for the industrialization of residential

construction to occur; the industry must translate and eventuate into current residential construction the concepts of contemporary manufacturing, among these are process design, product design for manufacturing and assembly, workflow management strategies, and upstream/downstream procurement control methods. It is further believed that the housing industry will gain efficiencies in work methods, reduce errors in construction, address trade skill shortages, reduce housing costs, and optimize productivity by industrializing current residential construction processes and systems.

Single family residential construction has historically been the product of a craft-based production system and has matured into a subcontract management process, devoid of significant 'craftsmanship,' nor added builder value. The contemporary focus on construction improvement appears to target management techniques, e.g., flexible contracting (subcontracting) and computerised project scheduling in lieu of production management techniques associated with manufacturing. Christofferson (1999, p. 70) notes that a staffer with the US National Association of Home Builders estimates there to be approximately 29,000 items to account for during construction of a new home. This is not far from the 30,000+/- orderable parts, excluding nails, screws, loose, or preassembled pieces like door hardware, that Architecture Forum (1937) estimated for construction of a typical house over sixty-five years earlier. Therefore reaching HUD/PATH's goals to accelerate the adoption of innovation will only occur when the number of parts to design, engineer, procure, assemble, and construct are transformed into systematic flows through an industrialized processes, akin to integrated manufacturing. This has been the charge with much of HUD's technology research and thus the agency's current efforts to transfer research knowledge into practice.

Characteristics of residential construction such as fragmented subcontracting reduces a builder's risks but results in a loss of systems integration and overall process efficiency thus resulting in increased production error, low efficiency, and poor quality (HUD, 2000, p. 39). This is evidenced by the lack of integrated designs for major subsystems, i.e., structural, HVAC, electrical, and plumbing systems. This lack of integration frequently results in a tangled mess of subsystems affecting overall housing performance and affordability. Previous research reveals that industrializing residential construction is best served through full systems integration that accommodates four areas of integration; physical integration, performance integration, operations integration, and production integration. Information integration is a fifth form of integration and is considered the umbrella form of integration and is necessary to actually achieve these discrete forms of integration (HUD, 2000, p. 40).

Research indicates that information integration offers the greatest transferable opportunities to improve overall productivity, quality, and cost effectiveness in homebuilding. (HUD, 2000, p. 67) The current research question, at hand, is how to develop a transfer mechanism and in what forms a transfer guide can take that offers an understandable and usable transfer opportunity for small and medium size homebuilders.

2.0 RESEARCH STRATEGY AND FINDINGS

The research is currently in progress toward developing a transfer guide that utilizes past research efforts and applies those results in a form that is simple and usable for assisting small and medium builders in their acquisition and expansion of industrialized process and techniques that optimize performance, production, operations, and physical integration. The transfer guide phase of the project is an outgrowth of the previous research and is the effort to get the research results to the homebuilder. The discussions that follow explore the strategy and findings for the original research in addition to the strategy for development of the transfer guide.

2.1 DATA COLLECTION AND FINDINGS

Data collection is being accomplished through an advisory board of builders that participates in the research by allowing access to field sites, office practices, and management techniques, including design, engineering, procurement, and operations. The advisory board has been composed of a cross section of small, medium, large, modular, and production homebuilders, prime contractors, speciality contractors, component manufacturers, designers, engineers, and research consultants. Upon postulating the strategy of 'industrialization' as a translation for transformation, a review of the literature was conducted, than interviews and observations were used to gather data for compilation, mapping, and analysis.

The literature and interviews resulted in case studies that evidenced manufacturer's who adopted information integration applications including Just-in-Time (JIT) supply chain management, Manufacturing Resource Planning (MRP, MRPII), Enterprise Resource Planning (ERP), object oriented CAD (OOCAD), and design for manufacture and assembly (DFMA) have experienced productivity and quality gains due to their highly integrated design, production, and procurement systems. Coupled with the literature search a data collection process was implemented that allowed detailed process maps to be produced depicting various work/information/production flows for the different types of builders (HUD 2000, p. 69).

Analysis intimated that various implementation priorities for industrialization transference to various volume size builders are appropriate. A summary of these proposed implementation priorities follows.

