

# Commercialization for Innovative Products in the Residential Construction Industry

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Dissertation submitted to the faculty of the Virginia  
Polytechnic Institute and State University in partial fulfillment of the requirements for the degree  
of

Doctorate of Philosophy  
In  
Environmental Design and Planning

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July 25<sup>th</sup>, 2008  
Blacksburg, Virginia

Keywords: Innovation, Diffusion, Adoption, Commercialization, Residential Construction

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## Abstract

This work presents the development of a new framework for the commercialization of innovative products in the residential construction industry. It is the aim of this work to identify commercialization decisions, actions, risks, barriers and accelerators specific to the residential construction industry market that will increase the acceptance of product innovations for those developing them.

Commercialization is broadly defined as the process of developing a business enterprise from an idea, through feasibility and implementation, to its acceptance into a market (USDOE 1999, Goldsmith 2003). Commercialization frameworks describe the concurrent decisions and actions along the innovation development process, optimizing all of the technical and business decisions required for a successful introduction to the marketplace. Successful commercialization frameworks serve as a form of development plan, promoting solutions to questions and problems that arise along the development path.

This research derives such a framework for the commercialization of innovative products and makes it specific to residential construction through the following tasks:

1. Understanding standard terminology: defining innovation and commercialization as they relate to this work.
2. Creating a lens for the unique nature of commercialization in this industry: deriving a commercialization framework (matrix) from the research literature in business, construction, and concurrent engineering, capable of accepting later alterations.
3. Understanding the manufacturer's role and risks: conducting case study interviews for fifteen innovative residential construction products that specify important tasks, risks and benefits for commercialization.
4. Understanding the role, risks and benefits of builders, as users of innovation: comparing case studies and workshop surveys of many residential construction industry players that focus on the builder to establish parameters for the innovation commercialization matrix.
5. Linking both manufacturer and builder: comparing manufacturer commercialization best-practices with builder adoption patterns for innovative products over time.

In specifying a commercialization framework to residential construction, this work finds the following:

1. Innovation is not invention.
2. Developer/builders are a single stakeholder along the supply chain in a commercialization venture.
3. Innovation commercialization is the process of developing a product from concept, through feasibility and implementation, to its acceptance into a given market.

4. Commercialization is the coordinated technical and business decision processes (and resulting actions) required for successful transformation of a new product or service from concept to market adoption.
5. A framework for innovative products in the residential construction industry exists herein as a matrix of eight phases in time and eight technical and business functional areas. The framework's architecture accepts the various data inputs and establishes portions of commercialization important to construction industry products through noted areas, actions, and sequences and could indicate the importance of localized processes that require additional attention when taking a product to market.
6. Steps in the early stages of a commercialization project are most important and no new phases or functional areas for the framework are required. The framework version established herein contains steps that can be removed, not steps that need to still be added.
7. The most commonly used sequences of commercialization steps validate a concurrent-engineering approach.
8. The first phase of this work's framework is an essential starting point for any commercialization project.
9. Commercialization projects require early integration of marketing within a product's design.
10. All phases of the commercialization process are essential, while phases 1-4 of our commercialization framework are *more* critical to success than phases 5-8.
11. Early missteps largely *increase* the possibility of later risks.
12. The functional areas Process Planning (PP), Human Resources (HR) and Accounting and Information Systems (AIS) are relatively routine for commercializers of residential construction products.
13. The residential construction industry delays the heavy investments in process development and capacity expansion to a late stage of a commercialization project and proceeds cautiously in these functions.
14. Manufacturer case studies suggest an intriguing hypothesis that residential construction products present such significant challenges in other functional areas that financial management (FM) issues are somewhat routine. FM therefore, by comparison to other residential construction-specific commercialization actions, might be perceived as less of a barrier to success.
15. Champions are important to the development process.
16. Based on these case studies, this work posits the hypothesis that a key function of corporate champions is to coordinate successfully all corporate and departmental entities involved in a commercialization project and the role of the product champion as commercialization coordinator should be the subject of future research.
17. Developer/ builders are the supply chain members most influential in determining commercialization success.
18. Addressing the developer/builder risk along the entire supply chain is one key determinant to a successful commercialization project.
19. This research proposes the extension of concurrent engineering (CE) to concurrent commercialization (CC) as a strategy for meeting the challenge of developer/builder adoption.

20. Successful concurrent commercialization requires risk sharing among all members of a product's supply chain, which requires information sharing and knowledge transfer among supply-chain members early in a commercialization project.
21. CC is a significant predictor of commercial success.
22. The closer one comes to achieving CC, the better one's chances are of commercial success.
23. Products with lower CC percentage did not achieve commercial success, suggesting directions for future research.
24. This research also finds significance in specific thresholds within the adoption process in coordination with CC:
  - a. The initial threshold of innovator seems to play an important gateway role within adoption.
  - b. Only certain products pass beyond this threshold easily and all have CC in their development.
  - c. The early adopter threshold seems difficult for a product to successfully cross at both the early and later part of the threshold.
  - d. Once the threshold of early majority is obtained by a product, commercial success seems certain.

The work contained herein is presented in a manuscript format, meaning that each chapter is published or in the process of being published. The following refereed conferences contain chapters of this work: *The European Conference on Product and Process Modeling* and *The Royal Institute of Chartered Surveyors COBRA Conference*. The following refereed journals contain, or are considering, chapters of this work: *European Journal of Innovation Management*, *Construction Innovation* and *The Journal of Product Innovation Management*.

This research is supported by the NSF Grant *Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market* and *Modeling Diffusion of Innovation in the Residential Construction Industry*. All opinions are those of the authors and not NSF or HUD.

## List of Definitions

Definitions of the following terms are necessary for understanding this work:

- *Users* are firms or individual consumers that expect to benefit from *using* products or services by manufacturers (Von Hippel, 2005).
- *Manufacturers* expect to benefit from *producing* and *selling* a product or service to users (Von Hippel, 2005).
- *Users-as-Manufacturers* are firms or individuals whose use of a product or service benefits their ability to improve or sell new products.
- *SMEs*<sup>1</sup> (*Small to Medium Enterprises*) are firms with the number of employees between 1 and 499 (Rothwell, 1989).
- *Builders* are firms that procure and deliver living units within the residential construction industry.
- *Builder SMEs* are firms that procure and deliver less than 200 living units within the residential construction industry (Toole, 1998).
- *Builder Involvement in Commercialization* is defined as each step within commercialization where builder actions are considered by the manufacturer and therefore affect the ensuing process.
- *Commercialization* is the coordinated execution of all necessary processes within the technical and business functional disciplines between a product's conception and the penetration of that product into a given market.
- *Product Commercialization Framework*, as opposed to a model, is the basic arrangement of all steps integral to a product's development process. In contrast, a model would account for all of the known properties of commercialization in Residential Construction, the purpose of this study.
- *Commercialization Tasks of Importance* are individual, separate functions within all functional disciplines of commercialization that have greater effect on overall success than others; also known as Important Cells or Important Steps
- *Commercialization Risks* are inherent characteristics within the commercialization process that hinder overall success; Commercialization risks a category of barriers.
- *Commercialization Benefits* are inherent characteristics within the commercialization process that benefit overall success; also known as accelerators.
- *Inventor* is the individual or firm that first develops an innovation to a useful state, as proven by documented, useful output.
- *Invention* is the development of a novel idea, product or process, for the firm or individual utilizing it, to a useful state.
- *Innovation* is the implementation of a novel idea, product or process, for the firm or individual utilizing it, into actual use.
- *Developer/builders* are entities positioned in the construction supply chain between distributors or retailers of products and the installers of products. They deal in land inventories, the assembly process and procurement. In contrast, the label "developer" is generally ascribed to managers of land inventories, with minor involvement in the assembly process, and "builders" is distinguished by a core competency of efficiently managing the assembly process.

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<sup>1</sup> It is important to note that Rothwell's criteria is based on SME literature for all industry and SME construction firm sizes are typically much smaller in range. This work will use Toole's (1998) units built for SME firm sizing.

## Attribution of Co-Authors

While the majority of the work presented in this research was the sole responsibility of the author, the work as a whole would not have been possible without the continued efforts and support of the co-authors involved. Specifically, Dr. Walid Thabet, Dr. Ralph Badinelli and Dr. Ted Koebel offered editing through intellectual, methodological and organizational guidance. Many of the ideas for this work resulted from their original thought, from which the author explored further directions that became the research presented herein. The author is eternally grateful for the continued efforts and contributions of the co-authors and acknowledges that this work would not have been possible without their contributions. A brief description of their backgrounds and contributions are included as follows.

**Prof. Walid Thabet-** Ph.D. (Department of Building Construction, Virginia Tech) is the primary advisor and committee chair. Dr. Thabet is the Principal Investigator of NSF-PATH *Grant Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market*, a basis for much of this dissertation work. He coordinated the investigation of commercialization for innovative products in residential construction. His duties included, but were not limited to, the guidance of all work, the literature review, the development of methodologies and the specific development of Chapters 3, 4, 5, 6 and 7.

**Prof. Ralph Badinelli-** Ph.D. (Pamplin College of Business, Virginia Tech) is a secondary advisor and committee member. Dr. Badinelli is a Co-Principal Investigator of NSF-PATH *Grant Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market*, a basis for much of this dissertation work. He also coordinated the investigation of commercialization for innovative products in residential construction. His duties included, but were not limited to, the guidance of all work, the literature review, the development of methodologies and the specific development of Chapters 3, 4, 5, 6 and 7.

**Prof. Ted Koebel-** Ph.D. (Department of Urban Affairs and Planning, Virginia Tech) is a secondary advisor and committee member. Dr. Koebel is the Principal Investigator of NSF-PATH *Modeling Diffusion of Innovation in Residential Construction*, a work from which Chapter 7 draws. His duties included, but were not limited to, the guidance of all work, the literature review, the development of methodologies and the development of Chapter 7.

**Chapter 3:** Developing a New Commercialization Model for the Residential Construction Industry.

All work for this chapter was performed directly by the author and through guidance from Virginia Tech faculty and committee members listed above. Each committee member offered editing through intellectual, methodological and organizational guidance.

**Chapter 4:** Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction.

All work for this chapter was performed directly by the author and through guidance from Virginia Tech faculty and committee members listed above. Each committee member offered editing through intellectual, methodological and organizational guidance.

**Chapter 5:** Validating a Commercialization Model for Innovation in Residential Construction: Industry Case Study Analysis.

All work for this chapter was performed directly by the author and through guidance from Virginia Tech faculty and committee members listed above. Each committee member offered editing through intellectual, methodological and organizational guidance.

**Chapter 6:** Understanding the Role of Residential Builders in the Concurrent Commercialization of Product Innovation.

**Akshat Nayyar** is an MS student in the Department of Civil Engineering at Virginia Tech. His contribution for this chapter included literature review targeting case-studies of product diffusion and helping to identify barriers/accelerators to product commercialization. He was also responsible for contributing to the format, implementing and gathering data from the workshop.

**Sean Wilson** is an MBA student in the Pamplin College of Business at Virginia Tech. His contribution for this chapter included literature review targeting Delphi technique and location decision modeling. He was also responsible for contributing to the format, implementing and gathering data from the workshop.

**Chapter 7:** Understanding Concurrent Commercialization for Product Innovativeness Thresholds.

All work for this chapter was performed directly by the author and through guidance from Virginia Tech faculty and committee members listed above. Each committee member offered editing through intellectual, methodological and organizational guidance.

## **Dedication**

This work is dedicated to my wife, Alyce, and my daughter, Annabella. You make me a better person; you make me want to be a better person. You are the “simum.”

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# Chapter 1 - INTRODUCTION

## ***Background and Problem Statements***

Economists have long debated the impact of innovation on economic growth. Schumpeter (1910) established firm-level innovation theories, identifying small to medium enterprise (SME) innovation as a driving force of changing market structures and then later (1943) suggesting that larger firm research and design (R&D) departments were fundamental in innovation production. Rothwell (1989) more recently suggested these same firm level impacts change through time, depending on the industry. In the construction industry, Barrett and Sexton (2003) found that firm level (inter or intra-firm) innovation performance had a significant impact on innovation and its adoption for the entire industry. In residential construction, a recent NSF-PATH (Partnership for Advancing Technology in Housing) conference listed, among other factors, successful commercialization of firm-driven innovations as vital to the future of the industry (Koebel, 2004). Successful innovation development from concept to market, also termed commercialization, is universally accepted as vital for the health of industry (Conference Board of Canada, 2004) and is central to the future health of residential construction markets (HUD, 2005).

The processes followed by those profiting from their ideas often provide the best guidance on how to achieve success (Bell Gully, 2005). Those who have successfully taken an innovation to market or adopted a new product to their benefit are our greatest resource for success in future commercialization. Still, little of this knowledge has been captured for the residential construction industry. Residential construction does not even understand its own specific definition of innovation commercialization.

Commercialization is a long process and having a sound technology or idea for a product that one wants to market profitably is not enough to guarantee success (USDOE, 1999). Commercialization frameworks serve to facilitate this success through identifying all technical and business decisions or actions required in getting a product to a desired market.

Since commercialization frameworks are not available for the construction industry, other-industry models serve as a basis. The US Department of Energy's (USDOE) commercialization model targets independent inventors and small businesses developing "new energy-saving technologies." Goldsmith (2003) received national recognition for his successful approach for facilitating the commercialization of advanced technologies. Others promote a "lifecycle" model, considering commercialization as a cycle from invention

to intellectual property protection, and then starting again (Bell Gully, 2005). Government models often result from examples of proper and improper process (PATH, 2001).

Complexities among residential builder firms also contribute to adoption failure. Large firms, those producing more than 200 homes per year, are more subject to increased uncertainty of expected benefits through these industry complexities (Toole, 1998). Toole (1998) further identifies the severe consequences of poor adoption decisions for these large firms. While larger firms often emphasize innovation as their future, small and medium enterprises within construction are more apt to experience severe consequences of adoption due to exposure to their larger business environment (Womack and Jones, 1996, Sexton and Barrett, 2003). This heightened sensitivity requires better planning and flexibility from the SME firm, resulting in more flexibility towards uncertainty over time. Current studies on the effects of user firm characteristics on innovation adoption are limited and do not analyze time series data or represent the effects of external factors on product adoption (Blackley and Shepard, 1992 and Toole, 1998).

A commercialization model must also identify the needs of manufacturers. Little is known of manufacturer commercialization best-practices in residential construction, probably due to their proprietary nature. Manufacturers sit along the construction supply chain as key players that must clearly understand the benefits of selling an innovative product or service. No study of proper commercialization practice would be complete without their knowledge. Manufacturers would benefit from a commercialization model for residential construction that clearly identifies tasks, risks and benefits to future innovation development.

Currently, most builders consider innovation resistance good business practice. Therefore, innovation commercialization in residential construction must also identify the needs of builders. In residential construction, the builder is another key member of the supply chain whose benefits to innovation adoption must be understood. Builders would also benefit from a commercialization model for residential construction that clearly promotes their role in the process as well as optimal tasks, risks and benefits to future innovation adoption.

This study will therefore define commercialization for residential construction through the development and validation of a framework for innovative products. This product commercialization framework, increasingly becoming a model as its properties are known, is the basic arrangement of all steps integral to a product's development process. This work creates such a framework to solve the following problems that resist adoption for innovative products in residential construction.

*Problem #1: There is no standard terminology in residential construction for innovation commercialization.*

A framework specific to the residential construction industry must have a basis in a consistent definition of terms for innovation and commercialization. Current definitions of Commercialization, New Product Development (NPD), Diffusion and Adoption are confusing in general innovation literature, which transfers into research specific to residential construction. An initial step to studying innovation within residential construction is the establishment of a standard set of terms.

In general literature, innovation commercialization is commonly called New Product Development. NPD literature and studies primarily attempt to understand and benefit innovation process for manufacturers. NPD findings concentrate on specific areas of product development implementation within commercialization. In keeping with a typical Concurrent Engineering (CE) approach, commercialization for this study is the coordinated execution of all necessary processes within the technical and business functional disciplines between a product's conception and the penetration of that product into a given market. Identifying specific definitions for construction innovations is the initial step to creating an industry-specific commercialization model.

Also vital to innovation success is the process of understanding separate markets, the focus of innovation use theory and literature. Literature on innovation use primarily tries to understand and accelerate the innovation acceptance process through user behavior. These social behavioral analyses for users of products are the basis of diffusion and adoption theory. Despite much work, recent research confirms that product innovators in the US construction industry still need standard terms for their market (NAHB, 2001). Creating these standard terms is an initial step to creating an industry-specific framework.

*Problem #2: There is no current framework of innovation commercialization for specifying to residential construction.*

The construction industry does not completely understand or appreciate the role of innovation for its future. While innovation success is widely viewed as good for the future of industry, construction contains unique characteristics that promote resistance. Construction firms, as users, typically protect themselves by resisting the adoption of possibly bad innovation, thereby reducing risk (BTI, 2005). Construction product manufacturers are typical of large corporations who protect themselves through the development of

complementary products that introduce minor improvements to these resistant markets (Christensen, 2004). Innovation success nevertheless remains a cornerstone to economic growth (Scherer, 1986). Identifying a framework of innovation commercialization, for specifying to residential construction, would facilitate economic success and growth for builders, manufacturers and the entire industry.

*Problem #3: There are limited studies of manufacturer commercialization risks, benefits and tasks of importance for the residential construction industry.*

Previous commercialization studies, in construction, focused on technical aspects of the innovative product and lacked an understanding of successful commercialization process (PATH, 2001). Once a framework is established, it nevertheless requires testing from industry players. A broadly-tested commercialization framework for the residential construction industry would benefit universal understanding of how to best facilitate this basic, vital process of successfully getting new innovations to market. A study of manufacturer risks, benefits and tasks of importance specific to residential construction commercialization reduces risk for future innovation development.

*Problem #4: There are few studies that currently investigate the role of developer/builders in residential construction product commercialization, and specifically the risks and benefits of the process for these builders.*

Within manufacturers' markets, users of innovations are the most likely to innovate successfully and serve as a "leading edge" (Von Hippel, 2005). Becerik (2004) and Margulies (2003) found that uncertainty of expected benefits, for the adopting firm, would limit innovation marketplace success in the Architecture, Engineering and Construction (AEC) industry. Although studies have typically targeted manufacturer best-practices or user preferences, perhaps industry resistance lies not in new product development or the characteristics of these new products, but in a manufacturer's fundamental understanding of an innovation commercialization process specifically for the construction market. Builders, as a leading edge of the residential construction industry, might better predict success for innovative product commercialization. A stronger understanding of builder adoption preference might allow "user-as-manufacturer" tendencies, thereby better predicting innovation commercialization success. Still, the builder's role in commercialization needs definition. The ability for manufacturers to learn from these lead-users for the residential construction industry would reduce product uncertainty along the commercialization framework, hence improving upon the commercialization process.

*Problem #5: There are no studies that compare manufacturer commercialization practices with builder adoption patterns for innovative products over time.*

Studies of building firm adoption and use patterns are commonly the basis for understanding residential construction product innovation uncertainty. Product uncertainty, and therefore resistance, often results from few observable benefits to the user. No studies to date look at building firm adoption patterns over time for innovative products or the commercialization processes of manufacturers during these periods of time. Understanding specific commercialization risks, accelerators and tasks during, and prior to, adoption might reduce uncertainty of benefits to both manufacturers and firms.

Firm-level uncertainty of benefits could be the main factor hindering adoption (Toole, 1998). Other commonly accepted factors affecting adoption are firm characteristics; tasks/activities associated with using new products and materials; a firm's perceived benefits; a firm's market and competitive strategies; size of builder; competition; business cycles (growth, payback, and downturns); and fragmentation (Koebel *et al.*, 2003, Hassell *et al.*, 2003). Again, Builders better understand these complexities of construction that contribute to the difficulty of introducing innovation. For example, each innovation may have to be compatible with numerous parties in the supply path before arriving at the builder (Koebel, 1999; Hassell *et al.*, 2003; Toole, 2001). Specifying a roadmap for successful commercialization process according to users would facilitate manufacturer understanding of market needs.

Complexities within builder firms also contribute to adoption failure. Risk variability among firms requires better planning and flexibility from all firms, resulting in the need for more flexibility towards uncertainty over time. A study identifying specific areas of commercialization tasks performed during and before product adoption might reduce risk for all firms.

## ***Research Objectives and Scope***

The overall goal of this research is to develop a commercialization framework for innovation commercialization in residential construction and test this framework with manufacturers, builders and others involved in the supply chain through identifying roles, risks and benefits specific to the industry. This work will achieve its goal through the following objectives:

*Objective #1: Establish consistent terminology for innovation commercialization in the residential construction industry.*

Compare terminology for innovation theory, NPD and commercialization through literature review and establishes central definitions applicable to this study of a framework for residential construction.

This work will draw on the following sources for its definitions:

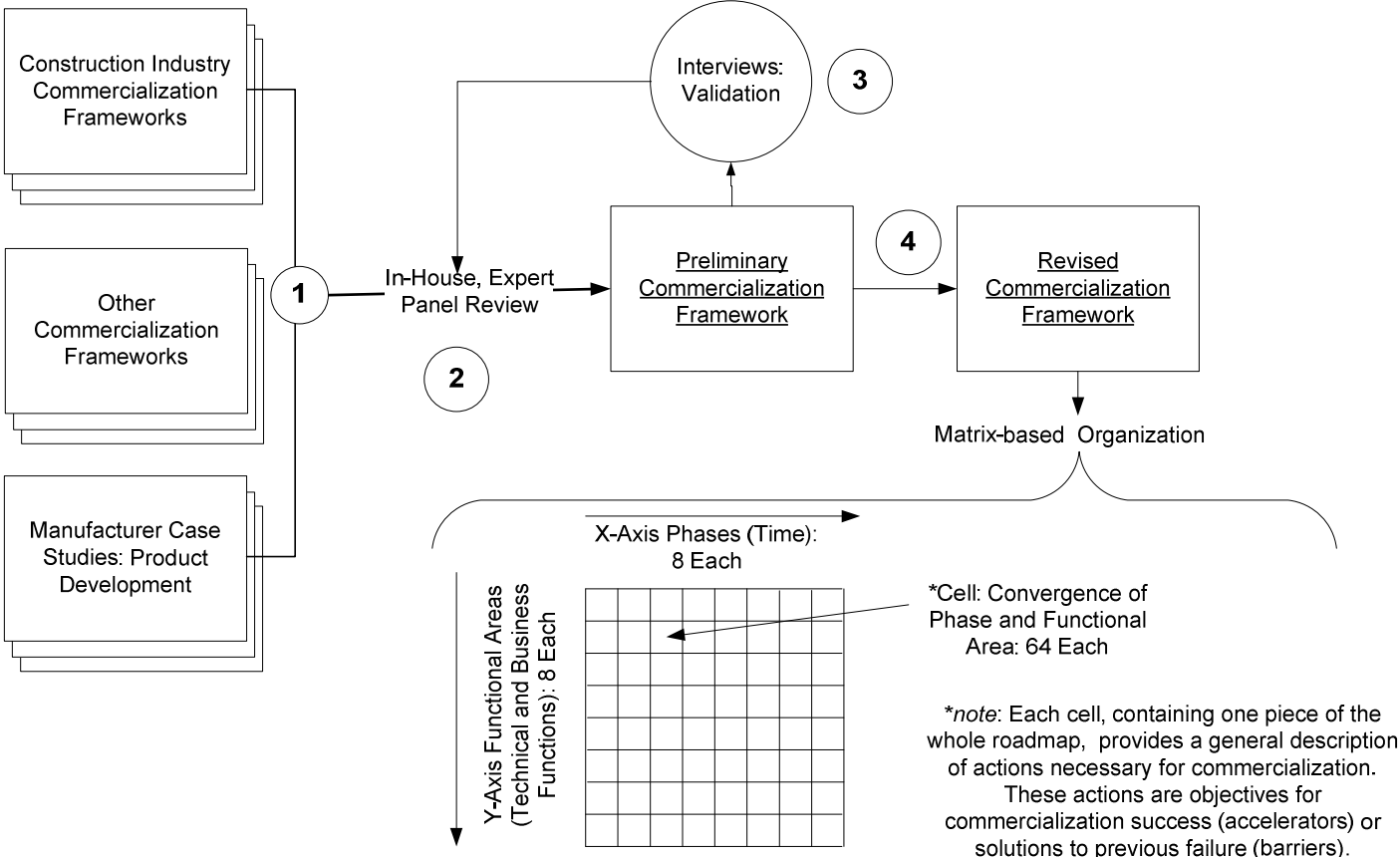
- General commercialization definitions in business literature and those specific to the residential construction industry through industry-based (HUD or PATH) reports
- New Product Development literature that defines and promotes specific functional areas of research and development (R&D) for manufacturers
- Innovation diffusion literature that promotes specific definitions for the construction industry
- Innovation adoption literature that promotes specific definitions for the construction industry