2.2 CHARACTERIZATION AND INDUSTRALIZATION OPPORTUNITIES FOR SMALL-VOLUME RESIDENTIAL BUILDERS

Small-volume homebuilders are characterized, by HUD (2000, p. 62) as building fewer than 20 homes. The US Census Bureau (2000) characterizes small builders as building less than 25 homes and in 1997 this group accounted for 39% of all single family homebuilding starts. Small builders also typically employ four or less people. This category makes up a significant portion of the US residential construction industry. Due to their small volume these builders have limited operating finance and capital support and extensive industrialization technologies may require capital investment that is beyond their capacity (HUD, 2000, p. 63). These builders also lack the supply chain influence that can force a change in the way they currently operate and thus the adoption of industrial technologies is likely to be driven by their suppliers, and/or distributors who wish to broaden their markets.

Many small-volume builders are small enough, typically four or less employees, that the builder personally performs many information management building tasks. In many instances, the builder is responsible for design; either through purchasing or provided by the client, direct product and material procurement, project scheduling, subcontractor coordination; job site supervision, they arrange for permits and inspections; deal with the home owners, and interact with banks and owners on financing, and may also do basic job cost accounting. This effort engages the small volume home builder at a highly personal one on one level. Although capital investments may need to be addressed by external sources the implementation priorities identified by the previous research includes:

- the development of procurement/production scheduling systems to improve workflow and,
- the introduction and implementation of object oriented CAD systems that allow process linkages from order, design, engineering, procurement, through production (HUD, 2000, p. 64).

2.3 CHARACTERIZATION AND INDUSTRALIZATION OPPORTUNITIES FOR MEDIUM-VOLUME RESIDENTIAL BUILDERS

Medium-volume builders are typically characterized as regional builders with an annual volume of 25-100 homes. These builders are in a better position than small-volume builders to respond to the challenges of industrialization. Their capital investment, systems, and training are at a higher level than a small builder and they are likely to have supply chain influence. Many builders in this category have begun explorations into industrialization through wall panelization and higher level procurement, scheduling, and account/cost control tools (HUD, 2000, p. 64).

Although accounting and cost control tools are in use their extension to include pre-construction activities still lacks maturity. Providers of integrated information systems have begun offering linked accounting and procurement systems in a Web-based format. This integration should offer medium-sized builders an opportunity to industrialize some of their better-developed operations-management techniques. HUD (2000, p. 65) reports that the missing link for medium size homebuilders are systems tools, for design, production simulation modelling, and field construction information necessary to form an enterprise resource planning (ERP) solution. Thus for medium-size builders who construct from 25-100 homes and upwards to 200 homes per year the implementation priorities are:

- introduction of OOCAD systems linked to purchasing and accounting systems that provide integrated information ERP for customers, suppliers, materials purchasers, subcontractors, payments, and inspections,
- the use of supply chain influence and ERP to move to JIT procurement,
- development of integrated information systems for, resource management, scheduling, and construction progress reporting,
- development of field staff tools for onsite use of the information systems,
- access production modelling and simulation systems for further refinement of existing field processes, development and analysis of new processes.

2.4 CHARACTERIZATION AND INDUSTRALIZATION OPPORTUNITIES FOR LARGE-VOLUME RESIDENTIAL BUILDERS

These builders are characterized as ‘Giants’ and typically build over 200 homes per year. They exert considerable supply chain influence, utilize national supply contracts, and maintain sophisticated information management systems at both the national and regional levels that integrate finance, procurement, sales, and marketing. Although there is sophistication in accounting and procurement there appears to be little difference in the site construction methods used by this sector and the medium-size builder. Job site ordering and production scheduling are typically done by a field superintendent, who is responsible for the construction of 10–20 houses annually. While CAD systems are used in the design, very little use is made of object oriented CAD or building information modelling (BIM) software to initiate an integrated workflow in scheduling, engineering, procurement, and production. Feedback to and from the field is considered a significant obstacle to further industrialization of the process. Implementation priorities for high-volume builders include: (HUD, 2000, p. 66)

- transform the current use of CAD to an object oriented or BIM focused system to engage resource management, scheduling, ordering, and supervision information and link it to the company’s existing purchasing and accounting systems for an integrated ERP,
- develop tools for field staff to enable onsite use updating of the integrated ERP,

- use design for manufacture and assembly (DFMA) and other production modelling, analysis and simulation systems to further refinement existing field processes.