*Objective #2: Create a commercialization framework for innovation commercialization in residential construction (see Figure #1).*

The model outlines phases and functional areas for technical and business best-practices in getting innovative products to market. The overall research approach consists of the following process:

1. Review other commercialization frameworks from the business literature, websites or industry-based reports. Define terms for this domain-specific study through the literature review: Innovation, Commercialization and Acceptance. Review published industry case study on the process of innovative product development.
2. In-house expert panel review and synthesize a preliminary commercialization framework for the study.
3. Validate the preliminary commercialization framework through industry interviews on innovative product development practices. Perform in-house expert panel review of these data and reach consensus as to their influence on the framework.
4. Modify and further specify the commercialization framework into a final form

**Figure 1: Objective #2 Research Steps**



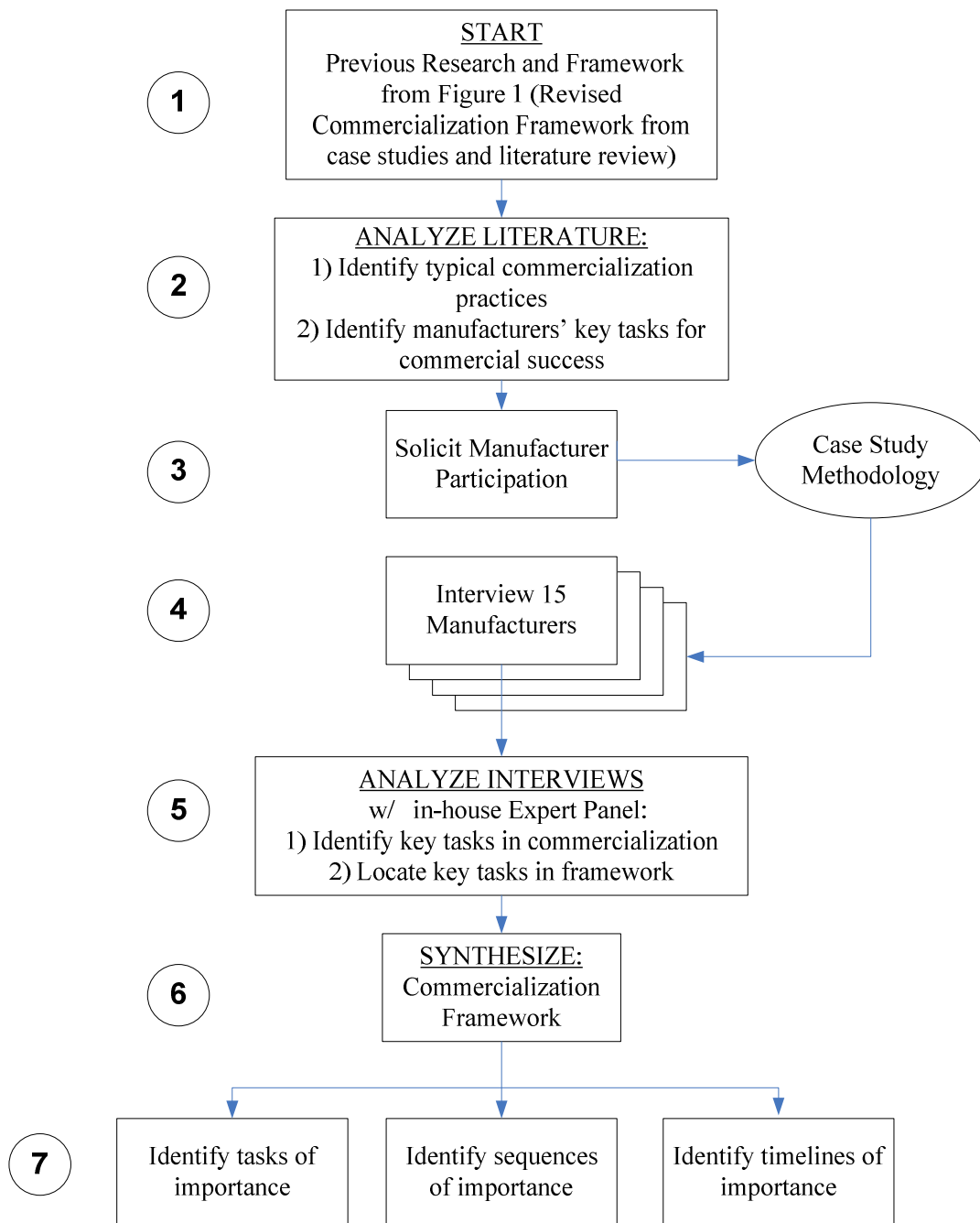
Objective #3: *Identify manufacturer commercialization risks, benefits and tasks of importance (see Figure #2).*

Specify the commercialization framework to data obtained through interviewing manufacturers and analyze their experiences in the residential construction industry. Each interview solicits descriptions of key decisions that were made during the successful commercialization of innovative products; the data are presented as case studies. Data analysis identifies the critical decisions for successful commercialization and also diagrams sequences and timelines of these critical decisions among different types of products and business environments.

The following steps reveal manufacturer commercialization practices:

1. Begin with revised commercialization framework from Objective #2.
2. Review case-based literature on commercialization processes and key tasks for commercial success for manufacturers of innovative products in residential construction
3. Establish a survey for industry interviews of the commercialization process and solicit manufacturer participation based on this survey.
4. Conduct fifteen interviews with innovative product manufacturers in residential construction
5. Solicit individual interpretation of interview excerpts by an in-house academic panel of construction and business experts. Establish group consensus by the same expert panel with respect to each manufacturer's key tasks and their location within the commercialization framework.
6. Synthesize the data: a) timelines of the commercialization process from interview excerpts; b) sequences of the commercialization process from interview excerpts; and c) tasks of importance for the commercialization process from interview excerpts.
7. Summarize tasks of importance, process (timelines) and sequences as barriers and accelerators for manufacturers of innovative products in residential construction

**Figure 2: Objective #3 Research Steps**

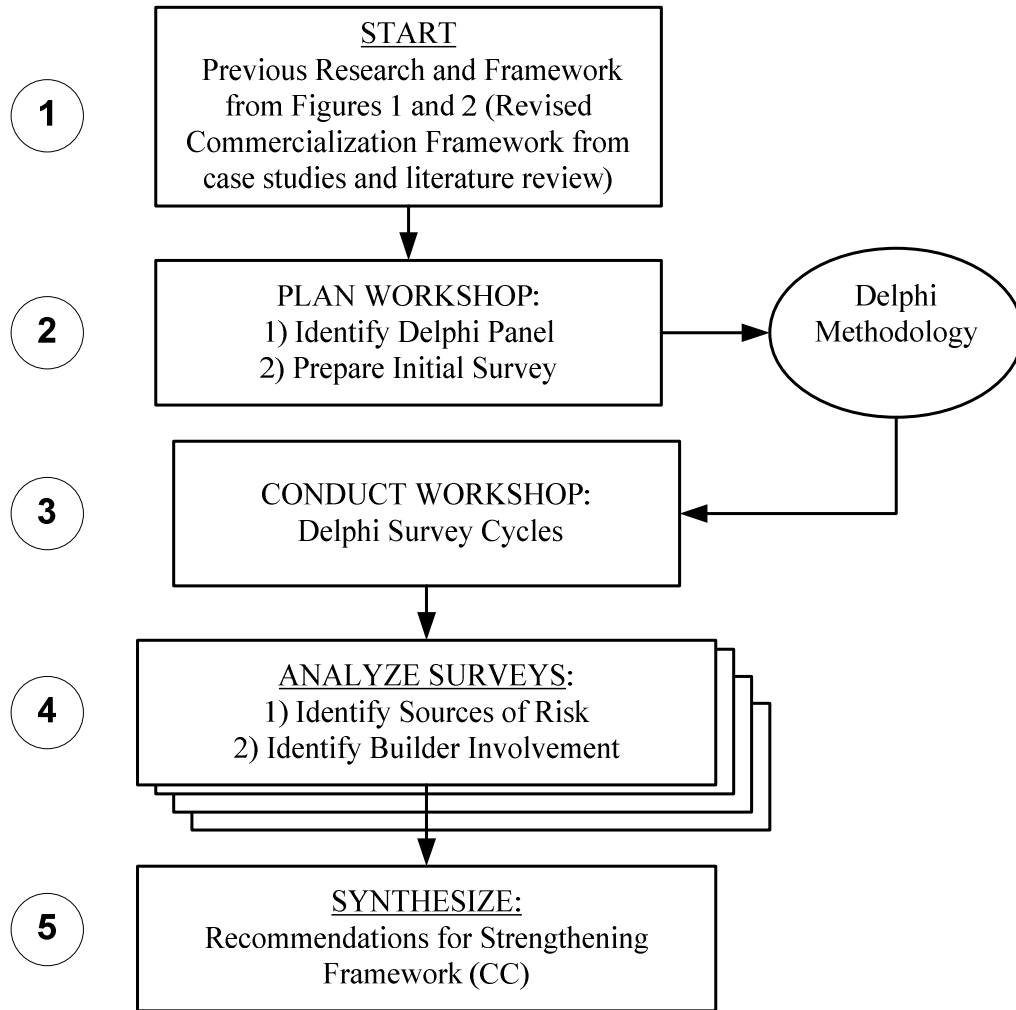


*Objective #4: Better understand the role of residential builders, defined as users, in the commercialization of innovative products (See Figure #3).*

Workshop survey data on the role of builders further specify our domain-specific commercialization model for residential construction products. This work creates consensus about the role and risks of builders within commercialization. It presents workshop data through three surveys, draws consensus on this quantitative and qualitative data and specifies the implications of these data for the commercialization framework. This work aims to identify risks, benefits and the role of builders in product commercialization through industry expert consensus in the following ways:

1. From the literature, establish the role of the builder in commercialization, a set of risks specific to the residential builder and the unique nature of the industry. From the literature, establish a modified Delphi consensus method applicable for use in conducting a survey and workshop to identify builders' roles, risks and accelerators in product commercialization. From case study interviews of manufacturers (see objective #3), establish the manufacturer's view of the role of the builder in the commercialization process.
2. Plan a workshop to validate the role and risk of builders using surveys and exterior, industry-based expert panel discussions to gather consensus from experts.
3. Conduct a survey on the role of builders in the commercialization process. Specifically request: barriers, accelerators, key decisions and critical actions in the process (similar to manufacturer survey). Establish consensus through a review of the survey data in a workshop setting. Administer a second survey with modified questions on builders' roles, risks and accelerators in product commercialization. Establish consensus through a review of the survey data in a workshop setting. Administer a third survey with modified questions on builders' roles, risks and accelerators in product commercialization after the workshop.
4. Analyze surveys through in-house expert academic panels to identify sources of builder/developer risk and involvement in commercialization.
5. Synthesize findings and make recommendations for strengthening the framework.

**Figure 3: Objective #4 Research Steps**



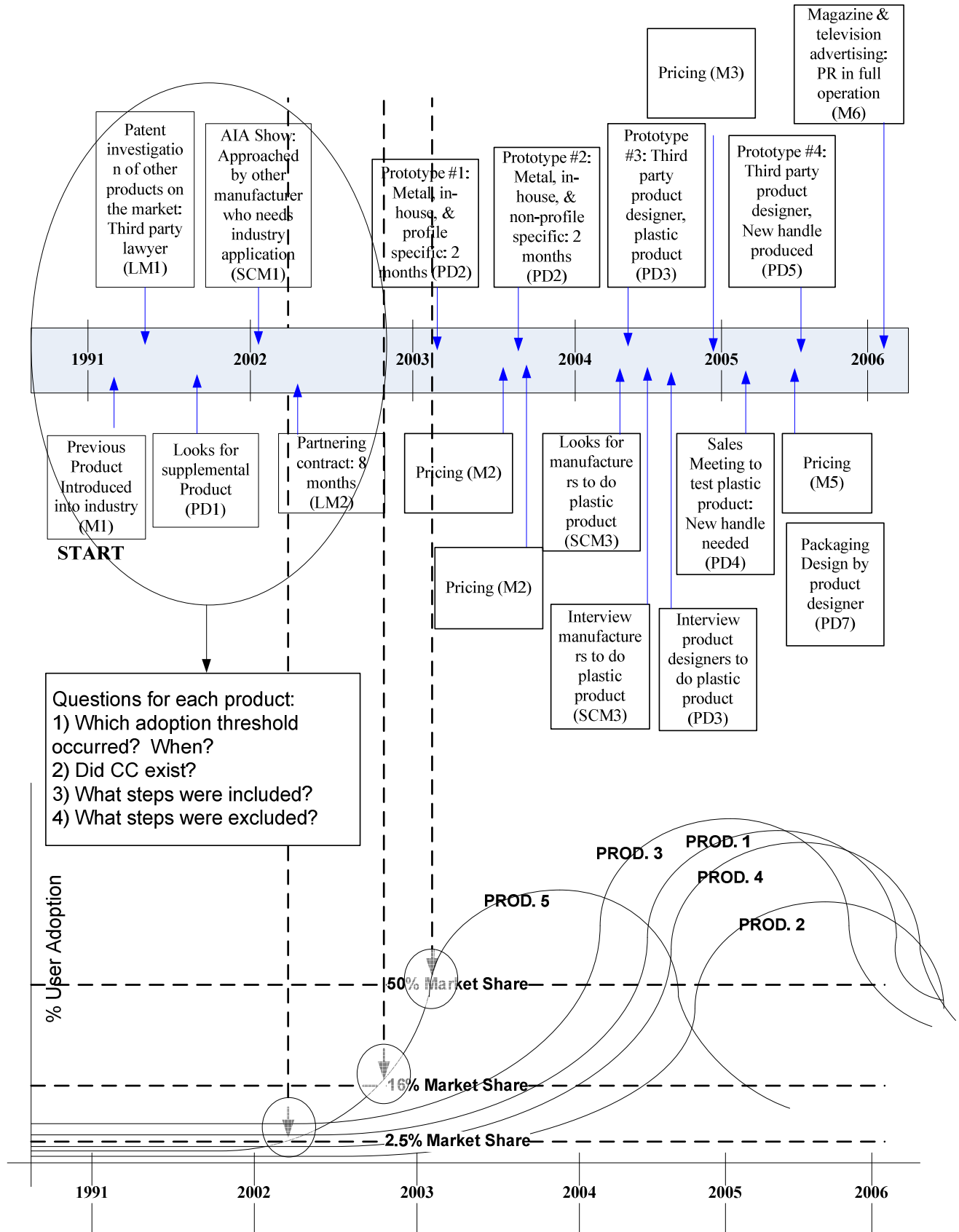
Objective #5: Map the commercialization process leading up to and during the threshold of adoption for thirteen products in the NAHB Builders' Practices Survey, specifically to assess the use of concurrent engineering and its affect on the process (see Figure 4).

Studies of manufacturing-firm product development practices and installing-firm adoption patterns are commonly the basis for separately understanding product innovation uncertainty. Manufacturing firm development strategies typically represent innovation as a process improvement. Product adoption improvement strategies often look at *innovativeness*, how individuals or other units of adoption might be earlier in adopting new products than other members of a social system (Rogers, 1995). *Innovativeness* categorizes these individuals and reflects discreet moments of adoption and adoption thresholds. Many studies attribute innovation uncertainty, and therefore delay, to improper development strategies or a lack of observable benefits at the point of adoption (Clark and Wheelwright, 1993; Von Hippel, 1988). No current studies, however, compare innovative technology adoption thresholds with commercialization best-practices for manufacturers in residential construction.

This work argues that commercialization best-practices for manufacturers in residential construction lead to higher adoption thresholds sooner in the commercialization process of products for the residential construction industry through the following:

1. Defining central terms for this work and innovation commercialization in residential construction.
2. Locating these products in the NAHB Builders' Practices Survey (BPS) between the years 1996 to 2005 and assembling their data for this initial study.
3. Using case studies to record the commercialization process before and during the adoption thresholds for thirteen BPS products in this study.
4. Specifically verifying the use of Concurrent Commercialization (CC) for these products.
5. Finally summarizing the findings and proposing future directions for the research.

**Figure 4: Objective #5 Process**



## ***Research Methodology***

While there is much debate over the system of evaluation best suited for behavioral and social science, this work contains “mixed methods” which consider qualitative and quantitative methods compatible (Tashakkori and Teddlie, 1998). The compatibility of these accepted research methodologies exist herein as the following standard practices: qualitative case study interviews with in-house academic expert panel consensus and quantitative surveys with Delphi methodology and external expert industry panel consensus. The following sections provide background on the appropriate use of these methods for this study. All methods used in specific, individual chapters of this work are explained in the appropriate chapter, not below.

### ***Qualitative Case Study Analysis through Interview Questioning***

As a method, the case study preserves flexibility, which is paramount to qualitative methods. A case study is an investigation of the technical aspects of a “real” phenomenon through the use of interviews of individuals who have expertise and/or experience with those phenomena (Yin, 2003). Case studies are often the only useful methodology when a researcher seeks to understand structural relationships among interacting entities, the content of processes, the reasons behind decisions, and other questions about how or why a process is performed (Marshall & Rossman, 1989).

Specific to the construction industry, the qualitative data obtained from case studies are designed to transform a preliminary framework into an increasingly specific adaptation to the construction industry. In effect, the research will serve as a “field-test” of the commercialization framework through execution of Maxwell’s (1996) four main components for case-study research:

1. Establish a relationship with innovative product manufacturers
2. Sample these manufacturers and their products through interviews
3. Collect these interviews as case studies
4. Analyze these interviews through expert panel consensus about the key elements, decisions and actions of the commercialization process that are important to success.

According to Fowler (1995) question-and-answer processes, such as case study interviews, are becoming increasingly necessary and valuable in social science studies. The complex nature of this study required answers that connected disparate backgrounds and organizational cultures. *Contextualizing strategy* attempts to understand data in regard to their relationship among differing elements (Maxwell, 1994). The interview questions of this work use this strategy to understand innovation within the differing phases and functional

areas of a commercialization project for subjects and organizations across the residential construction industry.

Early in the interview process, it became obvious that collecting data on the commercialization processes of existing firms and their products might be difficult. Nevertheless, focusing the setting, population or phenomenon was crucial to the research design (Marshall & Rossman, 1989). The backdrop of the *International Builders' Show 2006* provided many opportunities for access to experienced innovation developers as survey participants. During the show, these participants were too busy to participate, but expressed their interest. Once away from the show and presented with possible survey questions, these participants were no longer willing to participate; the proprietary nature of information and time commitments were cited as some reasons for lack of interest. It therefore became obvious that a larger amount of creativity in acquiring data would have to be utilized.

Marshall & Rossman (1989) consider the ideal setting for a research focus to be where: entry is possible; a suitable mix of processes, people, programs, interactions, and structures of interest are present; the researcher is likely to build trusting relationships and data quality and credibility of the study are reasonably assured. Toolbase.org lists manufacturers and installers of many innovative residential products. The website identifies innovations and contacts within corporations to gain entry into the specific processes for these products. Other participants were found through word of mouth in the Building Construction Department at Virginia Tech. Through email, telephone and in-person interviews, these two resources provided entry to the diversity of our industry study.

Of those few willing to participate, there seemed genuine excitement about understanding commercialization better and being part of an extended study. Participants were also willing to provide thorough feedback on product development and adoption processes not able to be captured in a survey's binary or multiple answer format. These respondents were indicative of larger trends in this work: those willing to participate had real passion for the topic. The case study format therefore provided the flexibility to capture this passion, its process and diversity in participants, established trust through respondents' review of their own interview, and provided a forum for group validation of data to ensure consistency of findings. Once entry was gained, Yin (2005) prescribes five steps in conducting a viable case study:

1. *Derive Case Study Questions:* Literature on the subjects of new product development, commercialization, adoption and diffusion of innovation focused our study of the commercialization framework. Each of our case studies therefore began with a pre-determined list of standard questions from this same literature that exposed all aspects of a subject's commercialization project to our framework.

2. *Posit Case Study Propositions:* The research next verified the usefulness of the framework through specific research hypotheses such as: the commercialization framework is appropriate in terms of its content, its position within the functional areas and the time frame of a commercialization project.
3. *Determine the Unit of Case Study Analysis:* Innovative product manufacturing and user firms were the unit of case study analysis for our research: an individual company that had experience in the commercialization of at least one product.
4. *Establish Criteria for Recording and Interpreting Data:* Each firm, upon agreeing to the analysis, confirmed our need to tape and transcribe the interview.
5. *Establish Decision Rules for Validating or Refuting Propositions from Data:* Reliability of data was established by soliciting each answer through consistent methods.

The case studies attempted to also solicit meaningful answers that allowed comparison to larger groups of people. To keep this general atmosphere, Seidman (1991) suggested a rapport with subjects that did not require discussions of a personal nature. In interviews, this research therefore introduced the topics consistently to all potential subjects. The work began by explaining the background of the research and a privacy policy, as well as determining whether the product under consideration would fit well with research goals. All policies and goals were sent to the subject in soft copy form after the initial conversation, when the subject seemed appropriate to this work.

This work also provided sample publications for each subject to ease concern over privacy in published work. The research team always sent the following preliminary set of questions as well, serving as the basis for all interviews:

1. What is your firm size and organization? How does your company champion the commercialization of innovative products?
2. Please discuss the history of your product.
3. Please discuss the position of your firm within the supply chain.
4. Please discuss your product in further detail in regard to its commercialization process until today. On a timeline, what decisions were made and what actions resulted from these decisions? What lessons were learned?
5. What decisions along the commercialization process would you consider MOST important?
6. Who was involved in key decisions? What did each individual need to decide?
7. What are the backgrounds of individual decision makers and their position in the company? What are their job descriptions and what incentives do those positions require from the corporation?
8. Who has final authority over all decisions? What is his/ her background?
9. Assuming we have an innovative product and we would like to commercialize this product, what options does the industry offer us? For example, was there a rule-based system for decisions to partner? Were there criteria for licensing?
10. What initial decision limits and constraints do you place on products you are considering for commercialization? Can they be entirely new products or must they support previous innovation? Are there legal limits, human resources limits, marketing limits, technology limits?

Final interpretation of the literature, case studies and findings was always based on expert panel opinion. While much work was performed on an individual basis, the expert panel continually validated this work. The expert panel consisted of individuals with Business, Architecture, Engineering and Construction backgrounds. These individuals offered diversity from the academic perspective while serving as experts on business and construction related concerns. While interviews established trusting relationships through a question-and-answer process, the panel later reviewed them for accuracy from both the respondent and the researcher. Consistent interview format and frequent panel group review of all case study answers established reliability of findings within the participant data. The academic expert panel examined these interview transcripts line by line and performed content analysis of them. Responses to the interview questions were then directed at specific steps of the commercialization process as defined by our generic framework, thus specifying the framework to this industry.

### ***Quantitative Methods through a Modified Delphi Technique of Surveying***

This research used Delphi Methodology to gather consensus, both from panels of industry experts and academic experts. In Objective #3, Delphi Methodology was used to gather consensus among academic experts as to the location of case study information within the commercialization framework. In Objective #4, Delphi Methodology was used to gather consensus among industry experts, through a series of surveys, as to the location of builder risks and roles within the commercialization framework.

Expert consensus results from a series of question-and-answer surveys whose responses are returned to the researcher. The administrator then summarizes answers and reports to each panel member all of the opinions expressed by the panel.

Objectives #3 and #4 included a modified Delphi technique when analyzing interview and literature data. The modification for this work meant not using a survey instrument to reach consensus. Instead, each member of the panel was provided a file containing all interview transcripts. Each member of the expert panel would discuss a location within the commercialization as a group and then vote individually on his opinion. Consensus as to the location of the transcript item was reached when all members of the panel agreed.

The workshop in Objective #4 reached consensus through various industry stakeholders. In the workshop setting, the Delphi method was administered and monitored by an unbiased researcher who was the point of

contact for each industry member. Again, expert consensus resulted from a series of question-and-answer surveys whose responses were returned individually to the researcher through a website portal. The administrator then summarized answers and reported to the industry group all of the opinions expressed by the panel. Each resulting survey was reworded based on the current consensus and re-administered. All individual voting was anonymous so that the influence of personality and peer pressure was avoided. Each round of questionnaires produced a narrower diversity of opinions so as to guide the panel toward a "correct" opinion (Linstone and Murray, 1975).

The workshop setting relied on the proper administration of three surveys. Fowler (1995) listed the following basic standards for survey construction:

1. *What the question means and the kind of answer that will meet the question objectives must be understood by all respondents;* this work therefore used clear instructions with all respondents and definitions of all terms used in the survey and included these terms in the administration of surveys for reference
2. *Respondents must be able and willing to perform the tasks required to answer the questions;* this work therefore ensured that all respondents understood their obligation previous to the survey administration and were allowed to leave the process at any time (3 such situations occurred). All respondents were reported within the survey anonymously
3. *Survey questions must constitute a protocol for an interaction, a question and answer process, that will be consistent across respondents, and, when they are involved, across interviewers; and three main types of question evaluation for validating technique:*
  1. *Focus group discussions;*
  2. *Intensive individual interviews;*
  3. *Field pre-testing of procedures.*

A consistent set of instructions and questions were given to each expert. Further, the surveys were administered on-line, including during the workshop, to ensure consistency of venue and anonymity of responses. This work validated each question through Fowler's techniques as follows: 1) each question was proposed and evaluated by a group of Building Construction and School of Business faculty and graduate students before placed on the survey; 2) previous, individual industry interviews originated many of the survey questions; 3) a "dry run" of the surveys and the workshop setting were pretested by the same group that evaluated the questions prior to their administration.

Since we were introducing the broad topic of commercialization to the panel, we decided to consolidate the phases of our model for the first survey in order to lessen initial confusion. Survey #1 asked questions regarding the barriers and accelerators present within the phases of our condensed framework and the importance of the phases and functional areas. A typical question asked was "How important is Product

Design in the Design Phase,” referring to the early phase of our commercialization framework. The respondents were asked to respond with a rating on a scale of 1 through 5, with 1= not important, 2= somewhat important, 3= important, 4= very important and 5= critical. In summarizing each question on a survey, we counted the number of panel members who responded to the question with a rank of 5.

Responses to Survey #1 were presented to the panel on the first day of the workshop. The discussion of the workshop centered on four functional areas within the commercialization framework: Product Design, Process Planning, Marketing and Supply-Chain Management. Survey #2 therefore sought specific details about these areas, as well the original areas of consensus, by asking about developer/builder decisions and actions within key steps of the commercialization framework. The survey also asked for the key performance indicators, decision variables and salient factors regarding the important commercialization decisions. Survey #2 was administered to panel members via a web site after the first day of discussion at the workshop. We discussed the results of Survey #2 on the second day of the workshop and then concluded our meeting. Again, discussion seemed to concentrate on the same steps of the commercialization framework. The panel members requested time to process all of the discussion before entering into another survey.

Survey #3 was distributed online after the workshop and was based on the respondents’ feedback from Survey #1 and Survey #2 and the workshop discussion. As our final evaluation of survey responses, we counted the number of respondents who ranked a statement with a score of 5 as an overall score for the question. If two-thirds of the panel responded with a rank of 3 or higher, we declared that a consensus had been reached on the statement.

## ***Broader Impacts***

*Impact #1: Establishment of a domain-specific commercialization framework.*

Getting an innovation into the market requires more than just developing something that works. Technical development needs to be matched to an increasingly sophisticated system of accessing potential markets and the channels through which the product may reach them. This coordinated linkage of technical and business steps that develop an innovation for a given market comprises the commercialization of the innovation. Many are denied access to traditional homebuilding product commercialization processes and must create their own framework. Others with current frameworks might not understand all of the processes required for the most effective product development process. This work will offer a framework that benefits all innovators.

*Impact #2: Establishment of a roadmap for innovators of a residential construction product.*

This work is motivated by recurrent failures of developers of innovative new homebuilding products in bringing these products to market successfully (HUD, 2005). The diffusion of new homebuilding techniques and the growth of new industries in the provision of construction materials are stifled by these failures. Advances in innovative technology are widely regarded as major sources of improvement in the competitive position of firms and industries and major factors for increased national economic growth and standards of living (Porter, 1985). This work offers a model that could aid in the advancement and growth of innovative technology in the residential construction industry.

## **Research Organization**

*Description:* This work's proposed route for successfully achieving a doctoral degree is through a coordinated set of published documents, working documents and documents being prepared for journal and conference submittal. This set of documents will comprise two (2) refereed conference papers and three (3) refereed journal articles. The definition of published documents here is proposed as those works considered with a status of "revise and resubmit" or "accepted" by a publisher. All chapters are written so that they can be read and understood by people other than those knowledgeable in the industry and the subject of innovation theory and new product commercialization. Chapters three through six are "ready-for-publication," individual documents. These papers follow the formatting appropriate for papers submitted to a leading journal and often contain repeated background and methodological information. Each paper contains literature review to establish the validity of the individual topic covered therein. These papers also contain figures and tables, as well as pertinent references, at the end of each chapter (as opposed to the end of the dissertation). Following chapter descriptions is Figure 5 that outlines the organization and goals of this dissertation.

### **Chapter 1: Introduction**

Chapter one outlines the contents and purpose of this work.

### **Chapter 2: Developing Standard Terminology for Innovation Commercialization in Residential Construction**

Chapter two will establish standard terminology for this work through literature review and a discussion of current terminology on this subject. This will not be one of the published articles.

### **Chapter 3: Developing a New Commercialization Model for the Residential Construction Industry**

McCoy, A.P., Thabet, W.T. and Badinelli, R.D. (2006). "Developing a New Commercialization Model for the Residential Construction Industry." *ECPPM Conference 2006 Findings*.

### **Chapter 4: Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction**

McCoy, A.P., Thabet, W.T. and Badinelli, R.D. (2008). "Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction:" *Construction Innovation*, Vol. 8 No. 2, pp. 137 - 155.

## **Chapter 5: Validating a Commercialization Model for Innovation in Residential Construction: Industry Case Study Analysis**

Review and Resubmit Status: McCoy, A.P., Thabet, W.T. and Badinelli, R.D. (2008?). “Towards Establishing a Domain-Specific Commercialization Model for Innovation in Residential Construction Part 2: Industry Case Study Analysis.” *Construction Innovation*.

## **Chapter 6: Understanding the Role of Residential Builders in the Concurrent Commercialization of Product Innovation**

Review and Resubmit Status: McCoy, A.P., Thabet, W.T. and Badinelli, R.D. (2009). “Understanding the Role of Residential Builders in the Concurrent Commercialization of Product Innovation” *European Journal of Innovation Management*.

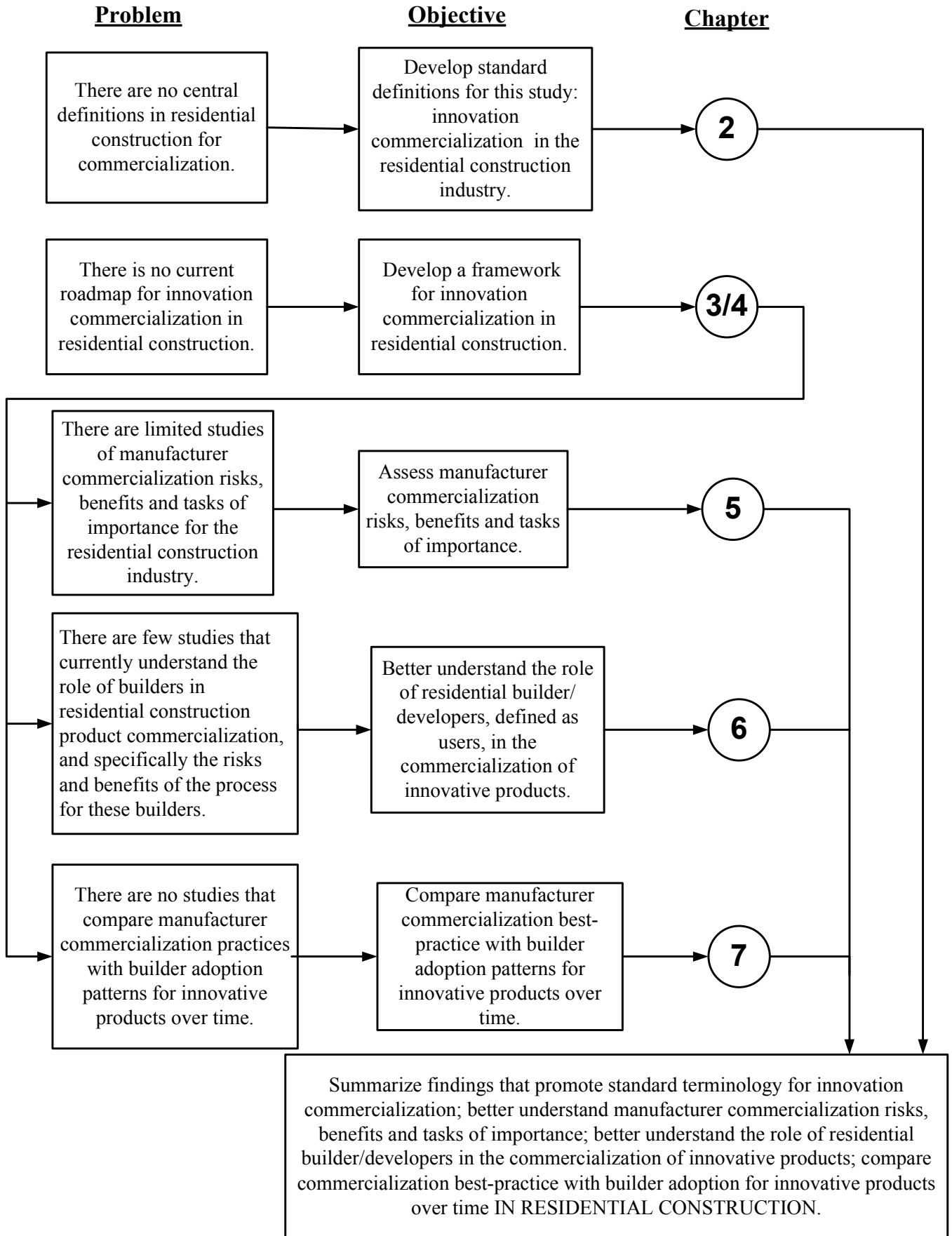
## **Chapter 7: Understanding Concurrent Commercialization for Product Innovativeness Thresholds**

Review and Resubmit Status: McCoy, A.P., Badinelli, R.D., Koebel, C.T. and Thabet, W.T. (2008). “Understanding the Effect of Concurrent Commercialization Practices on Product Adoption Thresholds.” *COBRA: The RICS Construction and Building Research Conference 2008*: Dublin, Ireland. Expanded version for submission to: *Journal of Product Innovation Management*.

## **Chapter 8: Summary**

Chapter Eight will provide a summary of findings for all articles, establishing specific steps, tasks, risks and benefits important for a framework of commercialization in residential construction.

**Figure 5: Dissertation Organization & Goals**



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## Chapter 2 - Developing Standard Terminology for Innovation Commercialization in Residential Construction

### *Introduction*

Also vital to innovation success is the process of defining markets, the focus of innovation use theory and literature. Literature on innovation use primarily tries to understand and accelerate the innovation acceptance process through user behavior. These social behavioral analyses for users of products are the basis of diffusion and adoption theory. Despite much work, recent research confirms that product innovators in the US construction industry still need unique definitions of standard terms for their market (NAHB, 2001). Creating standard terminology is an initial step to creating an industry-specific model.

Current research on innovation behavior often looks at key players on opposite sides of the development process: the developer and the user. Development research studies of innovation typically focus on the manufacturer side and take the point of view of business management. These studies view developers as active *promoters* of an innovation throughout a supply chain with the goal of achieving wide-spread adoption by users. Research topics such as New Product Development (NPD) and commercialization look at the manufacturer side. Studies of innovation use typically focus on behavior and consider it to be a natural process with end users more or less passive *receptors*. Research topics such as Diffusion and Adoption look at the user side of the equation.

Innovation research for residential construction has failed to establish standard definitions of associated terms, though, creating confusion. This confusion further challenges the relevance of certain studies as they pertain to the whole of innovation research. Assembling applicable definitions is therefore important to establishing the standard terminology used for studying innovation in construction. This work establishes terminology central to this study of innovative products in the residential construction industry.

Much of the research that attempts to better understand, and therefore facilitate, manufacturer development relies on theories of business. Commercialization is often confused with the academic topic of new product development (NPD). NPD research generally attempts to better understand and improve specific areas of the product development process for manufacturers. In contrast, commercialization incorporates all of the decisions and supply chain entities required over time for the successful development of a product. This research promotes a new direction for commercialization. The aim of this work is to define commercialization as a universal process that consolidates the disparate strands of literature, both of the manufacturer and user, that each separately studies innovation. The structure of this work is as follows: first, a standard meaning of innovation versus invention is distinguished; second, major areas of innovation research are identified based on both sides of innovation research, including gaps for understanding construction innovation therein; and lastly, commercialization is promoted as an inclusive concept for innovation studies in residential construction.

## ***The Context of Innovation***

The terms invention and innovation have their linguistic roots in the Latin word “innovare,” meaning to “renew, make new or to alter (Souder, 1987).” Through time, application of this original meaning has created additional connotations for the same root. Historically, invention has represented a new product in the stage of concept or idea development (Holmen Enterprises, 2001) or the process of understanding the market for such a new product (Scherer and McDonald, 1988). The invention or the process of inventing is therefore limited to such “fundamental” technical and business functions as: research, feasibility assessment and preliminary market testing and analysis (Holmen Enterprises, 2001 and Scherer and McDonald, 1988). Invention might also be a preliminary, detailed product design or process modeling clearly distinguished from existing arts (Slaughter 1998), but does not become an innovation until it is implemented or institutionalized (Van de Ven, 1986).

Innovation contains different historic beginnings, mostly in Post World War One (WWI) European culture. Alfred Weber began defining innovation for economics in the early twentieth century through “location theory:” optimal industrial factory locations for material and labor supply, consumer access and sharing the potential of resources with other factories, termed *agglomeration* (Hall, 1998). Through *Capitalism in the Twentieth Century*, economic study of Weber’s theory expanded to include the optimal technical and business decisions for industrial growth, often based on central factors. Joseph Schumpeter further argued that profits followed a long business cycle of fifty-five years, requiring new profit generation from innovative technologies. According to Schumpeter, Innovative technologies were reactions to the current system that no longer produced profits; “not inventions, but commercial applications that required the capitalist to collaborate with the entrepreneur” (Hall, 1998). Without innovation, he believed capitalism would not survive its long-cycle depressions of profits from stale technologies. The few, brightest entrepreneurs within the capitalist system were required to transcend existing profits through innovation, making the success of innovation, as a concept, integral to the future health of the commercial environment.

Throughout the last century, research to optimize environments for innovative technology growth (competitive advantage) has evolved traditional terms. In turn, these separated studies have generated their own meaning for innovation, often specifying the term further.

## ***Defining Innovation***

One way to arrive at a useful definition is to rule out what innovation is not: it is not invention (Vaitheeswaran, 2007). New products might be an important part of the process, but they are not the essence of it. These days much innovation also happens in processes and services. Novelty of some sort does matter, although it might involve an existing, outside idea. Innovations also create value through wealth, social welfare or fresh thinking (Vaitheeswaran, 2007). They are commonly studied based on two perspectives: that of the manufacturer or the user. *Manufacturers* are firms or individuals who expect to benefit from selling a product or service and *users* are firms or individual consumers that expect to benefit from using a product or service (Von Hippel, 2005). Either through manufacturer or user influence, innovation requires a standard definition inclusive of all perspectives, while able to respond to the needs of construction. This work therefore defines innovation as the implementation of a novel idea, product or process, for the firm or

individual utilizing it, into actual use. Manufacturers are at the beginning of this implementation process and users, as installers, towards the end.

Manufacturer-based innovation development studies see innovation as both a process and discrete event (Cooper, 2003; Clark and Wheelwright, 1993). Studies of innovation as a discrete event consider attributes of the product for improving the development process (Kuczmariski, 1988; Souder, 1987). Defining a product early might prescribe a better market or development path (Clark and Wheelwright, 1993). Manufacturer-based studies of innovation as a process consider better development through organizational practices (Sexton and Barrett, 2003). Current research topics for manufacturer-based innovation literature include: Concurrent Engineering (CE); Supply Chain Management (SCM); New Product Development (NPD); Knowledge Transfer (KT) and Commercialization. Innovation supply chain also plays a major role in improving manufacturer-based success of innovation (Sexton and Barrett, 2003). The supply chain stakeholders most often associated with studies of manufacturers' development process, besides the manufacturer, are: suppliers, distributors and retailers.

User-based innovation studies attempt to understand individual adopter characteristics or group behavior that might better facilitate acceptance (Sexton and Barrett, 2004; Hickling Consultants, 1989; Slaughter, 1998). Current research topics of user-based innovation literature and theory can be typically considered either Innovation Diffusion or Innovation Adoption. Stakeholders along the supply chain most often incorporated in studies of innovation adoption and diffusion are: developers, builders, code officials and owners. It is important to mention that other entities such as architects, engineers or sub-contractors are considered as part of developer or builder's team and are often studied as such.

Figure 1 examines the manufacturer and user sides of innovation, topics therein, literature and supply chain entities involved in residential construction. Both sides view the process of properly understanding innovation as one method for facilitating product adoption (Souder, 1989; Koebel, 2003).

[Figure 1 here](#)

## ***Innovation Development***

On the manufacturing side of Figure 1, innovation classified as a discrete event might prescribe a new product's development path or understand better markets for a new product. Studies that prescribe innovation process often attribute characteristics that define or limit its development. Innovations that properly respond to markets create new resources, processes or values or improve a company's existing resources, processes or values (Christensen et. al., 2004). For example, innovations for technology markets contain attributes such as *sustaining innovations*, *low-end disruptive innovations* or *new-market disruptive innovations* (Christensen et. al., 2004). *Sustaining innovations* move companies along established improvement trajectories as improvements to existing products on dimensions historically valued by customers. *Low-end disruptive innovations* occur when existing products and services are "too good" and hence overpriced relative to the value existing customers can use. *New-market disruptive innovations* occur when characteristics of existing products limit the number of potential consumers or force consumption to take place in inconvenient, centralized settings. Cagan (2003) classifies innovation according to the amount of knowledge that the

product contains. *Radical innovations* are ideas that have impact on or cause significant changes in whole industry. It provides a brand-new functional capability, which is a discontinuity in then-current technological capabilities. *Incremental innovations*: Small ideas that have importance in terms of improving products, processes and services. They improve the existing functional capability of an existing technology through improved performance, safety, quality, and lower costs. *System innovations*: ideas that require several resources and many labor-years to accomplish. It is a radical innovation that provides new functional capability based on reconfiguring existing technologies. *Next-generation technology innovation* is incremental innovation within a system that can create new technical generations. More recent work creates larger categories for innovation such as *autonomous*, able to be pursued independently from other innovations or *systemic*, benefiting only complimentary innovations (Chesbrough and Teece, 2006), or takes the broadest view, calling innovation “the overall process; creating and applying knowledge to develop new or improved goods, services and processes for public or private benefit Industry (Canada, 2004).” The definitions that drive innovative product development still do not understand unique characteristics of innovative construction products. Discrete views of manufacturer-based innovation for the construction market have previously been characterized as *fundamental*, *adaptive* and *functional*, *direct substitute*, *visible cosmetic* and *invisible innovation* (Hickling Consultants, 1989). None of these discrete views alter previous definitions, though, distinguishing them for the construction industry.

Manufacturers’ organizational culture is important to successful management of innovation as well. Only through the intervention and management of people can an organization realize the benefits of an innovation (Isabelle, 2004). Shaw et al. (2005) describe innovation as “the response to environmental challenges or future opportunities.” Often, the key precipitating environmental factors for innovation are uncertainty, risk and change (Shaw et al. 2005). Even with a successful development process, large gaps in understanding the benefits of an innovation exist for the process of organizations in the construction industry (Sexton and Barrett, 2003). Unfortunately, no studies target manufacturer best-practice specifically for innovative construction products.

Concurrent engineering (CE) is also a methodology for new product design, which has been successfully applied in many industries over the last few decades. Conventional forms of CE are founded on the close cooperation of stakeholders from marketing, engineering and the supply-chain in the design and marketing of a new product as well as the sourcing of its components. The influence of market expectations, needs and wants in the earliest stages of product design is viewed as a cornerstone of CE and the emphasis of conventional CE is on achieving a product design that will be competitive in the marketplace (Miller, 1993).

The construction industry understands the concept of concurrent engineering and has made some strides to incorporate the concept in building design and assembly processes. CE for the construction site has historically been limited to “sample walls,” where a test panel of the final wall assembly is built early in the process by all parties involved to resolve issues of process and quality. A recent advancement in project concurrency is the architect-sponsored extranet, an attempt to coordinate project information early in the process as well, which has largely failed to a lack of client buy-in (Margulies, 2003). The industry still needs a broader view of CE to successfully commercialize products.

## ***Innovation Use***

On the user side of Figure 1, innovation described through product attributes or adopter characteristics attempts to prescribe individual adoption and facilitate acceptance. Rogers (2003) originally defined innovation as “an idea, practice, or object that is perceived to be new by an individual or other unit of adoption.” There are three distinct types of innovations: *Continuous*, *Dynamically Continuous* and *Discontinuous*. *Continuous innovation* is a simple changing or improving of an already existing product where the adopter still uses the product in the same fashion as they had before. *Dynamically Continuous Innovation* can either be a creation of a new product or a radical change to an existing one. *Discontinuous innovation* is a totally new product in the market, where, since the product has never been seen before, there are total changes to consumers buying and using patterns.

In construction research, Holmen Enterprises (2001) referred to innovation from the user’s perspective as “the implementation or adoption of new processes, products or services.” The identification of what is considered “new” often varies, though. In one sense, the use of a product, process or service might be new to a company or individual. Companies and individuals vary in their adoption behavior (e.g., early adopters or late adopters) and the product might not be new to the market. PATH, through National Evaluation Services (November 2002), sponsored research to better define innovation for users in US housing as *graduate*, *mature*, *emerging* and *on the horizon technologies*. Slaughter (1998) examined organizational tendencies while incorporating attributes of the innovation for a market and defined innovation as “the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change.” Five types of innovations that affect state of the art in construction while still relating to construction systems as: *Incremental*, *Radical*, *Modular*, *Architectural* and *System* (Slaughter, 1998). *Incremental innovations* present small change, based upon current knowledge and experience, with impacts confined to the improvement of the specific element or component. *Radical innovations* are breakthroughs in science or technology that change the character and nature of industry and create a new way of understanding a phenomenon. *Modular Innovations* are different than other types of innovation in their region of change. Modular innovation may be developed within organization and implemented with a minimum of negotiation with parties involved in the development and is more significant change than incremental in basic concept but also has limited impacts on the other components. *Architectural Innovations* involve small changes within components but major changes in links to other components and improve performance within components. *System Innovations* are identified through the integration of multiple independent innovations that must work together to perform new functions to improve the facility performance as a whole.

Innovation described through organizational adoption promotes better understanding of inter and intra-firm characteristics. Slaughter’s (1993) earlier work in the residential construction industry considered innovation based on organizational magnitude of change and expected linkage to other industry components and systems. “Gaps in understanding” for organizational areas of innovation study have created a lack of clear definitions throughout the construction literature, though (Sexton and Barrett, 2003).

Organizations within residential construction, not just innovation research, require definition as well. The label “developer” is generally ascribed to managers of land inventories and subcontractors of the assembly process. Builders

are distinguished by their core competency of efficiently managing the assembly process. In many cases of home construction, the developer and the builders are the same business entity and the roles of both of these entities in adopting or refusing to adopt innovation in construction products are very similar. Hence, the use in this work of “developer/builder” refers to a single stakeholder along the supply chain in a commercialization venture. It is this group upon which this work largely focuses.

The world of developers/builders is characterized by de-centralization of resources, knowledge and projects, which often reinforces attitudes of risk aversion. Many homebuilders are small entrepreneurs with informal business plans, organized to minimize exposure from cycles in the industry. Resisting cycles requires these corporations to stay small and nimble, keep inventories low, contract out to specialty subcontractors, and build primarily on contract and use careful accounting. During slow cycles (market downturns), they quickly reduce production and payroll. Few direct employees enable this ability for downsizing or, in the case of a specialty developer/builder, the ability to spread work among many clients.