3.0 DISCUSSION

Toole's (1998, p. 330) analysis of over 100 homebuilders revealed that homebuilders perceive technological innovations as a risk that is reducible by gathering and processing information about the innovations. The objective of the transfer guide is to assist in pointing toward effective innovations and encourage their adoption. Other research also reveals that adopters of high and low uncertainty non-diffused innovations consult more external sources of information during their adoption process. HUD (2004, p. X) reports that the types of single family home building firms most likely to be early adopters of product innovations were likely to have a technology advocate within the building firm and use technology transfer programs like PATH and relies on established manufacturers standing behind their building and construction products. These findings are useful for identifying additional strategies, such as applying focus areas for adopters to explore and gain needed knowledge and applicability of champions to enhance and promote the opportunities for transfer.

HUD's *Industrializing the Residential Construction Site Phase II, Information Mapping* (2001, p. 64) focuses on information flows, linkages, filtering, and their impacts on errors and disconnects in the residential construction work processes. These linkages provide the greatest opportunity for applying interface management techniques to improve production flows. Additionally HUD's recognition of the inherent differences in the focus of office-based (process-oriented) vs. field-based (action-oriented) activities offers insight into the use of information integration as the key to transforming current homebuilding practices. From the HUD research, the domains and linkages that offer advancement of industrialization in the office to field transformations are:

- sales to design to production: this is an important linkage as it allows real time decision-making for up-to-date scheduling, procurement and product selection,
- production to design/engineering: This works to eliminate the chronic errors in drawings or designs that undermine the belief in the accuracy, currency, and completeness of the information presented,
- customer service to design to production: This linkage reinforces the feedback mechanisms that allow early detection of poorly performing innovations.

The transfer guide research is concentrated less in field to office linkages and more on overall enterprise wide linkages within the domains of design, engineering, procurement, and production. It is these domains of influence that appear to offer the more effective integrative aspects for transformation from a craft-based site-determined enterprise to an integrated industrialized process.

4.0 TRANSFER GUIDE DEVELOPMENT

4.1 BUILDER ADVISORY BOARD

A representative cross section of small, medium, and large builders were approached to assist in the transfer guide's development. Five builders agreed to participate in the development and realization of the transfer guide. Builders 1 and 2 are small-volume (5-10 homes/year) semi-custom builders. Their product design is provided through stock or owner furnished house plans with frequent one-off minor modifications, including site adaptations subcontracted to local architects. All other work is subcontracted to a select group of contractors with procurement and supervision provided by the builder.

Builder 3 is a medium-volume (40-60 homes/year) custom/semi-custom/speculative builder. Builder 3 maintains a land acquisition, development, and home building enterprise and 'custom' designs each home in consultation with their client. Supervision is performed in-house. Framing has recently been subcontracted out and efforts are underway to transition to purchasing prefabricated open and closed wall panels and subcontracting labour.

Builder 4 is a large-volume (700 homes/year) production builder and a subsidiary of an international building materials supplier, yet is not considered a 'giant.' Builder 4 provides in-house architectural services and offers pre-designed single-family detached house and townhouse plans with customizable options, sold through on-site sales models. The company owns and operates its own wood wall panel manufacturing plant. This facility is integrated within the upstream design environment with wall panel produced at the plant used in all home production. All of the onsite production is subcontracted. Outside material suppliers are used in conjunction with the builder's (parent company's) available resource chain.

Builder 5 is a medium-volume (200 homes/year) production builder. Builder 5 operates differently than most production builders in that they operate as a small-volume decentralized builder network within their own larger organization. These smaller entities are run by the "area builder" like a separate company within the larger company. As a result the supply chain for Builder 5 has broadened and the product standardization varies from one Builder 5 "area builder" to another. Design is provided in-house from a series of model plans and all construction work excluding "area builder" supervision is subcontracted.