Developers/builders of a larger size primarily manage land inventories and the assembly process. Many of these firms are closely held and are operated as business ventures, each for a small group of investors who are also managers. For these firms, experience is usually the basis of knowledge and independence is highly valued. Independence drives planning for growth, often reduced due to short-term cash flow for principal owners, rather than long-term corporate development. Investments for future corporate growth are therefore often overlooked or discouraged.

Production builders often embody exceptions to this industry culture. Large land inventories, standardized designs and production processes and an economy of scale are the basis of their business plans. As corporations, they have formal plans that contract for supplies, labor and set expectations of quality and efficiency. Core competencies remain the same: land acquisition, supply chain management and a process that creates a quality product, within budget and on-time.

Of importance is developer/builder’s continued resistance to new technologies due to perceived risks of adoption. Reasons for this resistance are often attributed to uncertainties specific to the industry such as: site variability, one-off nature, longevity of warranties, supply uncertainty and uncertainty inherent in the built environment. Uncertainty is the source of risk and represents the likelihood of the occurrence of an event while risk represents the effects of this event (Pritchard, 1997). This work therefore uses these risks and uncertainties of developer/builders as much of the basis for its research into facilitating innovative product adoption in residential construction. Similar to innovation studies of product attributes, diffusion studies often attempt to categorize innovation based on the characteristics of the market through which they will be adopted. At a basic level, diffusion is the spread of an innovation throughout a social system, according to individual firm adoption decisions that often begin at the time when the innovation is introduced to the market (Howard and Moore, 1988; Robertson and Gatignon, 1986; Feder and Umali, 1993). Previous studies of diffusion of innovative processes or products identified several variables as potentially important determinants of an individual firm’s decision to adopt innovations (Blackley and Shepard, 1996). Rogers’ (2003) *Diffusion of Innovation* explained diffusion as the process by which an innovation is communicated through

certain channels over time among the members of a social system. He developed the most comprehensive application of the diffusion of an innovation, classifying five characteristics that affect an innovation's diffusion (and thus defines the innovations): *Relative Advantage*, *Complexity*, *Compatibility*, *Trialability*, and *Observability*. Innovation is defined by those characteristics that benefit or detract from its market acceptance by a social group (Rogers, 2003).

A key interest in examining diffusion is the rate of diffusion. Most emphasis in current literature and in discussions about these topics is not about developing new products, processes, services, techniques, etc.; it is about their diffusion and their rate of diffusion by users of innovations. This does not mean that companies such as manufacturers that develop new products and equipment are unimportant or unnecessary. They are obviously critical to innovation because they are primary developers of innovations. Some factors affecting diffusion of innovation are called "contingent factors," the factors that can foster or impede innovation diffusion depending on how they are managed or implemented (Holmen, 2001). *Relative advantage* reflects cost, labor, time, and energy savings. Adoption of an innovation is not only related to the existence, size and type of advantage, it is also related to how concrete and how immediate the advantages are. Relative advantages impact directly on the economic, social and psychological risk assessment. *Complexity* of innovation is seen as too risky and incompatible. Simplicity contributes or detracts from a potential adopter's understanding of how the innovation works or of the scientific or engineering principles upon which it is based. Complex products require extensive research and product trials upfront. High or low *compatibility* refers to changing or not changing work habits of builders, trade people, or contractor and end-users. If product does change working habits then product is not considered as compatible and in such case compatibility will impede the process of diffusion. Low compatibility directly affects the risk assessment component of the diffusion process. *Trialability* is directly related to risk perception. Trying a product allows an adopter to evaluate the practical risks involved. If the product performs to the expectations then it facilitates the process of adoption. *Observability (or communicability)* is the visibility of an innovation to potential adapters. This refers to ease of seeing and explaining an innovation.

In residential construction, the ratio of R&D expenditures to value-added for the construction industry as a whole is less than that for most industries (Blackley and Shepard, 1996). Several characteristics peculiar to the structure of the industry are generally cited as reasons for the lack of technological progress: variable or highly cyclical sales, the small average size of firms, the vertical and horizontal fragmentation of the industry, the absence of significant barriers to entry, institutional factors, such as local code requirements and the strength of unionization (Blackley and Shepard, 1996). Barriers to innovation diffusion in the US housing industry vary. Large builders seem to be first to adopt new materials that offer a cost savings, improvement in production process, reduction in call-backs or exposure to liability (Koebel, 2003). Smaller builders are often first to adopt technologies where high consumer awareness of a material exists, the price of the new technology is significantly higher than what it replaces, or if the home construction process must be substantially altered (Koebel, 2003). Homes in geographic areas where homebuyers and builders have an increased awareness of a new technology or find a technology most useful are likely to be first to adopt (Koebel, 2003). Others defined factors that affect the spread of an innovation, or characteristics of the innovation that affect its adoption by end-users, in the US residential construction market (Hickling Consultants, 1989 and Slaughter, 1993). Contractors, owner's, designers and other construction team members have low tolerance for *risk* and will stay away from any

innovation that carries a market risk, a competitive risk and especially a financial risk. If the distributor launching a new product does not have *distributor strength* through prestige and resources, he may not be able to undertake the promotional, advertising and training activities needed and therefore fail to give the push necessary to establish the product on the market. *Trade resistance* occurs when an innovation disrupts a builder's scope of work or schedule. Any product or process innovation has the potential to upset this carefully balanced situation. The approval of any product in the market depends upon *regulatory* resistance and approval from regulatory bodies, which in turn determines the pace of diffusion. It reflects the government's need to set standards in product performance and testing or secondary or delayed effects of product. The high fear of *liability* amongst the small builders is not checked by the communication network (peers) and this results in builders and sub-trades people rejecting innovations for fear that they may lead to unforeseen liabilities down the road. *Government support* or assistance for R & D, demonstration, training, or sales support is an obvious aid to diffusion since it lowers costs, favors communication, reduces risk and increases relative advantage. Finally, consumers have formed strong opinions about certain products and these opinions often constitute *consumer* resistance, affected the purchasing behavior of builders and developers who are unwilling to take market risks or even to spend time and money in the process of educating the consumers. For Slaughter (1993), *Timing of commitment* refers to when the innovation must be introduced into a project schedule, including design and construction. The commitment is the degree to which resources are assigned to the implementation of the innovation when an organization may publicly acknowledge its use of the innovation. *Co-ordination within project team* is the degree to which an innovation requires communication among the members of a project team, including clients, designers, contractors, subcontractors and all contractual parties. Increased co-ordination will act as a barrier. An innovation may require *special resources* (special equipment or trained personnel) and these resources will only exist within specialty companies, which will act as barrier. *Supervision competency* considers the nature of the supervision activities, including the organizational level at which the supervision is required. Since some innovation may require supervision only at the level of the performance task this characteristic will be an accelerator to diffusion of innovation.

The characteristics of adopters and markets still serve as a form of prediction, not necessarily as a roadmap for prescribing success. do not address business actions and decisions

## ***Innovation Commercialization***

Most define commercialization as a phase of the manufacturing process. The phase might have "more to do with taking research and development (R&D) from the lab to the stage where it can find application in an industrial setting (Cornford, 2004)." Sometimes the commercialization phase is specifically placed in the development process, such as a "pilot production" phase, where many units of the product are produced and the ability of the new or modified manufacturing process to execute at a commercial level is tested (Clark and Wheelwright, 1993). At the same time, one must evolve a business structure appropriate to more than just technical development. At the very least, a product development structure must meet the needs for market research, the requirements for capital, and its obligations to government agencies (for example, paying taxes, meeting environmental regulations, keeping records to support patent claims). In addition, it must protect your (and other people's) investment in your technology.

To commercialize an innovation one must do more than just have proper stages of development (Rourke, 1999). One must match technical development to an appropriately synchronized, increasingly sophisticated assessment of both your market and the channels through which your product may reach it. Commercialization includes the full spectrum of activities required to move a new technology, product, or process from its conceptual stage to the marketplace (US Department of Energy, 2005). It is the for-profit stream of innovation, turning knowledge into new goods, services or technologies that are sold in the marketplace (Industry Canada 2004). Commercialization also addresses limits inherent in the process of taking a product to market by defining commercialization as the whole process (PATH, 2001) and is “all of the innovation activities related to the sale of products (goods, services, or processes) when they are sold rather than used (OECD 1993).” Commercialization represents the effective implementation, growth and diffusion of an innovation activity and can commonly be defined in terms of the degree to which it gains good currency and becomes an implemented reality, incorporated into the taken-for-granted assumptions and thought structure of organizational practice (Van de Ven, 1986).

Kuczarski (1988) discussed the need in product development for a road map to frame new product concept development, citing this as one of the more common reasons that impedes risk-taking. In addition, adequate homework and research early in the process are usually woefully lacking in many companies as they don't see the value of investing time up-front; impatience reigns, and failures result (Kuczarski, 1988). Goldsmith (2003) created a "Product Commercialization Model" as a road map to developing strategic plans and actions for the commercialization of technology products. The Goldsmith model combined specific actions required for success, broad phases of process and specific characteristics required for products' success. His model considered commercialization as phases with technical, marketing and business activities that must be considered as you move through the process. The model is a framework to help one develop progress measures, identify information and technical assistance needs, project development costs, and forecast financing requirements. A conclusion to be drawn from a review of other recent commercialization models is that in spite of their differing context and purpose, several common themes appear to be related to successful commercialization (OECD, 1997).

One common theme within the literature is high importance on the early stages of commercialization; if early process is sound then major resulting problems may be avoided. Early “concept definition” is an integral part of any model, usually happening separately while concurrent to other operations (Casto, 1994). It is an integral building block for good practice, similar to what Ginn and Rubenstein's (1986) called the “R&D stage.” The concept definition is not only for the product itself, but for the entire organization surrounding that product and better enables the organization to understand how a product fits its goals, not just the outside market. Casto (1994) also separated concurrent activities through a reiterative loop process. Loops for a commercialization framework are necessary if items along time need to work outside of the larger process, while allowing organizations the ability to continually review the product within the larger product development.

Shaw's (2005) “two tier model of corporate entrepreneurship and innovation” furthers the loop diagram. This strategic framework is similar to other models through a breakdown of the process into distinct stages: Discovery, Opportunity Finding, Application, and Adoption and Diffusion. The framework then allows separate, concurrent actions to happen

along the outside of the main framework; a reiterative loop similar to Casto (1994). This process again offers corporations an ability to review.

The United States Department of Energy (USDOE) innovation process model by Rourke (1999) was created to promote the commercialization of innovative products in the US energy technology industry. While not written for the construction industry, his model divides the commercialization process into three major steps: *Innovation, Entrepreneurial, and Managerial*. Each major step contains separate stages: *Technical, Marketing, and Business*. This work later presents much of these recent models of commercialization in the residential construction industry and defines a framework for better understanding innovative residential construction product success (McCoy et. al, 2008). Commercialization theory and the framework of implementation herein are lacking in the context of residential construction, though. For the residential construction industry, successful commercialization strategy requires not just a sound framework, but shared benefits among all members of a product's supply chain. Once achieved and applied to the larger construction context, a product could be defined as a building site, a building delivery method, non-traditional collaboration strategies and processes or new products.

## **Central Definitions**

Construction innovation literature presents further confusion to the already complex world of innovation research. Commercialization definitions within the business community are equally complex, depending on the context, and do not currently consider residential construction. Unfortunately, scholarly literature is not more consistent in the use of these terms than is popular use (Koebel and McCoy, 2006).

One way to arrive at a useful definition of innovation is to rule out what innovation is not: it is not invention.

Innovation might be defined from both perspectives as "invention plus application (Kuczarski, 1988)." Innovation is the implementation of a novel idea, product or process, for the firm or individual utilizing it, into actual use.

Manufacturers are at the beginning of this implementation process and users, as installers, towards the end. Adoption and Diffusion theory characterize many of the users and markets for innovation success but do not incorporate the larger framework of development. Neither provides standards for innovation development, either. The answer lies in commercialization of products, both as a manufacturing and user-based exercise, as some have hinted.

Applying innovation suggests that innovation is not just a new idea but a way of transforming a new idea into a commercialized product. Commercialization is separate from innovation in that it is based with the sponsoring organization while looking to the user market. Stakeholders must preliminarily prescribe characteristics to products in order to locate a market. The literature provides many avenues for this classification. The market should also be involved in the development process. These stakeholders must also look upon innovation as a multidisciplinary and focused management process that reduces the risks in developing truly innovative ones for the commercial market. The innovation development process often responds to the market in two ways: arising in response to a documented need or demand, referred to as "needs-generated" or "technology pull" innovations; arising from a technical capability, referred to as "means-generated" or "technology push" innovations (Souder, 1987). The development process invariably needs a

purpose. Therefore, the introduction and identification of a new consumer need or the development of additional technology within the market place context through commercialization provides a basis for the integration of terminology for all stakeholders (Shaw et al., 2005; Cornford, 2004).

Integral to residential construction, this work defines developer/builders as a single stakeholder along the supply chain in a commercialization venture. Developers generally manage land inventories and subcontract the assembly process, while builders have as their core competency the efficient management of the assembly process. This work views developers and builders as the same business entity. The roles of both of these entities in adopting or refusing to adopt innovation in construction products are very similar.

Commercialization of innovation requires a broad view of business, while specific to the industry. Commercialization is often considered a process within new-product development, not an expansion of it (Christensen, 2004 and Clark and Wheelwright, 1993). Much of the new-product development business literature focuses on individual best-practice steps of manufacturers or departments such as R&D (Souder, 1987, Clark and Wheelwright, 1993 and Kuczmarski, 1988). In business, some early studies looked at limited views of new product commercialization through the specific lens of R&D/ Production. R&D has often been central for technology innovation through knowledge transfer, but can also resist knowledge transfer, becoming a barrier (Ginn and Rubenstein, 1986). Commercialization, as a broad concept, accepts all phases of innovation development and accepts the larger goal of product acceptance, as shown in Figure 2.

Figure 2 here

This work define commercialization as the coordinated technical and business decision processes (and resulting actions) required for successful transformation of a new product or service from concept to market adoption. This work also considers commercialization as the coordinated execution of all processes required for product innovation success from a developed state to implementation within a given market.

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Figure 1: Innovation and Commercialization Studies

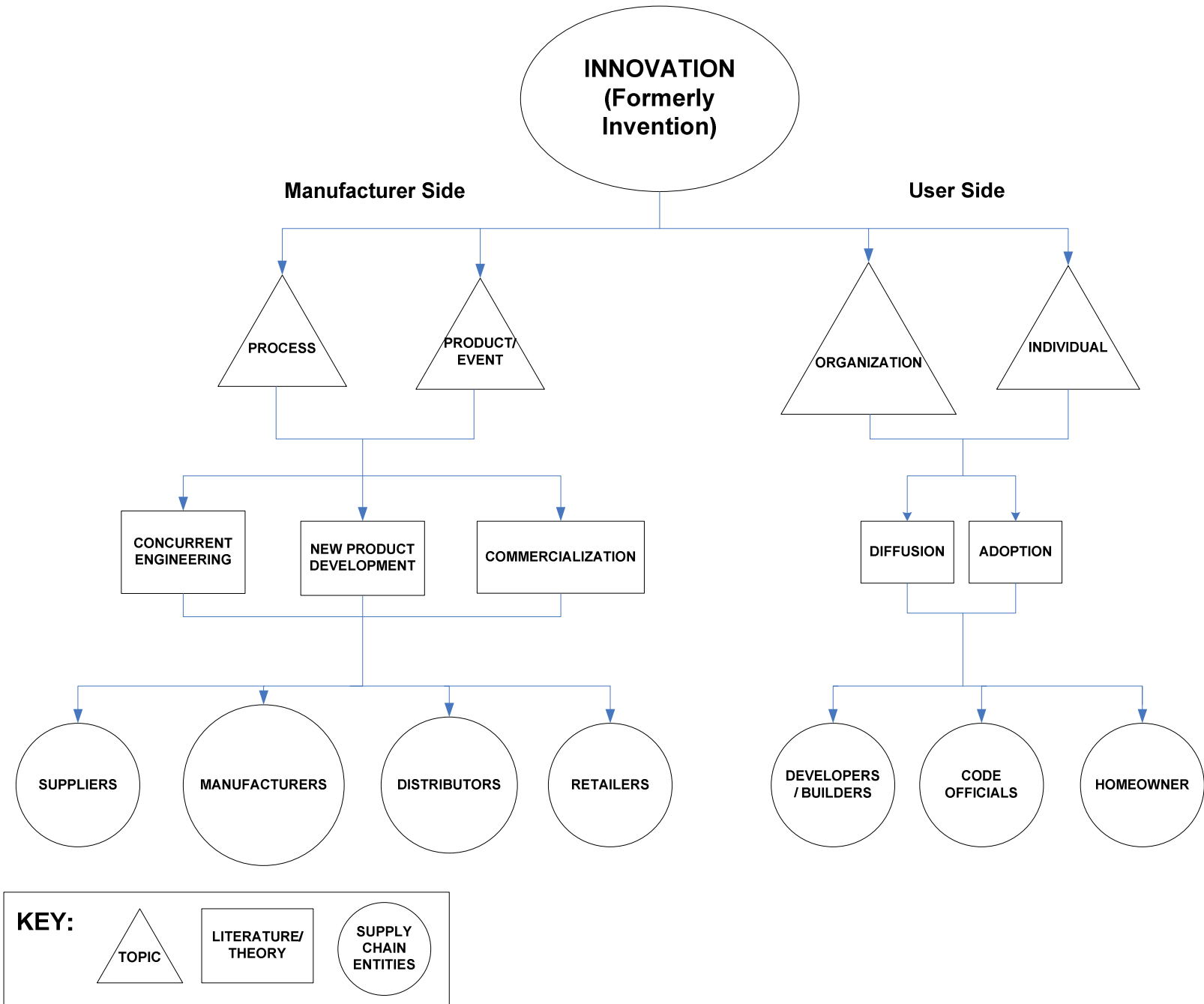
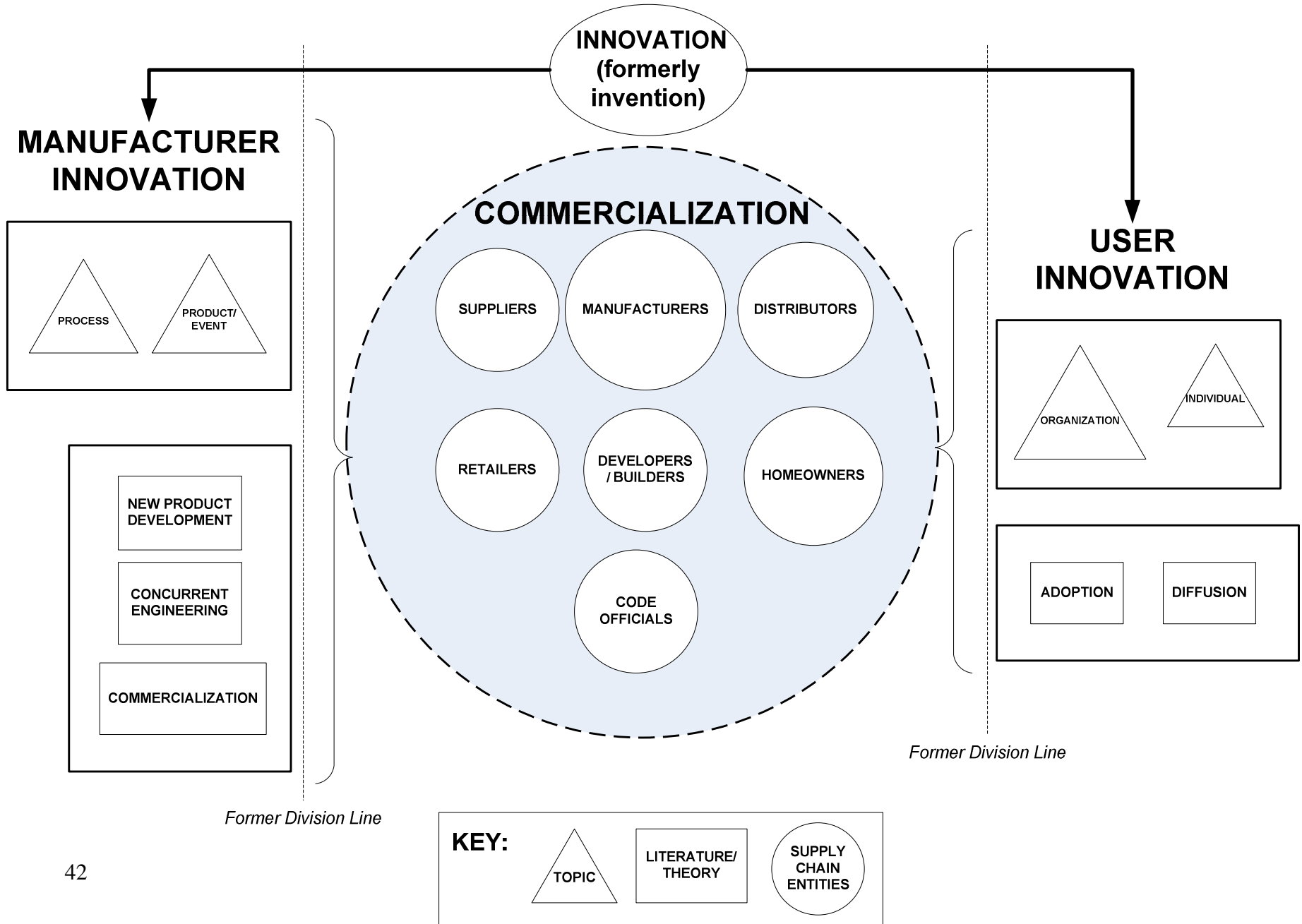


Figure 2: Commercialization of Innovation



# Chapter 3 - Developing a New Commercialization Model for the Residential Construction Industry

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**ABSTRACT:** We describe the development of a new model of the commercialization of innovative products in the homebuilding industry. Our research is motivated by previous HUD-sponsored<sup>2</sup> studies of numerous failures of entrepreneurial business ventures in the commercialization of such products, which were caused primarily by poor business strategies. The general approach to our model-building effort consists of three stages: we derive a generic commercialization model from the research literature in business, construction, and concurrent engineering; we derive a classification scheme for innovative products from literature on innovation in product design; we derive a set of specific alterations to our commercialization model in order to reflect the unique challenges of construction products from case studies of innovative products in the homebuilding industry for which commercialization has succeeded or failed.

## Introduction

This paper presents the initial stages of the development of a new roadmap for the commercialization of innovative products in the construction industry. It is the aim of this work to promote a set of model-based decision rules and decision support systems that will increase the acceptance of innovations in the residential building market and aid the acceptance of new technology in the construction industry.

There are several different interpretations of commercialization. For example, some view commercialization as the process of developing an idea to the licensing of that idea (Gully,

2004). Others, including the authors of this paper, define commercialization more broadly as the process of developing a business enterprise from an idea, through feasibility and implementation, to its acceptance into a market (USDOE 1999, Goldsmith 2003).

Commercialization models describe the sequential decision process of coordinating and optimizing all of the technical and business decisions required by the successful introduction of a new product or service to the marketplace. A successful commercialization model serves as a roadmap, promoting solutions to questions and problems that arise along the path of commercialization. Our research is directed at developing such a roadmap.

The general approach to our model-building effort consists of three stages:

6. We derive a generic commercialization model from the research literature in business, construction, and concurrent engineering
7. We derive a classification scheme for innovative products from literature on innovation in product design
8. We derive a set of specific alterations to our commercialization model in order to reflect the unique challenges of construction products from case studies of innovative products in the homebuilding industry for which commercialization has succeeded or failed.

## Commercialization Modeling

Throughout the world, innovation is viewed as a critical factor in the future health of the construction industry. Hence, there is universal interest in successful commercialization of innovative construction products. In particular, the United States is on the verge of becoming either a net importer or a net exporter of construction materials. The success of small-sized, limited-resource innovators will be key players in the success of the construction industry and the US national economy.

A useful reference for developing a general commercialization model is, *From Invention to Innovation*, published by the United States Department of Energy (DOE, 1999). This

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<sup>2</sup> The views expressed in this paper are those of the authors and do not necessarily reflect those of HUD or NSF.

document was created to promote the commercialization of innovative products in the energy technology industry. Although it was not written for the construction industry, the US DOE's work offers many elements of a universal commercialization model.

Early in its paper, the USDOE offers a commercialization model in the form of a table. They divide the commercialization process into three major functions: Technical, Marketing, and Business. Next, three major stages of these functions are proposed: Innovation, Entrepreneurial, and Managerial. The innovation stage occurs early in the commercialization process and accomplishes the design of an innovative product or process, market analysis and the strategic business plan. The entrepreneurial stage comes next and finalizes all essential elements of the commercialization plan including the product design, the structure of the supply chain, the pricing and promotion plan, the securing of financing and the satisfaction of regulatory requirements. The managerial stage is the final stage of the commercialization process and executes the initial production, distribution, sales and installation of the product.

The US DOE commercialization model divides each of the three major stages of commercialization into several more detailed sub-stages. Further detail on the various stages and steps is explained in terms of action items with a definition of terms placed at the end of the DOE report for clarification. The DOE model offers us a framework for a commercialization model. Our adaptation of the DOE model is shown in Table 1.

Goldsmith (2003) also produced a commercialization model as part of the Arkansas Small Business Development program at the University of Arkansas. Dr. Goldsmith presents on his website a version of a commercialization model outline that is promoted as a universal solution for the advanced technology industry. According to him, "flexibility, quickness, and information are critical to success."

He first divides the commercialization model into three major categories: Technical, Marketing, and Business. Under this model the three main stages of commercialization are the Investigation Phase, the Development phase and

the Commercial phase. Like the US DOE model, Goldsmith's model has distinct sub-stages within which he places action items to show the commercialization process.

Goldsmith describes the separate action items in detail through website pages that link descriptions of each sub-stage to the overall commercialization model. In these descriptions Goldsmith provides the actions, critical term definitions and milestones. His model "does not provide the answers, it helps to ask the right questions."

Bell Gully oversees an international law firm that supports the development of new IT business ventures (Gully, 2004). His objective is to explain early stages of commercialization as a vehicle for having an idea protected and licensed for use by others. Accordingly, his commercialization model offers a breakdown of only the early stage of the commercialization process. In this model, no technical side is presented. However, like other models described in this paper, the Gully model uses a diagram to show the sequence of sub-stages in the commercialization process. The main parts of the process are: Idea, Protection and Development of the Idea, A Decision to Sell or Not, Growing the business, and Beginning the Process again.

The first few steps of the Gully model are similar to those proposed in the first stage of the Goldsmith and US DOE models. However, the Gully model image is not linear, but circular, reflecting the concept of a regenerative lifecycle of an innovation.

For each sub-stage of the commercialization process, Gully presents a final synopsis that offers "steps to success." The steps are the consistent elements that can properly be compared with those of other models. For example, growing the business steps of success include: Picking the right Partner, Giving away only the rights others may need, making all deals a win-win situation, Joint Venturing, Addressing ownership, Using local expertise and assistance, and Taking risks. Each of these "steps to success" contains further definitions and terms relevant to other models.

Since commercialization models are not available for the construction industry, other industry commercialization models have

provided us a basis for a generic commercialization model. Consolidating our review of these models into one, universal form results in the generic commercialization model shown in Table 1. With the help of case studies from the construction industry, we will adapt this model to the industry.

The commercialization model consists of several phases that are consistent with the other industry models studied: a beginning idea phase, a second investigatory stage, a third production stage, and a fourth stage of acceptance into the market. Each phase has unique characteristics and some phases require more detail, which becomes a sub-phase called a stage. Each phase or stage represents a period of time indicated by sequence numbers, 1-8. The deliverables of each stage of the commercialization model are also a compilation of consistent outcomes required in other industry models. Each cell in this model reflects a broader view of the same cell in Table 2.

Our review of literature shows that a generic commercialization process can be broken down into three components: Technical, Marketing and Business. One obvious difference in our commercialization model is that the cells labeled “business” in Table 1 have been expanded to reflect the large number of different tasks that cannot be easily grouped under one description. Therefore, a cell like “accounting and legal” has its own separate set of deliverables through the process of innovation in Table 2. Eventually, all cells of Table 2 will become a separate, detailed diagram of commercialization along our roadmap. The detail of this roadmap is dependent on the amount of information available through literature and case studies related to each cell.

NUMBER		1	2	3	4	5	6	7	8
PHASE	IDEA/ INVESTIGATION	INNOVATION			COMMERCIAL			ACCEPTANCE	
		(early)	(middle)	(late)	(early)	(middle)	(late)		
STAGE	(none)	Feasibility	Planning	Innovation Review	Early Production	Design Review	Full Scale Production	(none)	
T	TECHNICAL	Concept Analysis	Technical Feasibility	Technical Prototype	Pre-Production Prototype & Test Prototype	Production Prototype & Testing	Product Feedback & Re-design/ Refine	Full Production	Support Production & Research New Products
B	MARKETING	Market Assessment	Strategic Marketing	Marketing Plan Development	Marketing Validation	Marketing Plan Implementation	Product Expansion & Analysis	Revise Marketing	Diversify Markets
	BUSINESS	Business Assessment	Economic Feasibility	Strategic Business Plan	Business Plan Validation	Begin Business	Realize Product's Cost of Doing Business	Refine Business	Continue Refining Business

**Table 1: DOE Commercialization Model**

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PHASE	IDEA/ INVESTIGATION	INNOVATION			COMMERCIAL			ACCEPTANCE	
		(early)	(middle)	(late)	(early)	(middle)	(late)		
STAGE	(none)	Feasibility	Planning	Innovation Review	Early Production	Design Review	Full Scale Production	(none)	
	1	2	3	4	5	6	7	8	
TECHNICAL	T	The innovation is defined in a succinct statement	Mockup: demonstrates relationships of parts, physical and illustrated	Working Model: demonstrates the connections and motions of the parts, physical	Engineering Prototype: demonstrates important design parameters (3T); reliability, speed, and accuracy	Production Prototype: meets performance standards, resolves production problems, illustrates quality control standards	Verifies that product is ready for full scale production.	Innovation production and all the related process necessary is up and running	Field and innovation production support, looking for new or supporting innovations to commercialize
	← APPLY CONCURRENT ENGINEERING PRINCIPLES →								
BUSINESS	M	Identify a potential market for the idea. Succinct investigation of market acceptability	Perform market research, market segmentation & product definition	Forecasting & diffusion planning, Advertising & promotion planning	Test marketing plan	Initial sales, promotion & advertising management	Revise marketing plan, product definition & diffusion plan	Sales, promotion & advertising management	Marketing Support. Look for new or supporting innovations in the field.
	Fin	Succinct description of financing options	Capital sourcing analysis	Determine capital configuration. Develop capital plan. Perform capital costing & risk analysis.	Test capital plan. Develop working capital management plan.	Capital acquisition. Working capital management.	Revise capital configuration. Revise capital plan	Manage financial resources	
	Ops	Succinct description of operations models & options	Capability sourcing & Supply-chain analysis	Supply-Chain Design. Capacity & operations planning	Pre-production run	Initial operations management. Measure supply-chain performance	Revise supply-chain design. Revise capacity & operations plan	Operations management	
	HR	Succinct description of human resource options	Labor sourcing analysis	Staff planning. Develop hiring/ development/ promotion plan. Perform labor costing & HR timing	Test staffing & HR plans	HR recruitment & development. Initial HR management	Revise staffing & HR plans	HR management	
	IT	Succinct description of information technology options	IT research	IS design. Develop IS implementation plan	System testing	Initial IS implementation & supervision. Measure system performance	Revise IS design. Revise IS implementation plan	IS management & supervision.	
	A&L	Succinct description of accounting & legal options	Research regulatory requirements	Design liability protections and accounting standards. Design accounting procedures	Review of protection and standards by external certifiers	Initial accounting activities. Accounting audit	Revise protection & standards. Revise accounting procedures	Accounting activities	

**Table 2: Construction Commercialization Model**  
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### ***Classifying Innovations***

The factors identified by many authors that influence innovation in housing products are common characteristics that accelerate or impede the process of diffusion of innovation. Characteristics of diffusion that improve the acceptability of innovations are considered accelerators.

Characteristics of diffusion that hinder the acceptability of innovation are considered barriers.

There are many such characteristics that affect innovation in construction. Holmen Enterprises (2001) identify five factors affecting the diffusion of innovations, called “contingent factors”: Relative Advantage, Complexity, Compatibility, Trialability, and Observability. Across the population of commercialization cases, each of these factors can be an accelerator or a barrier, depending on its value relative to competing market offerings. We now define these factors in the context of the construction industry.

The relative advantage of an innovation in the construction industry reflects the cost, labor, time, and energy savings that are associated with the innovation. Adoption of an innovation is influenced not only by the size and type of relative advantage, but also by how concrete and how immediate the advantages are. Relative Advantage has direct impacts on the economic, social and psychological risk of innovation diffusion.

The complexity of an innovation in the construction industry, measured relative to competing products or processes, indicates the degree of risk or incompatibility of the innovation. Complex products require extensive research and product trials upfront.

High or low compatibility of an innovation in the construction industry refers to the degree to which work habits of builders, trade people, or contractors and end-users must change in order to adopt the innovation. Low compatibility is directly related to the perception of the risk of adoption.

High trialability of an innovation in the construction industry allows a potential adopter to evaluate the practical effects of adoption without risk. If the innovation performs to the user's expectations then it facilitates the process of adoption.

Observability of an innovation in the construction industry is the degree to which the innovation's advantages are apparent to potential adopters. For example, innovations that are seen on a home's exterior are highly observable and this observability acts as an accelerator to commercialization. The commercialization of products that are more integrated into a structure or system is hindered by their low observability.

A different representation of innovation is provided by Slaughter (1998). Slaughter identifies four fundamental characteristics of innovation: Timing of Commitment, Co-ordination within the Project Team, Special Resource Requirements, and Supervision Competency.

Timing of commitment refers to a time within a construction project schedule when the innovation must be introduced. For the purpose of this discussion the project schedule includes all activities from the initial concept to the implementation, including design and construction. The timing of commitment is measured in terms of the degree to which project resources are assigned to the implementation of the innovation, or, when an organization must publicly acknowledge its use of the innovation.

Co-ordination within the project team is the degree to which an innovation requires communication among the members of a project team, including clients, designers, contractors, subcontractors and all contractual parties. In the construction industry, increased co-ordination requirements will act as a barrier.

In some instances, the use of an innovation may require special resources, such as special equipment or trained personnel, and these resources will only exist within specialty companies. If the resource is difficult to obtain, then this will act as a barrier.

Slaughter's supervision competency considers the organizational level at which supervision is required for the innovation to be implemented. For an innovation that requires supervision only at the level of specific task performance supervision competency is a relative accelerator of commercialization.

James Hickling Consultants (1989) identify characteristics of technology transfer and innovation. Among those not mentioned previously are: Risk, Distributor Strength, Trade Resistance, Regulatory Resistance, Liability, Government Support, and Consumer Resistance.

According to Hickling, contractors, owner's, designers and other construction team members have low tolerance for risk. They will stay away from any innovation that carries a market risk, a competitive risk and especially a financial risk.

Distributor Strength refers to the prestige and the resources of a distributor. These strengths make them able to undertake the promotional, advertising and training activities needed for successful commercialization. Many commercialization efforts fail because distributors are unable to provide the push necessary to establish a product in the market.

Trade resistance occurs when an innovation disrupts a builder's scope of work or schedule. Any product or process innovation has the potential to upset the inertia of trade practices.

Regulatory Resistance is the cost and time required to obtain approval of a product from regulatory bodies. This approval often determines the pace of diffusion and reflects a local or federal government's needs to set standards in product performance through testing and certification.

Liability reflects the increasing fear among builders of the downstream legal liabilities that can accrue from an innovative product or process. Liability results in builders and trades people rejecting innovations for fear that they may lead to unforeseen penalties.

Government Support comes in the form of R&D assistance. Testing, development, demonstrations and training are aids to commercialization since they lower costs, promote communication, reduce risk and increase relative advantage.

Consumer Resistance results from strong opinions among end users about certain products. These opinions affect the purchasing behavior of builders since consumers are their immediate customers. Builders are unwilling to adopt innovations that are not embraced by their customers.

Based on a review of these three papers, we can see that a long list of factors contribute to the success or failure of a commercialization effort. Our compilation of these factors reveals many shared characteristics. Through an ad-hoc factor analysis we consolidated the set of influences on innovation.

We reduced the set of characteristics to the following eleven factors: Timing of Commitment, Compatibility, Simplicity, Trialability, Observability, Trade resistance, Consumer resistance, Regulatory resistance, Supporting Innovation, Relative advantage, and Co-ordination within project team. Again, based on the literature review, these characteristics have individual definitions and do not overlap in meaning. Each characteristic contains the same meaning explained earlier.

### Commercialization Modeling in Construction

The Partnership for Advancing Technology in Housing, or PATH, is another US Government agency that is interested in innovation. PATH's report, *Commercialization of Innovation: Lessons Learned* (PATH 2001), contains case studies of the commercialization of EIFS and I-Joists through which barriers and accelerators of innovation are identified. In other words, PATH offers no model with the specific stages and phases as described before, but rather analyzes the commercialization of real products through these stages. The PATH case analyses provide estimates, for each innovation, of the value of each of the five factors defined by Holmen. From these estimates, we can see how each factor served as either an innovation accelerator or barrier in each case. See Table 3. Also in the table are

			1	2	3	
	A / B	Timing of Commitment	Compatibility & Special Resources	Complexity / Simplicity		
7	I-Joists	B		Special resources needed as product required new manufacturing processes.	Simple to install, not simple to integrate into the housing system.	2T 3T
	I-Joists	A	I-joists were extensively studied and promoted before anyone tried to use them. Data logs mean no time commitment.	Functional compatibility advantages over predecessors in providing strength, increasing spans, decreasing the number of framing members, and reducing needed wood quantities.		3T 6T
8	EIFS	B			Complexity problems arose when different manufacturers made different versions of the same product. There was no industry consistency.	3T 7T
	EIFS	A	Adapters did not need to spend time figuring out product since it was already used in europe.	Very compatible because it integrated the functions of insulation, sheathing and exterior finish into one product. No special resources. Very complementary.	Not complex, but Simple by reducing set-up time of house assembly and eliminating some of the separate trades involved.	2T 3T

**Table 3: Factor Measurement Sample**  
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pairings such as “3T.” These are references to specific stages of our commercialization model, which we described earlier.

We extended the analyses of the PATH study to a larger set of innovation cases and performed the analysis of each case in terms of our set of eleven innovation factors: timing of commitment, compatibility, supporting innovation, simplicity, trialability, observability, relative advantage, consumer resistance, trade resistance, regulatory resistance and coordination within a project team. Case study literature such as [www.toolbase.org](http://www.toolbase.org) provided real-world examples of products’ accelerators or barriers for commercialization. For any product the value of each factor may indicate an innovation accelerator or barrier.

Our data for the factor measurements (estimates) are the answers to a list of questions about a specific set of demands that must be satisfied if an innovation is to accelerate the commercialization process. This list of questions was defined prior to the analysis of cases and was applied consistently to all cases. Below is a sample of typical questions.

#### Timing of Commitment:

1. If implemented in the middle of a project, will it affect the building schedule?
2. Does decision of implementing innovative product have to be taken at design stage?
3. Is a delay in the schedule caused by implementation of this innovation?

#### Compatibility/ Special Resources:

1. Is a change in the work habits of tradesman people required?
2. Does innovative product show compatibility advantages over a predecessor product?
3. Is the innovative product more efficient in material or time?

#### Complexity/ Simplicity:

1. Is implementation into building structure easily accomplished?
2. Is training required for implementation of product / technology?
3. Is extensive planning upfront necessary for application of the innovative product?

In these characteristic questions, an answer of “yes” implies that the factor is an accelerator and an answer of “no” implies that it is a barrier. Once placed against the steps and stages of the generic commercialization model shown in Table 2, the estimates of the innovation factors allow us to sharpen the general descriptions of the commercialization steps in the models in terms of the specific challenges of innovations in the residential construction industry.

### ***Continued Research in Commercialization of Innovations***

This collection of case studies is ongoing. Interviewing persons with experience in commercializing new construction products is our next step in refining the commercialization model and understanding where barriers and accelerators exist. Detailed interviews will reveal how innovation corresponds to our proposed model.

Our interviewing process first asks a contact to respond to basic questions about his/her definition of innovation. Next, we ask each respondent to describe the commercialization process. Respondents are specifically asked to note barriers and accelerators along this process and, most importantly, to identify the most critical stage and offer reasons for this identification.

Interview comments are then identified and plotted onto a commercialization chart based on the research team’s view of their relevance to each stage of the commercialization process. The contacts are sent the findings and asked for their opinion.

If the contacts are not interested in a phone interview or prefer to be involved in the research on their own time, a blank model can be sent to them for their review. In this case, they may write the research team with comments about barriers and accelerators or short phone calls can express their opinions, as they have already collected their thoughts.

Our research team is, naturally, always looking for new ideas on commercialization. Therefore, another ongoing step is an extended literature review. Articles are read, summarized into a shorter version and then placed into a model where the team sees their relevance.

## **Acknowledgments**

This research is supported by NSF Grant # CMS-0533322, *Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market*. The authors wish to acknowledge the contributions of Professor Ted Koebel, Neeraj Gadgil and Mansi Garware, without whose work this paper would not have been possible.

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# Chapter 4 - Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction \*

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**ABSTRACT:** Throughout the world, innovation is viewed as a critical factor in the future health of the construction industry. There is universal interest in successful commercialization of innovative construction products. This paper focuses on the United States, which particularly is on the verge of becoming either a net importer or a net exporter of construction materials. US small sized, limited resource innovators will be key players in this balance. Recent failures of entrepreneurial business ventures in the commercialization of such products suggest the potential benefit from a unique model for construction industry commercialization. This paper offers such a model that outlines phases and functional areas for technical and business best practices in getting innovative products to market. The overall research approach consists of five steps separated into two main phases. Phase one comprises 1) defining innovation and commercialization for the residential construction industry; 2) reviewing literature from generic commercialization models; and 3) establishing a new generic commercialization model for innovative construction products from such literature. Phase two comprises 4) capturing qualitative and quantitative knowledge from construction industry experts; and 5) developing a domain-specific commercialization model for the residential industry based on these inputs to reflect the unique challenges of construction products. This paper discusses phase one in full. It also describes work under phase two by presenting the results and analysis of one case study. It concludes with a discussion of current work being developed under phase two and future directions of the research.

**KEYWORDS:** ADOPTION, DIFFUSION, INNOVATION, COMMERCIALIZATION, RESIDENTIAL CONSTRUCTION

## ***Introduction***

Advances in innovative technology are widely regarded as major sources of improvement in the competitive position of firms and industries and major factors for increased national economic growth and standards of living (Porter, 1985). Innovation is increasingly becoming a key factor to productivity growth, given changing demographics, intensifying global competition, and accelerating technological change. It is also a generator of social value through production of goods and services that create safer communities, better health care and improved education, for instance (Conference Board of Canada,

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\* This research is supported by NSF Grant # CMS-0533322, *Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market*. All opinions are those of the authors and not NSF or HUD. The authors wish to acknowledge the contributions of Dr. C. Theodore Koebel, Akshat Nayyar and Sean Wilson, without whose work this paper would not have been possible.

2004). At least two key elements are required to achieve national economic growth: technological innovation, which must be transformed into commercially successful products, and services that meet customers' needs, and small technology-based startups, which must grow into medium to large viable enterprises that can successfully commercialize the new technology. (Conference Board of Canada, 2004).

Getting an innovation into the market requires more than just developing something that works. The technical development, or *invention*, must be matched to an appropriately synchronized, increasingly sophisticated assessment of both the potential market and the channels through which the product may reach it. At the same time, an appropriate business structure must evolve to support the different technical and marketing stages of the invention, while also protecting the inventors' investment in technology. This coordinated linkage of technical and business steps that develop a new technology for a given market comprises the commercialization of the innovation (Rourke, 1999).

Adoption of new innovative products in the residential construction industry is often hindered by challenging characteristics unique to the industry (Moavenzadeh, 1991; Slaughter, 1993a; Toole, 1994 and 1998; Toole and Tonyan, 1992). Among others, site variability and the one off nature of construction are characteristics which resist industry adoption (Koebel and McCoy, 2006). Innovative technologies nevertheless offer the potential for competitive advantage through new product and process technologies that can improve effectiveness of designs and efficiency of construction operations.

Complexities within the construction industry also make introducing these innovative technologies difficult. For example, each technology may have to be compatible with numerous parties (Koebel, 1999; Hassell *et al*, 2003; Toole, 2001). Some commonly accepted factors affecting adoption are firm characteristics; tasks/activities associated with using new products and materials; a firm's perceived benefits; a firm's market and competitive strategies; size of builder; competition; business cycles (growth, payback, and downturns); and fragmentation (Koebel *et al*, 2003, Hassell *et al.*, 2003). In addition, uncertainty could be the main factor hindering adoption (Toole, 1998).

The recently conducted innovation barriers workshop (Koebel, 2004) demonstrates that companies using PATH (Partnership for Advancing Technology in Housing) technologies are faced with heretofore unrecognized difficulty in getting products to market. All building product manufacturers must overcome problems inherent in completion of assembly, installation, and integration – “closing the deal” – at the building site. These are magnified for the small/limited resource innovators because of diffuse early demand and perceived risk. Many, if not all, limited resource innovators are denied access to traditional homebuilding product supply channels and must create their own.

This paper describes ongoing research motivated by findings from a recent National Science Foundation (NSF) workshop addressing barriers to technology transfer in the US housing industry. The

2004 NSF workshop found residential technology diffusion as one barrier to current technology transfer (Koebel, 2004). The research responds to this finding through the development of a unique model for commercializing innovative products in the residential construction industry. The work presented herein was motivated by recurrent failures of small sized, resource limited developers of new homebuilding products in bringing these products to market quickly and effectively. The diffusion of new homebuilding techniques and the growth of new industries in the provision of construction materials are stifled by these failures.

Commercialization models (e.g. Goldsmith, 2003) describe the sequential decision process of coordinating and optimizing all of the technical and business decisions required by the successful introduction of a new product or service to the marketplace. A successful commercialization model serves as a process roadmap that promotes solutions to questions and problems that arise along the path to market. Currently, the construction industry has no model unique to construction market characteristics. This paper is primarily directed at developing such a model for the construction industry.

The general approach to building such model consists of five stages that are presented in this paper:

Phase-1:

- 1) define commercialization and innovation for the residential construction industry;
- 2) review literature from other industry commercialization models;
- 3) establish a new generic model (or framework) for innovative construction products from such literature;

Phase-2:

- 4) capture qualitative and quantitative construction data and knowledge from industry experts;
- 5) redefine our generic model and develop a domain-specific commercialization model for residential industry based on these inputs, reflecting unique challenges facing construction products.

The process for developing such a model requires a preliminary framework with open architecture to accept multiple forms of data. Once accepted, these residential construction, case-specific data transform the framework into an increasingly domain-specific adaptation of the original version. This paper captures only one such input and its effect on commercialization of innovation in residential construction. It will offer the effects of further inputs in following publications.

## ***Innovation and Commercialization***

Studies on innovation and commercialization in various industries have failed to create universal definitions of these terms. A roadmap requires these definitions as a strong basis for analysis.

Understanding central themes is important, however, as a basis for establishing such definitions. The central themes of innovation are based on diffusion and adoption theory, while commercialization is based on theories of business. Innovation diffusion theory attempts to explain the characteristics of social groups that affect the acceptance of a product. Innovation adoption theory attempts to further explain the characteristics of individuals within those social groups that affect the acceptance of a product. Sometimes confused with new product development, commercialization explains the actions and decisions required in getting the product to a given market. Historically, innovation research has taken the point of view of social scientists who consider adoption of innovation to be a natural process and adopters as end users who are more or less passive *receptors* of innovative products. By contrast, commercialization research has taken the point of view of business management which views commercializers as active *promoters* of an innovation throughout a supply chain with the goal of achieving wide-spread adoption by end users.

The addition of construction innovation literature presents further confusion to the already complex industry. Commercialization definitions within the business community are equally complex, depending on the context. Unfortunately, the scholarly literature is not much more consistent in the use of these terms than is popular use (Koebel and McCoy, 2006).

Isabelle (2004) provides an integrative definition of commercialization as the “process of translating research knowledge into new or improved products, processes and services, and introducing them into the market place to generate economic benefits.” Cornford (2004) defines innovation as a “continuous stream of commercially relevant ideas”, and commercialization as “generation of local wealth with them” with success determined by the quality of linkages between the two. More specifically, Cornford (2004) defines commercialization as “...having more to do with taking research and development (R&D) from the lab to the stage where it can find application in an industrial setting. Actually using this know-how to develop a new product would be innovation”. In establishing a definition, this research also needed an understanding of industry concepts and characteristics.