4.2 TRANSFER GUIDE DEVELOPMENT STRATEGY

To successfully design and develop an industrialization transfer guide for use by small and medium size homebuilders it's essential that each builder's current state of industrialization be assessed. The research is currently focused at this level with development of a simple user applied assessment tool. Once the user establishes a level of industrialization the intent is to allow the transfer guide to provide focus areas to self direct resources to reach an envisioned objective. To validate the guide's effectiveness the builder advisory board will assist in testing the transfer guide throughout its development. In strategizing an transfer guide several objectives are essential for effectiveness. It was determined that the objectives stated below are fundamental for development of an effective transfer guide.

- a measurable consistency in categorizing the maturity level of builder industrialization,
    - this allows for identification of current status and transfer opportunities,
- identifiable workflow domains consistent with previous research,
    - these are design, engineering, procurement, and production,
- identification of industrialization criteria for use in assessment and transfer,
    - these are operations, tools, techniques, methods,
- measures dependencies and linkages,
- discussable transfer techniques.

4.3 TRANSFER GUIDE FOCUS

It is understood that a complete feedback loop incorporating linkages from the purchasing client to a satisfied homeowner and back is essential to a holistic approach yet it remains outside the defined scope of the research. Thus the technique for compiling and implementing the guide has been to create a hierarchical matrix for self assessment that establishes at the highest level, the expanded working domains, and then granulates each domain into categories with further refinements by incorporating operational process/product

methods criteria that supports varying levels of domain integration, see figure 1 and table 1 for further insight.

Within each domain are assigned degrees of industrialization from low to high characterized as 'acquiring,' 'advancing,' and 'achieving.' A series of questions are posed to the transfer guide user and an assessment is calculated based on the responses. The questions are focused within each domain and are developed to assess an established level of industrialization within each domain. The questions focus on operations, tools, techniques, and methods. A common four quadrant grid is mapped expanding from the centre into each of the four domains. Within each domain proposed degrees of industrialization are also set radiating away from the centre. The quadrants are divided by horizontal and vertical axes that are focused as "above the line," scope definition; while "below the line" is resource utilization. Above the line are the Design (D) and Engineering (E) domains that initiate and implement scope determinants. Below the line applies to vendor/suppliers resource relationships in the Procurement (P) domain and subcontracting resource relationships in the Production (O) domain. These involve the initiation and implementation of resources. The vertical axis also creates a sliding scale for measuring industrialization as functions of "to the right of the line" as 'initiating' and "to the left of the line" as implementing.