Previous research on innovation in project based organizations claimed that companies that made a transition from hierarchical (functional) organizations to project organizations suffered setbacks in systemic innovation adoption (Gann, 2000). However, these studies did not separate the influence of transitional disruption from organizational structure. Other literature focused on communication, change management, coordination issues and organizational characteristics (Taylor and Levitt, 2005 and Widen, 2006). The focus of the current paper is the challenge of building a business plan for commercialization. This research does not discount the organizational factors inherent in a project organization that may inhibit innovation. However, over-riding these concerns is the need for a sound business plan. This paper and research are directed at this latter problem.

The work of Taylor & Levitt (2005), and Widen (2006) was part of a body of research which viewed adoption as a largely behavioral issue so that the decision-making steps of knowledge, persuasion, decision, implementation and confirmation were influenced by attitudes. This paper does not contradict this view. However, it brings to bear an additional consideration on adoption decision making: the last six decades of decision modeling research and business process improvement, which has demonstrated that model-based decision support, can leverage a decision maker's intelligence, remove emotional biases and make tradeoffs that are too complex or too computationally burdensome for an individual or an organization to make. Models are particularly essential to understanding commercialization, as opposed to adoption, as the former process is driven by business decisions that succumb to normative analysis while the latter process is more appropriately studied via behavioral analysis.

Innovation adoption literature mostly describes end-user behavior. The construction industry presents unique challenges to product adoption due to site variability and the one-off nature of construction projects. Site variability refers to differing conditions due to site location and one-off nature refers to the differing nature of each product on a site. Site variability means that construction occurs at a point in the supply chain where it might be more difficult to understand the benefits of an innovation (Sexton and Barrett, 2004). Furthermore, construction supply chains to each site additionally complicate variability by tending to isolate any knowledge associated with the innovation that is discovered on-site. The construction site is at the end of the supply chain and new, project specific knowledge does not generally flow upstream.

Large manufacturers and distributors complicate this process by often resisting a reverse-transfer of knowledge and by protecting their competing products through patents, trademarks and copyrights (Rourke, 1999). When occasionally successful, tacit knowledge transfer upstream is considered public, non-proprietary information. Furthermore, two step distribution channels transfer knowledge from one client to another, allowing later adopters to wait for new knowledge, instead of acquiring it for themselves.

The one off nature of construction projects ensures that differing site conditions per project require new processes or products in support of project goals. A production homebuilder will often resist new products due to the risks involved, creating an incentive for applying known good practices and not embracing change. The application of core competency is considered a valued attribute (Toole, 1998). The financial benefits of improved performance of a builder due to innovations are generally passed on to the end user. Therefore, the construction supply chain has a uniquely problematic link one step before the end user in the form of builders who are predominantly resistant to change.

Diffusion literature often describes markets, or group behavior surrounding a product. Rogers (2003) develops the most comprehensive look at the diffusion of an innovation. This application, at its

basic elements, contains five characteristics that affect an innovation's diffusion (and thus defines the innovations): *Relative Advantage, Complexity, Compatibility, Trialability, and Observability*. An innovation, for Rogers, is defined by those characteristics that benefit or detract from its market acceptance by a social group. Rogers' (2003) does not consider the complexities of the residential construction industry, though.

Slaughter's (1998) work does consider the industry and is most accepted in construction industry discussions: "Innovation is the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change." This paper defines innovation as a novel product whose inherent criteria define non-trivial change in an institution's process. This use of a broad definition attempts to accept the complexity of the industry.

Defining commercialization requires a broad view of business, while specific to the construction industry. In business, some early studies looked at new product commercialization through the specific lens of R&D/ Production. R&D has often been central for technology innovation through knowledge transfer. Due to intense "interface" activity of this stage, R&D confusion can also resist knowledge transfer, becoming a barrier to commercialization (Ginn and Rubenstein, 1986). Ginn and Rubenstein (1986) nevertheless indicate R&D as a crucial part of the commercialization process that needs to be reflected in the broad view of organizational culture.

While some commercialization literature focuses on R&D/ Production for technology-specific industry and concept definition for manufacturing, both are industry specific and neither defines a generic process of commercialization. Generic definitions often offer a broader view. The *Energy Technology Commercialization Help Guide* defines Commercialization as "the full spectrum of activities required for moving a new technology, product, or process from its conceptual stage to the marketplace" (US Department of Energy, 2005). University Technologies International (2001) sees commercialization as the art of taking an invention or a technology and developing a product or service for either consumers or industry. Rourke (1999) calls commercialization "the full spectrum of activities required moving a new technology, product or process, from its conceptual stage to market place."

This paper defines commercialization as encompassing all of the necessary steps between a product's conception to the penetration of that product into a given market. For the purposes of this research, commercialization is the coordinated execution of all necessary processes within the following functional disciplines:

- Product design (PD)
- Process planning (PP)
- Marketing (M)
- Supply chain management (SCM)

- Financial management (FM)
- Human resource management (HR)
- Accounting and information technology (AIT)
- Legal and regulatory management (LRM)

Having defined innovation and commercialization, a generic model that reflects these definitions was the next step. The generic model also specifies the unique features of the residential construction industry.

## ***Existing Generic Commercialization Models***

No model currently exists for the commercialization of innovative products in residential construction. This paper assembles a model from current definitions in other industry publications. Isabelle (2004) presents a thorough literature review of various commercialization models and their differences. Outside of the literature, this paper relies on industry related publications. This section explores all of these influences.

Literature places high importance on the early stages of commercialization; if early process is sound then major resulting problems may be avoided. Casto (1994) promotes “concept definition” as an integral part of any model. It happens separately, concurrently to other operations and is an integral building block for good practice. Similar to Ginn and Rubenstein’s (1986) R&D stage, the concept definition is not only for the product itself, but for the entire organization surrounding that product. This process better enables the organization to understand how a product fits its goals, not just the outside market. Casto’s (1994) separation of concurrent activities is achieved through a reiterative loop process. A loop is necessary for the concept definition to work outside of the other commercialization processes. Loop diagrams represent an organization’s ability to continually review the product concept within the larger product development process.

More recently, Shaw’s (2005) “two tier model of corporate entrepreneurship and innovation” furthers the loop diagram. This strategic framework is similar to other models through a breakdown of the process into distinct stages: Discovery, Opportunity Finding, Application, and Adoption and Diffusion. The framework then allows separate, concurrent actions to happen along the outside of the main framework; a reiterative loop similar to Casto (1994), offering corporations the ability to review.

Resulting from industry publications, the United States Department of Energy (USDOE) innovation process model by Rourke (1999) was created to promote the commercialization of innovative products in the US energy technology industry. While not written for the construction industry, their model divides the commercialization process into three major steps: *Innovation, Entrepreneurial, and Managerial*.

Each major step contains separate stages: *Technical, Marketing, and Business*. Table 1 is a breakdown of the Rourke (1999) model with these steps, stages and the required actions.

Table 2 here

Assuming time to be along the y axis in Table 1, the Innovation Stage occurs early in the commercialization process and accomplishes the design of an innovative product or process, market analysis and the strategic business plan. The Entrepreneurial Stage next finalizes all essential elements of the commercialization plan including: product design, the structure of the supply chain, the pricing and promotion plan, the securing of financing and the satisfaction of regulatory requirements. The Managerial Stage is the final stage of the commercialization process and executes the initial production, distribution, sales and installation of the product.

Goldsmith (2003) also produced a commercialization model as part of the Arkansas Small Business Development program at the University of Arkansas. Table 2 illustrates Goldsmith's (2003) universal solution for the advanced technology industry, based on the website.

Table 3 here

Similar to the Rourke (1999) model, Goldsmith's (2003) commercialization model shown in Table 2 comprises three major categories: *Investigation, Development and Commercial*. Each phase is broken into three phases: *Technical, Marketing, and Business*. Unlike the Rourke (1999) model, Goldsmith (2003) uses distinct actions to define the process. The model places details on linked, sequential website pages. Each page's description provides actions, critical term definitions and milestones for the framework. For example, the web page for *Innovation>Technical>Technology Concept Analysis* defines the activity as "The process of determining that the physical features of the concept are potentially achievable and operational"; establishes the objective as "to succinctly define the concept, to assess the implementation potential of the technical aspects of the concept, and establish the uniqueness of the technical concept"; then asks the following questions, among others:

- Have you completed a technology database search?
- Have you researched related patents or copyrights?
- Have you researched technical journals and trade magazines?

Once questions are answered correctly, one can move to the next stage.

Other industry publications on commercialization concentrate on intellectual rights. Gully's (2004) commercialization model is an example of this non sequential process. Its "life cycle" commercialization model offers a breakdown of only the early stage of the commercialization process and

no technical side is presented. Like other models, the Gully (2004) model uses a reiterative loop diagram to show the following sequence: Idea, Protection and Development of the Idea, A Decision to Sell or Not, Growing the business, and Beginning the Process again. It presents “steps to success” as the consistent elements that can properly be compared with those of other models.

A comprehensive look at all of the literature and industry based commercialization models offers differing processes for taking a product to market. The next step required assembly of the different models into a generic model which allowed modification for the unique characteristics of the residential construction industry.

## ***A New Generic Model for the Residential Construction Industry***

While the vital stages and steps from literature provide a basis for assembling a new commercialization model, many case based industry inputs and literature will be used in future research to specify the model’s framework to respond to unique industry characteristics. This section discusses assembling the generic model. Table 3 is the final form of the generic commercialization model. Through a description of Table 3, this paper explains the layout and literature basis for the model, explains two cells in detail and explains the process of gaining industry data.

The generic commercialization model is an 8x8 matrix. The items on the x axis of the matrix are phases in time; actions performed in taking a product to market. Each phase number, indicated by numbers 1-8, represents a sequential order from concept to market. All phase definitions are listed across the top of Table 3. The “Concept” phase is mostly a research step. “Feasibility” actions are early actions needed for proper product development, while the “Planning” phase requires figuring out the resources for these actions. Two “Review” phases (4 and 6) test and adjust the product accordingly. A review is required of the planning and early production stages. “Early Production” is the first product release and all of the actions surrounding this production. After review and adjustment, the new product and its surrounding actions become standardized. Finally, the new product reaches a market.

The items on the y axis of Table 3 include technical, marketing, and other business-related functional areas encountered when taking a product to market. Functional areas are unconstrained in their order, not necessarily representing a sequence as the product moves from concept to market. All functional area definitions are listed in the first column of the table. “Product Design” is the technical design of the product, including concept design, prototype, production, standardization and supplemental product design. “Process Planning” establishes the needed production capabilities and capacities of the product and might include plant design and production line mechanics. “Marketing” understands a product’s unique market, including forecasting, planning and revisions of the plan. “Supply Chain Management” coordinates the suppliers and distributors needed for a product. Any portion of supply or distribution

coordinated outside of the company is considered outsourcing, while most internal work is covered by process planning. “Human Resources” deals with all personnel needs, including hiring, firing, and the decision to subcontract, reassigning and promoting. “Accounting and Information Systems” organize knowledge for a product’s development, including communication systems, internal auditing processes, software designs, and standards of access to knowledge. “Financial Management” pertains to all actions associated with product capital management, including financing rates and options, securing financing, estimating and planning. “Legal Management” deals with the legal entities, contracts, agreements, or regulations surrounding a product’s path to market.

Although not specifically shown in Table 3, the phases are consistent with generic industry models: Rourke (1999) and Goldsmith (2003) also begin with an idea/investigation phase that relates to phases 1 and 2, a second innovation phase that relates to phases 3 and 4, a third commercial phase that relates to phases 5 through 7, and a fourth phase of acceptance into the market that relates to phase 8. Industry literature also has the commercialization process or steps broken down into three main components: Technical, Marketing and Business. The technical component is refined into two functions of product design and process planning. Marketing is represented as one of several functions areas within the business component. The “review” phases of the model allow for the Casto’s (1994) and Shaw’s (2005) concept of the “reiterative loop.” In reviewing the phases at critical points along the path to market, the commercializers can learn from the product’s own development and improve. The phase 4 planning review reflects the literature’s insistence on getting early concepts correct (Ginn and Rubenstein, 1986).

Table 3 here

This paper offers next a description of the process for discovering a new commercialization model for residential construction. Due to the constraints of length, this paper does not offer more than one example of capturing case based validation. The next research phase (Phase Two) of model development captures multiple case based inputs in the form of interviews, while one was captured and is explained here.

Phase Two captured qualitative data through interviews with individuals who have participated in commercializing a product for the residential construction industry. It also incorporated existing case study literature which examined the process of introducing a product into the market. Analysis of the data related industry experience to the commercialization framework. Specifically, the interviews were filtered to identify critical cells, actions and sequences. In the next section, this paper presents one example of the interview data analysis.

Another goal of phase two was to produce detailed models of individual decisions within significant cells of Table 3. Objectives of these decisions and the actions required to accomplish these objectives

were expected to be similar to those of Goldsmith (2003). The total possibilities of detailed models is 64 (8 x 8), but future work will focus on fewer areas with significant value. For example, a detailed model of “M2: Marketing Feasibility” would include objectives of: understanding the market fit and segmentation for the given product. Recognizing the market fit might require researching competition, initial testing of the current market and identifying niches within a market. A detailed model of “LM3: Legal Management Planning” might include designing contracts and procedures. This step requires contracting a lawyer to create a partnering license, identifying partners for the contract design and outlining legal procedures for the new corporation. Many other objectives and actions are possible in a product’s development; all contained in the detailed stages of the commercialization framework of Table 3.

### ***Input from Construction Industry Experts- Example Case Study***

Phase two of the research validated the generic commercialization model by introducing data from product case studies within residential construction in the form of interviews. Yin (2005) promotes the case-study methodology as the best approach to investigating how or why phenomena occur. Phase two work acted as a “field-test” of the commercialization model through execution of Maxwell’s (1996) four main components for case-study research:

1. Establish a relationship with innovative product manufacturers
2. Sample these manufacturers and their products through interviews
3. Collect these interviews as case studies
4. Analyze these interviews through expert panel consensus about the critical cells, their decisions and actions, and sequences of the commercialization process that are important to success.

Typical collection processes began by determining the appropriate nature of the product and willingness of the subject. These case studies first established validity by soliciting each interview through consistent methods. For example, Seidman (1991) suggests excluding discussions of a personal nature. Each interview explained background and privacy policies while determining whether the product under consideration would fit well with objectives of this research. Consistent methods require a typical language for all interviews as well. For example, market acceptance for these studies is defined as the point in which a product has reached the market and has full production.

Accordingly, the consistent data collection process and language began by interviewing an individual with knowledge of taking an innovative product from concept to acceptance in the market. The interview solicited detailed descriptions of the firm, its product, its supply chain placement, its process to market and barriers and accelerators to market. The interview further solicited critical actions (boxes with dotted

lines in figure 1) and decisions required along the path from concept to acceptance in the market. All phone correspondence were taped for accuracy and dictated into a digital form. Dictations were returned to interviewees for final verification of their words.

The research team then examined interview transcripts line by line. The cells of Table 3 served as a basis for interpreting each statement made by an interviewee as a reference to a decision and action within the commercialization project. Maxwell (1994) refers to this methodological approach as *contextualizing strategy*, which understands data in regard to their relationship among differing elements. The interview questions used this strategy to understand innovation within the differing stages and functional areas of a commercialization project.

Decisions, and their resulting actions, identified within cells of Table 3 highlight important accelerators and barriers for commercialization success. Sequences among cells signify important relationships. As an example, Figure 1 represents these actions, sequences, and areas of importance in timeline form for one of the products (Product 1) included in this study.

Figure 1 here

Product 1 is an innovative product and process for stair-parts in the residential construction industry. Figure 1 offers the sequence and actions taken in getting this product to market. Critical actions and sequences, as stated by the interview subject, are captured in the dotted boxes. Sequences are noted through their placement along the timeline. All actions are tied to the cells of Table 3 by noting their location in parentheses after the description of the action. For example, Product 1's patent investigation was a critical action which needed to come before looking into supplemental products on the market. This is an action that takes place within the step that is designated "LM1: Legal Management."

Figure 1 illustrates many sequences and actions important to getting a stair parts innovation to the market. This innovation began with a long period of time devoted to research and development before getting to any manufacturing processes. The product was developed through legal management of patents, early market identification by looking for others on the market, understanding how the new product might improve on the current products and finding another industry partner for supplemental parts. This process lasted from 1991 to 2002 and was considered critical by the interview subject. The product next went through a series of prototypes and market pricing, all followed by testing. The testing for this product identified another supplemental product that required development for this product to be successful on the market. Finally, Product 1 was ready for supply chain management, final marketing plan revisions and initial production lines, which lead to the market. Noticeably missing in this product's interviewee's description of the commercialization was the financing. The financing for Product 1 was done mostly through its parent organization, which budgets the amounts of investment risk throughout a

commercialization and uses knowledge from previous product development. While only introducing Product 1 here, Phase Two of this work will draw further conclusions from a comparison of fifteen products.

Figure 2 here

The data capture and timeline analyses do not suffice to validate the commercialization model. The validation process must use the information from the timeline and translate it into a generic model form. Figure 2 shows an example of this translation. Like the timeline, Figure 2 offers critical cells, actions, and sequences of importance for an innovative construction product. Figure 2 differs by incorporating the backdrop of the commercialization matrix. Arrows will indicate sequences of importance.

### ***Summary and Future Work***

Due to a lack of models that describe the commercialization for innovative products in the residential construction industry, this paper introduces one. The model is based on generic industry models and the guidelines of research literature. The model aims to benefit future entrepreneurial business ventures in the commercialization of construction products.

The generic model matrix accepts different data inputs from product interviews and case study literature that further modify its structure. Each input validates portions of commercialization important to construction industry products through noted cells, actions, and sequences. This paper presents Product 1 as one of many construction products reviewed in this research.

Ongoing research continues to address model validation. Future research will determine how other products vary in their movement through the commercialization phases. A sample of these various paths will establish consensus or will highlight a lack of consensus. Further study will pursue the accumulation of examples of decisions, actions, and sequences of importance. Findings could indicate the importance of individual processes that require additional attention when taking a product to market. With greater attention, these processes might accelerate commercialization.

Another future research goal is a classification scheme of construction products based on the optimal sequence of steps for different product types. New innovators might benefit from a prescribed roadmap for commercialization that such a classification scheme would provide.

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## TABLES AND FIGURES FOR INSERTION

**Table 1: Rourke (USDOE) Model Breakdown**  
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<b>Rourke Terminology</b>			
<b>Stage</b>	<b>Step</b>	<b>#</b>	<b>Action</b>
<b>Innovation</b> <i>Product definition to engineering prototype</i>	Technical	1	Product Definition
		2	Working Model
		3	Engineering Prototype/Test & Refine
	Marketing	1	Preliminary Market Definition
		2	Market Analysis
		3	Identify Market Barriers
	Business	1	Define Development and Intellectual Property Strategy
		2	Find Money, File Patents
		3	Establish Intellectual Property, License Plan
<b>Entrepreneurial</b> <i>Prototype to production</i>	Technical	1	Production Prototype
		2	Limited Production
		3	Full Production
	Marketing	1	Initial Growth
		2	Full Market Analysis and Plan
		3	Establish: Customers, Distribution, and Endorsements. Publish
	Business	1	Expand: Distribution, Competitor Analysis, Response
		2	Increasingly Complex
		3	Find Big Money, Complete Business Plan, Form Business, Meet regulations, Arrange Insurance
<b>Managerial</b> <i>Production for major market</i>	Marketing	1	Find Big, Big Money, Start-up Business, Build Plant, Buy Equipment, HR Training, Arrange: Record Keeping, Purchasing, Transportation
		2	Monitor Costs, Finance Cash Flow, Refine Production
		3	Increasingly Complex
	Technical		Product Improvement, New Products
	Marketing		Complexities Intensify

**Table 2: Goldsmith Model**

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<b>Goldsmith Terminology</b>			
<b>Category</b>	<b>Phase</b>	<b>#</b>	<b>Action</b>
<b>Investigation</b>	Technical	1	Technology Concept Analysis
	Marketing	1	Market Needs Assessment
	Business	1	Venture Assessment
<b>Development</b>	Technical	1	Technology Feasibility
		2	Engineering Prototype
		3	Pre-Production Prototype
	Marketing	1	Market Study
		2	Strategic Marketing
		3	Market Validation
	Business	1	Economic Feasibility
		2	Strategic Business Plan
		3	Business Start-up
<b>Commercial</b>	Technical	1	Production
		2	Production Support
	Marketing	1	Sales & Distribution
		2	Market Diversification
	Business	1	Business Growth
		2	Business Maturity

**Table 3: Generic Commercialization Framework Reprinted by permission of Emerald Literati Network (UK)**

		PHASE								
		Concept	Feasibility	Planning	Review Planning	Early Production	Review Early Production	Standardization	Maturation	
		1	2	3	4	5	6	7	8	
<b>Definitions</b>		<i>Specifying conceptual design of product &amp; business</i>	<i>Assessing feasibility of product &amp; viability of business</i>	<i>Designing the product and the business plan</i>	<i>Testing product design and business plan</i>	<i>Initial product release</i>	<i>Evaluate initial release and revise product design and business plan</i>	<i>Standardize product design and business plan</i>	<i>Ongoing product/process improvement</i>	
<b>FUNCTIONAL AREAS</b>	<b>Product Design</b>	<i>Specifying the technical design of a product.</i>	PD1: Technical Research	PD2: Conceptual Design	PD3: Detailed Design	PD4: Test Prototype	PD5: Initial Product Release, Test in Field	PD6: Field Testing Results, Redesign	PD7: Standardized Product	PD8: Next Generation of Product Designs
	<b>Process Planning</b>	<i>Establishing the needed production capability and capacity</i>	PP1: Research Process Technologies	PP2: Select Process Technologies	PP3: Design Processes	PP4: Test, Review Processes	PP5: Measure Process Times, Quality, Costs	PP6: Early Production Results, Redesign	PP7: Standardized Process	PP8: Process Improvement Design
	<b>Marketing</b>	<i>Identifying the requirements of available markets for a product.</i>	M1: Market Research	M2: Market Fit & Segmentation	M3: Forecast Demand & Marketing Plan	M4: Review Marketing Plan	M5: Test Market through Production Run	M6: Revise Marketing Plan	M7: Manage Sales	M8: Discover New Markets
	<b>Supply Chain Management</b>	<i>Establishing the chain of business entities for manufacture and distribution</i>	SCM1: Identify Sourcing & Outsourcing Options	SCM2: Configure Supply Chain	SCM3: Detailed Design of Supply Chain	SCM4: Model Supply Chain Performance	SCM5: Execute Production Run	SCM6: Adjust Supply Chain	SCM7: Standardize Sourcing & Outsourcing	SCM8: Improve Supply Chain Management, Discover New Sources
	<b>Human Resources</b>	<i>Defining the personnel requirements for the supply chain and acquiring human resources</i>	HR1: Identify Project Leaders & Responsibilities	HR2: Create Leader Positions, Other Labor Roles & Responsibilities	HR3: Create Hiring, Firing, & Promotion Plan	HR4: Review Labor Costs, Reassign or Dissolve Labor	HR5: Recruit, Create, Train, & Supervise for Production Run	HR6: Review Staff Costs, Reassign or Dissolve Labor.	HR7: Manage Human Resources.	HR8: Review Human Resources for New Generation Product
	<b>Accounting &amp; Information Systems</b>	<i>Implementing the AIS system for all business functions</i>	AIS1: Research Information Technology	AIS2: Design Accounting & Other Information Systems	AIS3: Plan & Acquire IS Implementation	AIS4: Install & Test IS	AIS5: Audit IS through Production Run	AIS6: Revise from Audit	AIS7: Support & Standardize IS	AIS8: Improve IS
	<b>Financial Management</b>	<i>Acquiring capital for the commercialization project</i>	FM1: Identify Sources of Capital, Financing Rates	FM2: Define Capital Configuration	FM3: Prepare Capital Plan	FM4: Estimate Capital Costs & Risks	FM5: Acquire Capital	FM6: Revise Estimates & Capital Plan	FM7: Manage Capital Resources	FM8: Improve Capital Plan
	<b>Legal Management</b>	<i>Satisfying legal &amp; regulatory requirements</i>	LM1: Identify Liabilities & Regulatory Requirements, Tariffs, Partners	LM2: Design Liability, Warranty, Patent, Regulatory Protections	LM3: Write Contracts & Procedures	LM4: Review Protections & Standards by External Certifiers	LM5: Monitor & Control Production Run	LM6: Revise Contracts & Standards	LM7: Monitor & Control Claims	LM8: Adapt Contracts & Standards to Changing Environment

Figure 1: Product 1 Timeline Reprinted by permission of Emerald Literati Network (UK)

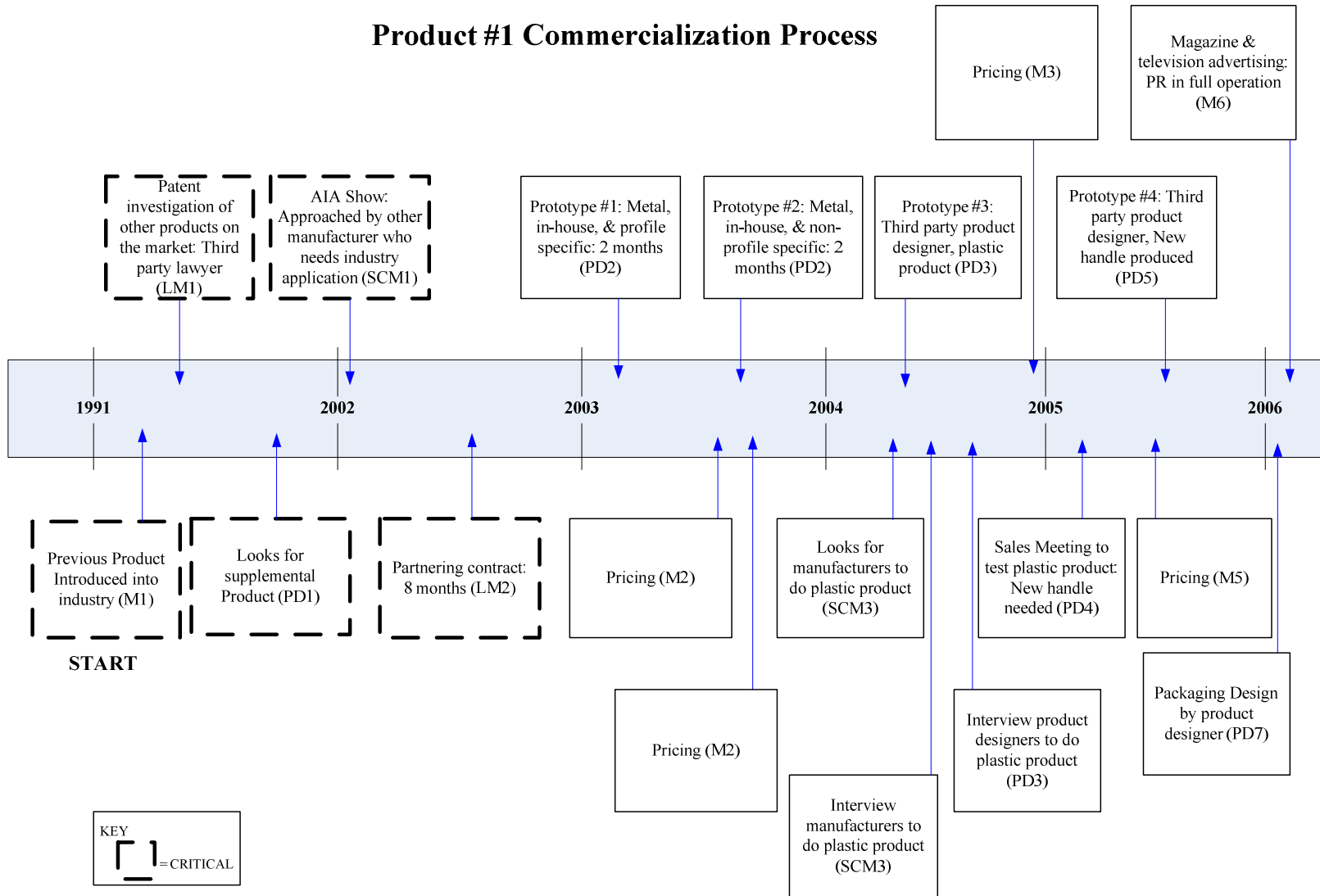


Figure 2: Product 1's Sequence Example Reprinted by permission of Emerald Literati Network (UK)

		PHASE								
		Concept	Feasibility	Planning	Review Planning	Early Production	Review Early Production	Standardization	Maturation	
		1	2	3	4	5	6	7	8	
		<i>Specifying conceptual design of product &amp; business</i>	<i>Assessing feasibility of product &amp; viability of business</i>	<i>Designing the product and the business plan</i>	<i>Testing product design and business plan</i>	<i>Initial product release</i>	<i>Evaluate initial release and revise product design and business plan</i>	<i>Standardize product design and business plan</i>	<i>Ongoing product/process improvement</i>	
<b>Definitions</b>										
<b>FUNCTIONAL AREAS</b>	<b>Product Design</b>	<i>Specifying the technical design of a product.</i>	PD1: Technical Research	PD2: Conceptual Design	PD3: Detailed Design	PD4: Test Prototype	PD5: Initial Product Release, Test in Field	PD6: Field Testing Results Redesign	PD7: Standardized Product	PD8: Next Generation of Product Designs
	<b>Process Planning</b>	<i>Establishing the needed production capability and capacity</i>	PP1: Research Process Technologies	PP2: Select Process Technologies	PP3: Design Processes	PP4: Test, Review Processes	PP5: Measure Process Times, Quality, Costs	PP6: Early Production Results, Redesign	PP7: Standardized Process	PP8: Process Improvement Design
	<b>Marketing</b>	<i>Identifying the requirements of available markets for a product.</i>	M1: Market Research	M2: Market Fit & Segmentation	M3: Forecast Demand & Marketing Plan	M4: Review Marketing Plan	M5: Test Market through Production Run	M6: Revise Marketing Plan	M7: Manage Sales	M8: Discover New Markets
	<b>Supply Chain Management</b>	<i>Establishing the chain of business entities for manufacture and distribution</i>	SCM1: Identify Sourcing & Outsourcing Options	SCM2: Configure Supply Chain	SCM3: Detailed Design of Supply Chain	SCM4: Model Supply Chain Performance	SCM5: Execute Production Run	SCM6: Adjust Supply Chain	SCM7: Standardize Sourcing & Outsourcing	SCM8: Improve Supply Chain Management, Discover New Sources
	<b>Human Resources</b>	<i>Defining the personnel requirements for the supply chain and acquiring human resources</i>	HR1: Identify Project Leaders & Responsibilities	HR2: Create Leader Positions, Other Labor Roles & Responsibilities	HR3: Create Hiring, Firing, & Promotion Plan	HR4: Review Labor Costs, Reassign or Dissolve Labor	HR5: Recruit, Create, Train, & Supervise for Production Run	HR6: Review Staff Costs, Reassign or Dissolve Labor.	HR7: Manage Human Resources.	HR8: Review Human Resources for New Generation Product
	<b>Accounting &amp; Information Systems</b>	<i>Implementing the AIS system for all business functions</i>	AIS1: Research Information Technology	AIS2: Design Accounting & Other Information Systems	AIS3: Plan & Acquire IS Implementation	AIS4: Install & Test IS	AIS5: Audit IS through Production Run	AIS6: Revise from Audit	AIS7: Support & Standardize IS	AIS8: Improve IS
	<b>Financial Management</b>	<i>Acquiring capital for the commercialization project</i>	FM1: Identify Sources of Capital, Financing Rates	FM2: Define Capital Configuration	FM3: Prepare Capital Plan	FM4: Estimate Capital Costs & Risks	FM5: Acquire Capital	FM6: Revise Estimates & Capital Plan	FM7: Manage Capital Resources	FM8: Improve Capital Plan
	<b>Legal Management</b>	<i>Satisfying legal &amp; regulatory requirements</i>	LM1: Identify Liabilities & Regulatory Requirements, Tariffs, Partners	LM2: Design Liability, Warranty, Patent, Regulatory Protections	LM3: Write Contracts & Procedures	LM4: Review Protections & Standards by External Certifiers	LM5: Monitor & Control Production Run	LM6: Revise Contracts & Standards	LM7: Monitor & Control Claims	LM8: Adapt Contracts & Standards to Changing Environment

# Chapter 5 - Validating a Commercialization Model for Innovation in Residential Construction: Industry Case Study Analysis

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**ABSTRACT:** This paper presents continuing research on the most effective processes for entrepreneurial business ventures to commercialize innovative construction products in the residential construction industry. Burgeoning interest in innovative products in recent years suggests that the successful commercialization of such products might be central to the future of the construction industry. Part One of our research offered a commercialization framework for the coordinated sequences of decisions and actions that make up a commercialization project. This paper, which presents initial results of Part Two, describes the validation of this model with data that were obtained through collecting and analyzing interviews of experienced product innovators in the residential construction industry. Each interview describes the key decisions and resulting actions that were made during the successful commercializations of innovative products in the residential construction industry. These data are presented as case studies. We discriminate accelerators and barriers to commercialization, prototypical processes of a successful commercialization and non-critical steps within the commercialization model. We conclude by deriving from our study directions for future research into the key decisions of the commercialization framework and offer anecdotal evidence towards the role of product champions for commercialization success.

**KEYWORDS:** COMMERCIALIZATION, RESIDENTIAL CONSTRUCTION, ADOPTION, DIFFUSION, INNOVATION

## ***Introduction***

A recent National Science Foundation (NSF) workshop addressed barriers to technology transfer in the US housing industry (Koebel, 2004a). The 2004 NSF workshop found residential technology diffusion as one barrier to current technology transfer (Koebel, 2004b). Our research is motivated by the need for prescriptive methods for commercialization of construction products and the potential value of such commercialization to the construction industry, the economy and the living standards of homeowners.

This paper presents the second phase of the development of a domain-specific commercialization model for innovative products in the residential construction industry. The ultimate goal of our research is to determine how to alleviate supply-chain barriers within the residential building market, therefore accelerating diffusion of new technology for the construction industry. This paper expands previous work by investigating important decisions

and actions, within the context of our commercialization model, through interview data collected from experts in the construction industry (McCoy et al., 2008).

Commercialization models describe the complex process of coordinating and optimizing all of the technical and business decisions required by the successful introduction of a new product or service to the marketplace (McCoy et al., 2006). A valid commercialization model serves as a roadmap to entrepreneurs, promoting solutions to questions and problems that arise for products along the path of commercialization (Goldsmith, 2003). A matrix of key decisions and actions which provides a framework for any commercialization enterprise is included in the Appendix (Item #1). McCoy et al. (2008) presented this commercialization framework as part of the first phase of this research. The second phase of our work analyzes data collected from fifteen recently commercialized construction products and uses these data to identify specifically the relative importance of steps in the commercialization process for residential construction products, further refining our framework for applicability to this industry.

Our research methodology for the second phase of our research is that of case study. A case study is an investigation of the technical aspects of a real phenomenon through the use of interviews of individuals who have expertise and/or experience with those phenomena (Benbasat et. al., 1987). Case studies are often the only useful methodology when a researcher seeks to understand structural relationships among, and relative to, interacting entities, the content of processes, the reasons behind decisions, and other questions about how or why a process is performed (Marshall & Rossman, 1995). The qualitative data obtained from the case studies transform our model into a specific adaptation to the construction industry.

This paper first establishes our methodology, then presents our case-study data analysis followed by interpretation and conclusions about commercialization of innovative construction products. We initially present interview narrative data as critical decisions and resulting actions that represent accelerators or barriers to commercialization. We then discuss these data as prototypical processes of a successful commercialization, including significant sequences which might signify important relationships. We interpret perceptions of non-critical steps within the commercialization model. We conclude by deriving from our study directions for future research into the key decisions of the commercialization framework.

### ***Data Collection & Consensus Methodology***

Yin (2005) promotes the case-study methodology as the best approach to investigating how or why phenomena occur. Accordingly, our work collected information about the specific

steps in a commercialization project in order to add domain-specific features to our commercialization framework. The typical data collection process began by interviewing an individual with knowledge of a project of taking an innovative product from concept to acceptance in the market. Our selection of subjects conforms to Patton's (1990, p.169) *purposeful sampling* and what LeCompte and Preissle (1993, p. 69) consider *criterion-based sampling*. Our sampling attempted to select persons with proprietary knowledge that could not be obtained from other subjects (Maxwell, 1996).

We further established the reliability of the data by soliciting each interview through consistent methods. Seidman (1991) suggests a rapport with subjects that does not require discussions of a personal nature. We therefore introduced our research to potential subjects by explaining the background of the research and our privacy policy, as well as determining whether the product under consideration would fit well with our interests. We also suggested to the potential subject typical language that we would use for our conduct of the interview and the ensuing case study. In order to preclude bias in responses, we did not allow our subjects to view the commercialization framework a priori. Once we received a commitment for the interview, we sent to the interviewee a set of questions, which were common to all subjects. These questions are listed in the Appendix (Item #2).

*Contextualizing strategy* attempts to understand data in regard to their relationship among differing elements (Maxwell, 1996). Our interview questions used this strategy to understand innovation within the differing stages and functional areas of a commercialization project, measuring the relative importance of individual steps with respect to the overall process. Some questions pertained to the context of the innovation within markets and technology, while others related the innovation to our commercialization framework and highlighted barriers through "lessons learned." Later questions were designed to elaborate on the details of previous questions. We also asked for individual opinion on important decisions within the commercialization process. Typical responses highlighted decisions and their resulting actions during commercialization by the respondent. These decisions and actions became the bases of case-study narratives.

Table 1 summarizes demographic information for these 15 narratives. Fully narrated versions of the case studies, not presented here, describe these firms' characteristics, the products' champions, industry contexts and histories and the product's commercialization timeline. The categories and types of the firms are wide-ranging, reflecting various housing systems and processes. The founding dates of the firms that we studied range from five to one hundred years.

Twelve firms are incorporated entities, two are non-profits and one is a sole-proprietorship with firm size, in terms of employees, ranging from 1 to over 500.

Table 1 here

A firm's position within the construction industry supply chain is another important element of the narratives for our study. Firm positions along the supply chain include franchising, manufacturing, distributing, supplying, installing, promoting, code compliance and quality assurance roles. Two similar products whose firms have different locations along this chain might face different commercialization challenges. For example, a firm's position might simultaneously have been fabrication manufacturer and assembly manufacturer, depending on its supply of materials, its role as a manufacturer and the necessary coordination among industry players.

Many of the respondents are product champions. A champion is defined as the person or committee, with final responsibility, which ensures that all steps of the commercialization project are completed properly and successfully. Product champions vary among committees, executives within the corporation or others with a position of power.

### ***The critical commercialization steps***

Souder (1987) asserts that there is no single path to successful commercialization, but many ways that vary in effectiveness. The surrounding conditions and environments determine which way is the most effective commercialization path in each case. Our data measure the relative importance of different steps in a commercialization process from the viewpoint of the respondents. It is important to note that the relative importance reflected in these data does not override the absolute importance of accepted product development methods.

This paper presents various summaries of interview narrative data. Since subjects were not allowed to view the commercialization framework, their descriptions of steps in a commercialization process were expressed in their own words. The research team performed content analysis by examining the interview transcripts line by line. Each researcher on the team independently identified each action or decision described by a respondent in terms of its location in the commercialization framework shown in the Appendix (Item 1). We also analyzed specific content within the interview transcripts to identify barriers and accelerators to commercialization. Once all of the team members had finished their analysis, group discussion resulted in consensus

about the placement in the commercialization framework of each step identified by a respondent. Figure 1 illustrates this data-analysis process.

Figure 1 here

## ***Critical Commercialization Actions and Decisions***

Table 2 shows the concentrations of important actions and decisions as is indicated by the data. We note that most of the commercialization steps which were identified by our respondents as essential are located between phases 1 and 4. This signifies the importance of early actions within a commercialization project to the success of the product. These early actions are mainly steps needed to establish a proper basis for commercialization, while later phases pertain to the processes of applying this basis. These results reinforce previous research, which makes the case that early stages of commercialization are vital to a product's development (Casto, 1994, Ginn and Rubenstein, 1986 and Isabelle, 2004).

Phases 5 and 8 specifically contain the least amount of consensus among our respondents about their importance. This finding could mean that the phases do not contain *relatively* important steps in the commercialization process. It could also mean that phase 5 is mostly considered by our subjects to belong in Phase 4 or Phase 6. Future model development might combine the phases for clarification of these findings. Phase 8's omission could signify a different definition by these subjects for acceptance of a product. In other words, full production and standardization of the product might be a better definition of acceptance into the market.

Table 2 here

## ***Commercialization Barriers and Accelerators***

Table 3 lists the barriers and accelerators to commercialization that were identified by our respondents. In order of prevalence in the data, concentrations of barriers are located in Phases 4, 1, 3 and 6. The Functional Areas of Marketing, Supply Chain Management, Product Design and Legal Management contain the most barriers. The most-mentioned barriers cite the following concerns:

- Poor market knowledge
- Poor supply chain and distribution coordination
- Poor regulatory knowledge

- Poorly trained personnel
- Poor market education and sales management

These results clearly indicate the importance of planning and review of product designs and business models. In these phases of commercialization, potentially fatal errors in market analysis, technical specification, code compliance and supply-chain planning become apparent.

In order of prevalence in the data, concentrations of accelerators for innovative products are located in Phases 4, 6, 1 and 2. This concentration pattern is similar to that of the barriers except for Phase 2, which replaces Phase 3. The functional areas of Marketing, Supply Chain Management and Product Design and Human Resources contain the most accelerators. Again, this pattern is similar to that of the barriers except for Human Resources, which replaces Legal Management. The most-mentioned accelerators cite the following opportunities:

- Proper product research
- Proper market research
- Proper product leaders and champions
- Proper product design concept for the market
- Proper market fit
- Proper market demand forecasting
- Proper product testing
- Proper market feedback and review
- Proper supply and distribution channel review
- Proper staffing plan adjustments and review
- Proper supply and distribution controls adjustments

These results also indicate the importance of planning and review of product designs and business models. The importance of product design in commercialization is obvious. The role of Legal Management was often mentioned as a both a barrier and accelerator, primarily because of the importance of code compliance and product liability that are unique to construction products. Market research emerges from our data as a critical step in commercialization. Clearly, when market research is done correctly this action can accelerate commercialization and when market research is done poorly, it acts as a barrier. The influence of supply-chain configuration, controls and coordination on commercialization success is interesting.

[Table 3 here](#)

## ***The Prototypical Commercialization Processes***

Previous work discussed the importance of sequence data (McCoy et al., 2008). To review, sequence data represent the precedence relationships among product commercialization steps. We asked respondents to place the most significant commercialization steps along a timeline in order to indicate graphically the relationships among actions and decisions. Linking the sequences from each timeline to the commercialization framework (Appendix, Item #1) allowed us to identify prototypical patterns of precedence constraints.

Most significant in our data are sequences with double arrows. A double-arrow relationship is a concise representation of two opposing, parallel arrows and refers to a pair of cells in the framework which represent actions which are consistently dependent upon each other and are performed concurrently. These relationships imply iterative, concurrent decision making across functional areas, which is consistent with the practice of concurrent engineering in product development. Concurrent engineering is a well-researched and proven methodology for product development which is most commonly coordinated from the functional area of engineering (Miller, 1993). Technical functions naturally motivate an iterative, concurrent decision process with other functional areas during a commercialization project. Our data suggest that prior to milestone-review stages of product development, choices of technical options generally are strongly influenced by marketing and supply-chain considerations. For example, one product's technical concept was entirely dependent on its market fit. Consequently, the product development and marketing functions worked closely to understand the product's concept through market segment identification. Similarly, legal, human resource, supply chain and financing functions often drive the technical decisions.

Also of note in the commercialization sequences obtained from our data are starting points. All products begin their development in Phase 1 of the commercialization matrix. This supports our initial hypothesis that the commercialization framework, depicted in the Item #1 of the Appendix, properly incorporates beginning actions of commercialization for residential construction products. No other preliminary step to our matrix is therefore required. Products differ in the functional area of their beginning, though. All but two products contain M1: Market Research within the first two actions. This suggests that, while companies might begin commercialization differently, market research follows closely. Marketing's placement within the first two steps of almost all successful cases is consistent with general literature and reinforces its importance to commercialization.

Recent concepts of innovation development advocate the establishment of “user-centric” manufacturing, through which installer preferences (market influence) drive product development early in the commercialization process and thus directly benefits the manufacturer and reduces uncertainty for the installer (von Hippel, 2005). We view the user-centric approach as a specific form of implementation of the market-driven, concurrent-engineering process which our respondents recommend.

### ***Perceptions of non-critical steps***

The data show that the functional areas that were ranked least important by our respondents are Supply Chain Management (SCM) and Financial Management (FM). The omission of these functional areas in some of our data cannot be construed as a suggestion that these areas are not part of every commercialization process. Our data reflect the relative, not absolute, importance of different functional areas and stages of commercialization processes. In the general commercialization literature, these areas are regarded as highly important in the product development process. Hence, the low level of importance of these functional areas, as perceived by our respondents, is, at first, somewhat confusing.

The sequence diagrams drawn from our data show financial actions only as important follow-up cells. An intriguing hypothesis suggested by these results is that construction products present such significant challenges in the early stages of other functional areas in the commercialization process, specifically marketing and technical development, that the financial-management issues, which certainly play a central role in commercialization, are somewhat routine by comparison.

While supply-chain management is generally considered to be highly important in the commercialization process, the relatively low level of importance to our respondents of this functional area is also intriguing. Clearly, supply-chain design and development are essential steps in any commercialization project, including construction projects (Jiang et.al, 2003, Vaidyanathan and O’Brien, 2003). Figure 2 shows a typical supply chain for construction products and is somewhat unconventional due to the inclusion of parties, such as developers/builders and inspectors, who may not physically possess a product, but who play critical roles in deciding whether or not the product proceeds to the next owner in the chain. Each party can influence strongly the success of commercialization through either veto or endorsement.

One possible explanation for the lack of emphasis on supply-chain steps by the case-study subjects is that, as assembly or fabrication manufacturers, they may consider these steps to be contained within other functional areas such as marketing or product design, the latter function being considered critical to engaging builders in the supply chain. This possibility might reinforce the necessity for the concentration of future research in the exposition of supply-chain issues to innovators in the construction-products industry.

Figure 2 here

For each case, some steps in the commercialization framework (Appendix Item #1) did not receive any score from our consensus. A “non-consensus” step does not mean that the respondents did not perform the step, but that the actions and decisions that comprise this step are not highlighted in the comments of the respondents. We conclude that non-consensus steps represent actions and decisions that are considered to be relatively easy or routine.

Two of the case studies report many actions in phases 5-8 of the commercialization matrix. In each of these cases, both from large corporations, each phase of the commercialization process is executed through the work of a committee, requiring all functional areas to be considered before moving to the next phase. In contrast, the highest number of steps mentioned in phases 5-8 by any of the remaining thirteen cases is six. Compared with the large number of steps mentioned in phases 1-4, this exclusion of later steps supports the conclusion that early steps are more critical to successful commercialization than later steps. This finding reinforces the claims often found in the research literature that early missteps largely increase the possibility of later risks (Casto, 1994, Ginn and Rubenstein, 1986 and Isabelle, 2004).

Among functional areas, the case-study narratives commonly omitted steps within Process Planning (PP), Human Resources (HR) and Accounting and Information Systems (AIS). Literature in the field of AIS for the construction industry points to a lack of awareness of benefits of information technology as a reason for its delayed use within the business of construction (Becerik, 2004, Macomber, 2004, Thomas et al., 2004, Vaidyanathan & O’Brien, 2003). There may be another reason for the meager references to the functional areas of PP, HR and AIS. Since Process Planning generally consists of product manufacturing activities, many of the corporations in our case studies could have considered subcontracting these functions. In addition, anecdotal evidence suggests that the steps within PP, HR and AIS, as internal functions, can require expensive investments that are risky until all parties in the supply chain are committed to the new product. Since builders and contractors are noted as the most reluctant participants in a commercialization, we believe that, compared to commercialization in other

industries, the construction industry delays the heavy investments in process development and capacity expansion to a late stage of a commercialization project and proceeds cautiously in these functions.

## ***Conclusions and future research***

While previous work presents a framework for the commercialization process of innovation in residential construction, this work tests that framework (McCoy et al., 2008). We use case studies of successfully commercialized products to specify the steps, sequences, and roles of importance. The paper analyzes case-study data to refine the commercialization framework for innovators of residential construction products in this difficult process. Future work will produce detailed models of the decisions within the important steps of the larger commercialization framework. These models will provide essential decision support to facilitate limited-resource innovators.

Our study reveals that steps in the early stages of commercialization are most important. Furthermore, no new phases or functional areas were suggested by the data. We therefore do not find our commercialization framework under-specified. The current version seems to have steps that can be removed without a large impact, not steps that need to still be added.