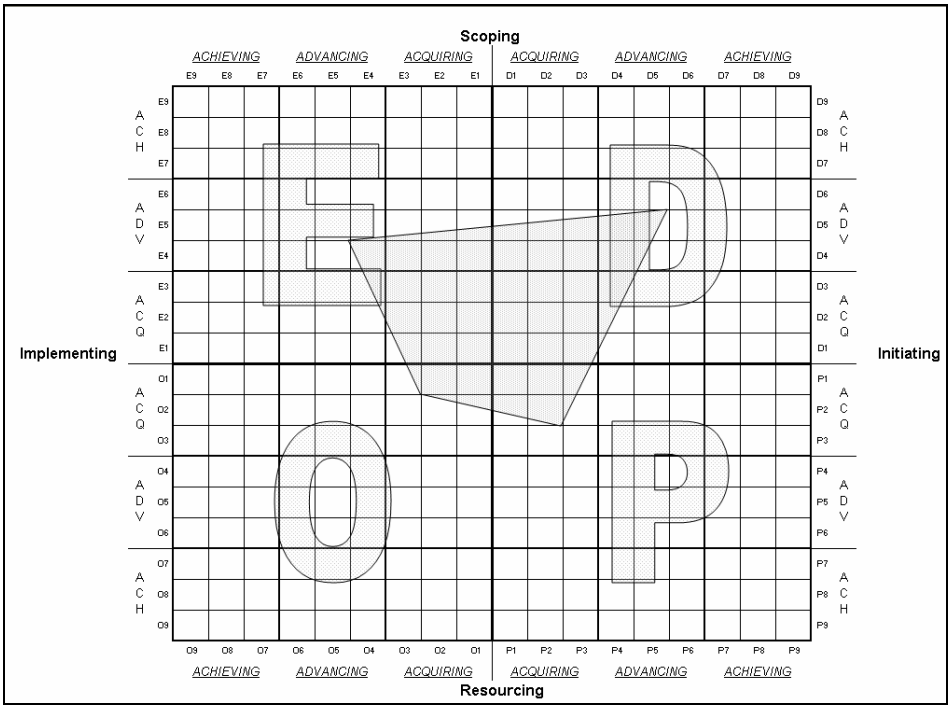

Figure 1 - The shaded polygon shows the identified level of industrialization

Figure 1 shows an overlay for a user that has established an 'advancing' level of Design (D) and Engineering (E) yet has not extended this same level of industrialization to Production (O) or Procurement (P). From a quick visual analysis of Figure 1 a user can surmise that the organization being assessed is advancing design and engineering industrialization yet hasn't expanded the linkages into the domains of Production and Procurement for their advancement. This particular example would allow discussions and points of reference for users and potential transferees to explore initiating their resource relationships with suppliers to capitalize on design linkages while implementing these same potentials to subcontractor resources, all with the intend of expanding . Additionally it is believed that builders can share this transfer guide with subcontractors and suppliers to in effect, measure their own levels of industrialization and thus help extend the overall enterprise.

Once a baseline understanding is developed, additional dialogue can initiate to expand the users understanding of acquiring, advancing, and achieving industrialization of the residential construction process. The transfer guide is intended to continue with insightful approaches for cross-category linkages, e.g., Procurement to Design, Design to Production, and Production to Procurement. These are currently being explored and represented by a linked investment classification domains that in turn creates an investment focus and leads toward addressing specific links that can be used to support transfer from an 'acquiring' state to an 'advancing' or 'achieving' state within the builder's targeted domains.

It is intended that a builder can use the transfer guide to adjust organizational focus on domain specific areas of investment in order to meet specific internal objectives. Thus, if the desire is to increase throughput, and the guide recognizes that procurement is a bottleneck, the builder can focus resources and investment in the procurement domain. Table 1 shows one potential example of a partial analysis derived within a portion of the design domain with desired linkages to Procurement.

In this example the builder's standard operational procedure for preparing design documentation is to use traditional three-dimensional CAD. The builder identifies this level as 'advancing' and as such is ready to move the design process to a higher degree of industrialization through investing in additional design software. Simultaneously, the builder would like to advance vendor coordination and also positively affect the Procurement domain. From this analysis the builder is also able to identify resources that are available for gathering more information and knowledge with the intent of advancing the overall enterprise. This is consistent with Toole's (1998) and HUD's (2004) findings that risk adverse builders are more likely to adopt innovation after doing research.

Table 1 - Example of a portion of industrialization focus matrix

Domain	Operational Criteria	Method	Current Degree			Investment Linkage	Investment Focus	Resource
			Acq	Adv	Ach			
Design	Production implementation							
	Documentation	2D	**-**					
		CAD		-				
		3D		**X**				
		OO CAD			-	**X**	**Design software**	**A/E, software vendor**
		BIM			-	**X**		
	Vendor/Supplier Coordination					**X**	**Design Software, Procurement**	**ERP, material supplier, BOM**

5.0 CONCLUSION

This research is still underway and delivery of the final transfer guide is still pending. What has been identified is that residential construction builders and clients in the US are moving beyond archaic processes and are working to accept new knowledge and toward that end focus academic research on getting this new knowledge to its clients. In this particular instance, that is the US homebuilding industry. This is being engaged through development of an Industrialization Transfer Guide for Small and Medium Volume Homebuilders.

The proposed components of this transfer guide advanced in the text are:

1. a self assessment component for gauging the degree of a company's industrialization,
2. a methodology for simple interpretation and workable fluency for establishing the advancement of industrialization in residential construction,

3. a focus matrix that gives users insight to investment strategies as they advance toward and achieve higher levels of industrialization,
4. a pocket handbook that can be used to comprehend industrialization characteristics and reinforce strategies for advancement.

The development of a transfer guide for industrialization of residential construction can take many forms but the fundamentals are that the integration of design, engineering, procurement, and production through information exchanges and linkages will lead to enhanced optimization of the processes, enable increased throughput, and increase affordability while raising quality.

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