Case-study data suggest the following hypotheses:

- The commonly used sequences of commercialization steps validate a concurrent-engineering approach.
- The data validate our commercialization framework with respect to the scope of commercialization phases and our claim that the first phase is an essential starting point for any commercialization project.
- The data support the validation of early integration of marketing within the product design.
- Although all phases of the commercialization process are essential, phases 1-4 of our commercialization framework are more critical to success than phases 5-8.
- Among functional areas, PP, HR and AIS, are relatively routine for commercializers of residential construction products.
- Early missteps largely increase the possibility of later risks.
- Compared to commercialization in other industries, the construction industry delays the heavy investments in process development and capacity expansion to a late stage of a commercialization project and proceeds cautiously in these functions.

- An intriguing hypothesis is that construction products present such significant challenges in other functional areas that the financial management issues, which generally play a central role in commercialization, are somewhat routine by comparison to construction-specific commercialization barriers.

Finally, these 15 case studies offer interesting anecdotal views into the role of champions. We previously defined a champion as the person, with final responsibility, who ensures that all steps of the commercialization project are completed properly and successfully. Company champions are listed in Table 1. Our data reinforce evidence from literature on new product development that champions are important to the development process. In some firms, the president of the company develops the product and is, therefore, the champion. In other firms the champion is a process-planning group which meets often to discuss the progress of the product development and to ensure obstacles are cleared. Still other firms assign key individuals to oversee each product's development, depending on whether it is inside or outside the company. Since larger companies often assign individuals, we assume that these firms allocate the resources of a full-time champion and, consequently, foster an atmosphere of encouraging innovation. Based on our case studies, we posit the hypothesis that a key function of corporate champions is to coordinate successfully all corporate and departmental entities involved in a commercialization project. Coordinating supply chain entities, for example, would produce a clear financial benefit for all involved. In a contrasting example within our studies, one firm had no clear champion, which reduced its ability to create builder awareness and distribute properly. Once this position was later established the product achieved success through better distribution, suggesting the importance of the role. Future study might pursue the role of champions in innovation development for residential construction.

Future research might further the implications for important early steps to "inventors" versus "innovators." Inventors move a product far enough along the commercialization process for patenting and selling/ licensing of rights. Innovators carry a product through the entire commercialization process. This idea directly relates to findings for salient processes and sequences, as they heavily favored early, risk-limited actions. For limited-resource inventors, financial constraints often dictate the contractual involvement of an innovator. Therefore, we foresee this juncture of the commercialization process as a key decision point, especially for small business enterprises. Future work will investigate the design and coordination of the supply-chain entities (players) in terms of financial risk-sharing. These supply-chain solutions might distribute risk, while also promoting cost benefits for all players involved.

## Acknowledgements

This research is supported by NSF Grant # CMS-0533322, *Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market*. All opinions are those of the authors and of neither NSF nor HUD. The authors wish to acknowledge the contributions of Dr. C. Theodore Koebel, Akshat Nayyar and Sean Wilson, without whose work this paper would not have been possible.

## Appendix

**Item 1: Innovation Commercialization Model** Reprinted by permission of Emerald Literati Network (UK)

		PHASE							
		Concept	Feasibility	Planning	Review Planning	Early Production	Review Early Production	Standardization	Market Release
		1	2	3	4	5	6	7	8
<b>FUNCTIONAL AREAS</b>	<b>Product Design</b>	PD1: Problem Identification	PD2A: Conceptual design, technical research	PD3: Detailed design, internal testing	PD4: Prototype, external testing,	PD5: Field testing	PD6: Design revision	PD7: Standardize product	PD8: Next generation of product designs
	<b>Process Planning</b>	PP1: Process research	PP2: Select processes	PP3: Design processes	PP4: Test, review process performance	PP5: Measure process times, quality, costs	PP6: Early production results, redesign	PP7: Standardized processes	PP8: Process improvement
	<b>Marketing</b>	M1: Market research	M2: Market fit & segmentation	M3: Demand forecast & marketing plan	M4: Review marketing plan	M5: Test marketing	M6: Revise marketing plan	M7: Manage sales	M8: Discover new markets
	<b>Supply Chain Management</b>	SCM1: Configure supply chain	SCM2: Identify sourcing options	SCM3: Detailed design of supply chain	SCM4: Model supply chain performance	SCM5: Execute production run	SCM6: Adjust supply chain controls	SCM7: Standardize sourcing	SCM8: Improve supply chain management
	<b>Human Resource Management</b>	HR1: Identify project leaders & stakeholders	HR2: Create leader positions, project team	HR3: Create staffing plan	HR4: Review & adjust staffing plan	HR5: Recruit, create, train, & supervise for production run	HR6: Review staff costs, performance, adjust staffing & training	HR7: Manage human resources.	HR8: Update human resources plan for next generation of products

<b>Accounting &amp; Information Systems</b>	AIS1: Research information technology	AIS2: Design accounting system	AIS3: Design information systems	AIS4: Install & test IS	AIS5: Audit production run	AIS6: Revise auditing procedures	AIS7: Standardize accounting systems	AIS8: Improve IS
<b>Financial Management</b>	FM1: Identify sources of capital	FM2: Prepare capital plan	FM3: Acquire Capital	FM4: Estimate capital costs & risks	FM5: Finance production run	FM6: Revise capital plan	FM7: Manage capital resources	FM8: Update capital plan
<b>Legal Management</b>	LM1: Identify liabilities & regulatory requirements	LM2: Establish patents, regulatory standards, incorporation	LM3: Design contracts, warranties	LM4: Review protections & standards by external certifiers	LM5: Monitor & production run	LM6: Revise contracts & standards	LM7: Monitor & control claims	LM8: Adapt contracts & standards to changing environment

**Item 2: Case Study Interview Questions** Reprinted by permission of Emerald Literati Network (UK)

11. What is your firm size and organization? How does your company champion the commercialization of innovative products?
12. Please discuss the history of your product.
13. Please discuss the position of your firm within the supply chain.
14. Please discuss your product in further detail in regard to its commercialization process until today. On a timeline, what decisions were made and what actions resulted from these decisions? What lessons were learned?
15. What decisions along the commercialization process would you consider MOST important?
16. Who was involved in key decisions? What did each individual need to decide?
17. What are the backgrounds of individual decision makers and their position in the company? What are their job descriptions and what incentives do those positions require from the corporation?
18. Who has final authority over all decisions? What is his/ her background?
19. Assuming we have an innovative product and we would like to commercialize this product, what options does the industry offer us? For example, was there a rule-based system for decisions to partner? Were there criteria for licensing?
20. What initial decision limits and constraints do you place on products you are considering for commercialization? Can they be entirely new products or must they support previous innovation? Are there legal limits, human resources limits, marketing limits, technology limits?

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## **TABLES AND FIGURES FOR INSERTION**

**Table 1: Case Study Demographics Reprinted by permission of Emerald Literati Network (UK)**

<b>Case</b>	<b>Type</b>	<b>Age of firm (yrs)</b>	<b>Annual Revenue</b>	<b>Legal Entity</b>	<b>Employees</b>	<b>Supply Chain Position</b>	<b>Champion</b>
1	Stair Railing System	14	#2 in the market	Corporation	75	Distributor, Manufacturer & Supplier	President
2	Glazing Laminate	15	N/A	Corporation	N/A	Manufacturer, Promotions & Code Compliance	Director of Strategic Alliances
3	Prefabricated Housing	10	33 million	Corporation	50+	Distributor & Manufacturer	Committee
4	Waste Management	10	N/A	Corporation	N/A	Distributor & Manufacturer	Vice President
5	Roofing System	100	N/A	Non-Profit Association	360 Members	Promotions, Code Compliance & Quality Assurance	Committee & Director of Operations
6	Metal Framing System	7	2 million	Corporation	20	Distributor, Manufacturer & Supplier	Operations Manager
7	Mechanical Equipment	65	#1 in the market	Corporation	317	Distributor & Manufacturer	President
8	Siding System	5	N/A	Corporation	4	Distributor & Manufacturer	President
9	Insect Abatement System	25+	N/A	Corporation	500+	Distributor, Manufacturer & Supplier	Committee
10	Construction Tool	5	0	Sole Proprietor	1	Designer & Manufacturer	Founder/ President
11	Renewable Energy System	25	N/A	Government Entity	N/A	Promotions & Code Compliance	Code Official
12	Structural Foundation System	30	N/A	Non-Profit Association	500 Members	Promotions & Quality Assurance	Vice President
13	Renewable Energy System	10	N/A	Corporation	10	Manufacturer & Distributor	President
14	Structural Foundation System	30	#1 in Market	Corporation	50 Employees, 25 Franchisees	Franchisor, Distributor & Manufacturer	President
15	Wall Panel System	20/75	5 million	Corporation	25+	Distributor	Committee & Sales Manager

Figure 1: Consensus Method Example Reprinted by permission of Emerald Literati Network (UK)

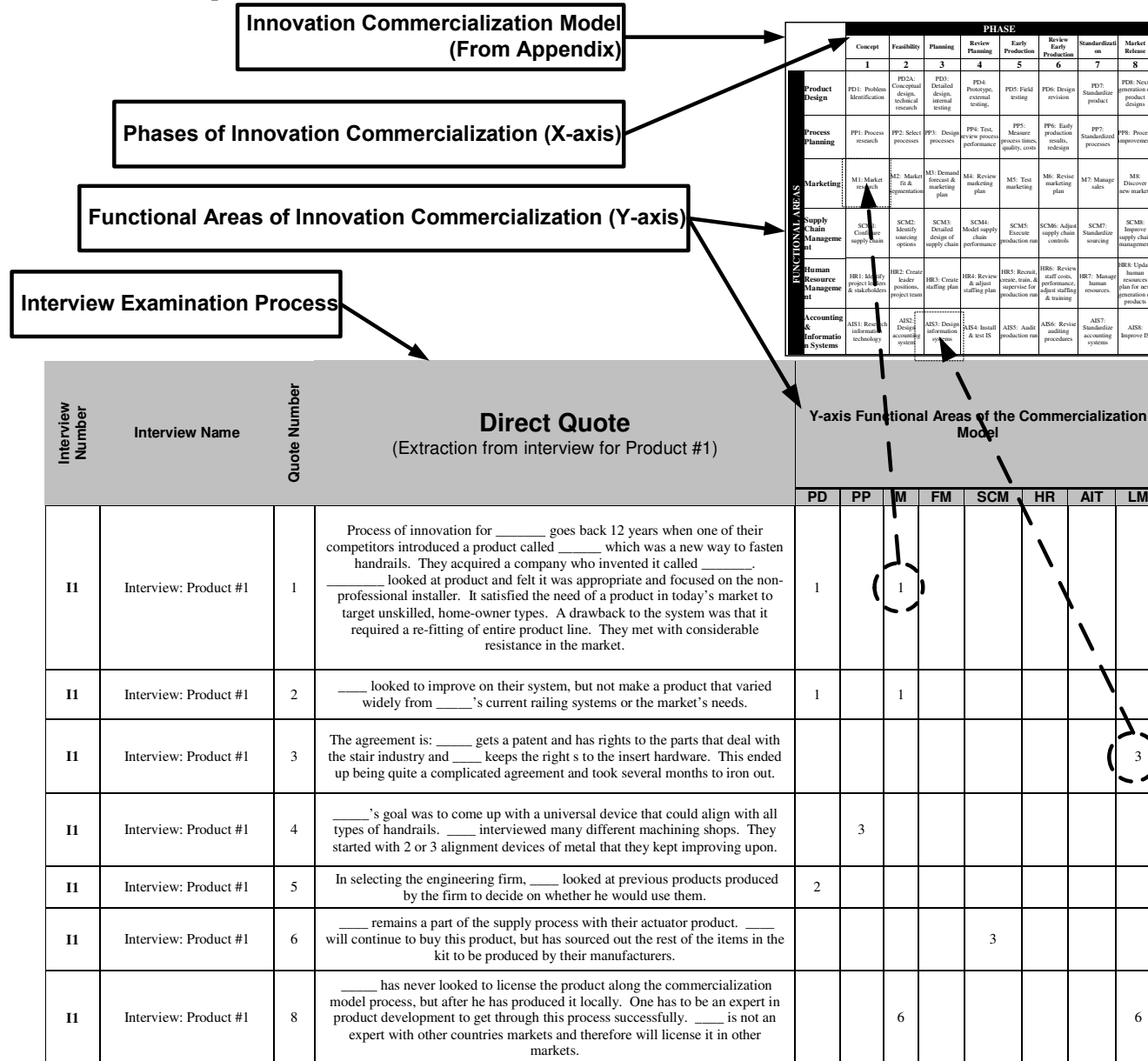


Table 2: Salient Commercialization Cells *Reprinted by permission of Emerald Literati Network (UK)*

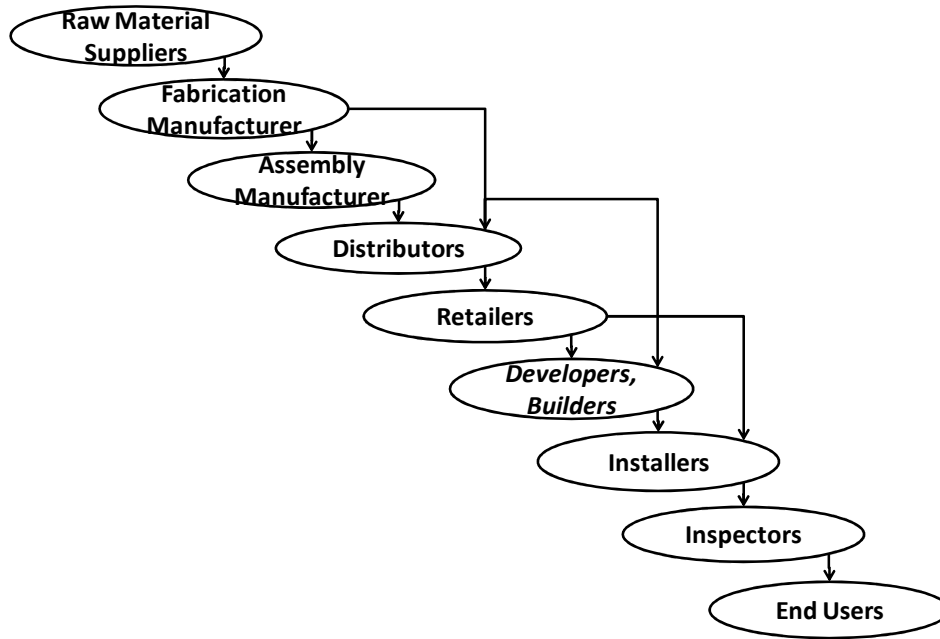
		PHASE								FUNCTIONAL AREA TOTALS
		Concept 1	Feasibility 2	Planning 3	Review Planning 4	Early Production 5	Review Early Production 6	Standardization 7	Maturation 8	
<b>FUNCTIONAL AREAS</b>	<b>Product Design</b>	18	25	13	12	2	2	0	6	78
	<b>Process Planning</b>	8	36	20	20	3	2	10	6	105
	<b>Marketing</b>	32	65	27	7	11	13	7	4	166
	<b>Supply-Chain Management</b>	6	7	7	3	1	3	2	0	29
	<b>Human-resource</b>	2	23	15	4	1	7	10	2	64
	<b>Accounting &amp; Info. Systems</b>	16	18	6	0	5	2	5	3	55
	<b>Financial Management</b>	0	4	1	0	0	0	0	0	5
	<b>Legal Management</b>	4	13	7	6	0	3	4	2	39
	<b>PHASE TOTALS</b>	68	166	83	40	21	30	38	17	

**Table 3: Commercialization Barriers and Accelerators Reprinted by permission of Emerald Literati Network (UK)**

Case	Type	Barriers	Accelerators
1	Stair Railing System	Poor distribution; Poor marketing; Not creating a “family” of products	Design review; Feedback Policy
2	Glazing Laminate	State-specific regulations and building code; Approval by engineers and architects	Complements existing products on the market; Simplicity of product; Proper advertising methods (internet); Aesthetic benefits of product; Product Champion
3	Prefabricated Housing	Personnel without industry background; Lack of product champions	Figuring out how the innovative product will affect their home (product) early in the process; Good marketing presence for innovations; Committee decisions for adoption of new products; Ability for product to complement current processes and products in the marketplace
4	Waste Management	State-specific regulations; Improper product testing and lack of informative literature; End-user education	Marketing; Distribution; Promotion and publicity; Technical design of product
5	Roofing System	Improperly trained personnel; Reliance on outside resources; Costs of product testing	Personnel trained with multiple skills; Pooling resources for training, testing and product education through a trade association; Good hiring processes; Attending industry conferences
6	Metal Framing System	Lack of properly trained human resources/personnel; Lack of accounting system; Lack of distribution; Lack of market knowledge	Not having to retool the manufacturing process for the innovation; Simplicity of the product and other product characteristics making it accurate; Feedback plan
7	Mechanical Equipment	Not being the first in the market; Product design lacking unique features; High cost of product; Not complementing previous products with new design	Complementing previous products with new product design; Not needing to re-educate end-users; Tracking system for new products
8	Siding System	Partnering with large corporations; Poor technical design; Government policy for small innovators; Poorly trained personnel; Difficulty of supply chain; Partnering with a company who does not share your vision for the product	Understand technical design of product needed by the marketplace; Financing from angel investors; Good distribution; Good partnering agreements; “Back door” negotiation ability when partnering; Product adaptability for various future applications; Quick product development and additional patenting; Understanding product limits
9	Insect Abatement System	Product cost (too high for market); Poor Client and end-user relationships	Good end-user relationships; Properly identifying the marketplace for your product; Understanding the industry; Creating advantage for the end-user through the product; Proper feedback; Proper company structure for product development (champions in individual departments)
10	Construction Tool	Cost of commercialization (after early phases); Cost of patenting	Developing something new; Personnel experience in the industry; Legal protection; Ability to discuss ideas with contemporaries (an inventors club)
11	Renewable Energy System	Poor feedback loops; Poor education of industry; Poor education of end-user; Poor installation techniques by end-user	FAB System: Features, Advantages, Benefits as development basis for product; Understanding a product’s market; Good problem identification for technical design of product; Good testing procedures
12	Structural Foundation System	Poor promotion and education of products; Product design and process design first (should make a business plan first); Poor identification of the customer	Product champions; Product education; Product research and literature; Code compliance; Proper business plan early; Understanding advantages of product early (cost, competitive, human resources, marketing); Proper Product testing
13	Renewable Energy System	Poor testing procedures; Poorly researching the market; Government policy and regulatory policy	Proper branding; Good distribution channels; Taking existing products and making them better; Supporting board of directors for the company with proper industry knowledge
14	Structural Foundation System	Poor planning in early stages of product development; “Founder’s Syndrome” (how a corporation grows after it has become successful with a product); Allowing users of the product to compete	Establishing a niche market; Designing a complementary product; Managing supply chain properly; Proper R&D facilities

15	Wall Panel System	Limits of the existing products for new innovation; Lack of early research into product limits and education	Problem identification for innovative product; Complementary innovations; Personnel with industry knowledge; Committee decision process
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**Figure 2: Innovative Product Supply Chain Reprinted by permission of Emerald Literati Network (UK)**



# Chapter 6 - Understanding the Role of Developer/Builders in the Concurrent Commercialization of Product Innovation

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## STRUCTURED ABSTRACT:

### **Purpose of this paper**

This paper presents part of continuing research on the challenges of entrepreneurial business ventures to commercialize innovative construction products in the residential construction industry. We use workshop and survey data on the role of the developer/builder to further develop our domain-specific commercialization model for residential construction products. The authors propose a cross-functional system to better facilitate innovation.

### **Design/methodology/approach**

The first stage of the current research consisted of a literature review, serving to operationalize the hypotheses through content analysis of sources of risk and the involvement of builders within a product's commercialization. The second stage of the research identified opportunities within the commercialization process for mitigating builders' risk through case-study interviews of 15 US manufacturers. The analysis and interpretation of these data determined the steps within our commercialization framework in which developers/builders can participate in the commercialization process. We further used the data from literature and case studies to create suggestions for risk-mitigating involvement by developers/builders, which we could validate through a survey of supply-chain participants. The third stage of the research derived a consensus among stakeholders along the supply chain regarding the most beneficial roles of developers/builders in the commercialization process. Stage three used Delphi methodology for surveying workshop participants in the study. Through a sequence of surveys and discussions in a workshop setting a consensus was developed.

### **Findings**

Successful concurrent commercialization requires risk sharing among all members of a product's supply chain. We advocate concurrent management in commercialization, which requires information sharing and knowledge transfer among supply-chain members early in a commercialization project. We advocate a special form of concurrent engineering for construction products, which we call concurrent commercialization (CC).

### **Research limitations/implications (if applicable)**

#### **Practical implications (if applicable)**

The research indicates that addressing the developer/builder risk along the entire supply chain is one key determinant to a successful commercialization project. It also indicates that commercialization involves more than just technical product design; commercialization cuts across all functional areas.

### **What is original/value of paper**

The research data along with our review of literature on product innovation and commercialization lead us to advocate concurrent engineering for construction products termed concurrent commercialization (CC). Since our research clearly indicates that the developer/builder is the most reluctant customer in the supply chain, CC applied to construction products emphasizes the influence of mitigating developer/builder risks in the design of a commercialization project.

## ***Introduction***

The complexity of the homebuilding industry presents challenges that resist the adoption of innovative products. Although developers/builders form only one group of stakeholders in the development and diffusion of new products, they are key players in this industry's notable resistance to innovation. Typical product supply chains contain many players including material suppliers, manufacturers, distributors, retailers, developers/builders, installers, regulatory bodies and end users. Among these players, recent literature suggests that developers/builders do not fully comprehend the benefits of new-product adoption and promote resistance to diffusion (BTI, 2005). Recent research and the findings presented in the current paper support the claim that the developer/builder's resistance to innovation forms a barrier to innovation that is unique to the homebuilding products industry.

Much of the business literature on new product development focuses on manufacturer R&D and best-practice. Recommendations for managing the project of developing a new product incorporate coordination of concepts such as Concurrent Engineering (CE). CE advocates the establishment of a complete supply chain, possible only if every member of the chain foresees net benefits to joining. This paper attempts to improve the role, risks and benefits of developers/builders as users of innovative technologies in residential construction.

The work presented herein is motivated by recurrent failures of small sized, resource limited developers of new homebuilding products in bringing these products to market quickly and effectively. The diffusion of new homebuilding techniques and the growth of new industries in the provision of construction materials are stifled by these failures. A recent National Science Foundation (NSF) workshop addressed barriers to technology transfer in the US housing industry. The 2004 NSF workshop found residential technology diffusion as one barrier to current technology transfer (Koebel, 2004).

Our research responds to this finding through the development of a unique framework for commercializing innovative products in the residential construction industry. Previous work developed and validated this framework for innovators in the residential construction industry through literature review and interviews that resulted in qualitative data from 15 case studies. The analysis and interpretation of these data offered conclusions about manufacturer practices in commercializing innovative construction products. Each interview described key decisions, risks and benefits during the successful commercialization of innovative products in the residential construction industry.

This work further validates this framework based on survey results from a workshop of construction industry experts who also reviewed and critiqued the commercialization framework. While previous

work centered on establishing the framework and tailoring it to the residential construction industry by testing it among manufacturers, this workshop acquired the perspectives of users of construction products, specifically builders. The workshop allowed us to discover roles and motivations of developers/builders, as business owners, in terms of risks and benefits in the adoption of innovative products.

Figure 1 shows a typical supply chain for construction products. Our representation of the supply chain is somewhat unconventional due to the inclusion of parties, such as developers/builders and inspectors, who may not physically possess a product, but who play critical roles in deciding whether or not the product proceeds to the next owner in the chain.

Figure 1 here

Risk along the supply chain plays a major role in determining the success of a product's development. Individual stakeholders of the supply chain can also influence strongly the success of commercialization through either veto or endorsement. Of the construction industry stakeholders, developer/builders are the most influential in determining commercialization success. Identifying their risks inherent in product commercialization is an important step in mitigating this risk. In this work, we establish the role and risks of developer/builders in the commercialization process through the following: determining roles and risks of developer/builders according to current literature; establishing manufacturers' impressions of builder/developers' roles and risks in commercialization through case study interviews; and soliciting opinions of stakeholders along the supply chain for these same roles and risks through workshop surveys. We then use a previously published case study to demonstrate that successful commercialization requires risk sharing among all supply chain members, specifically developer/builders. We finally advocate a new form of CE, termed Concurrent Commercialization (CC), as a risk-sharing solution early in the commercialization project.

Hypothesis #1: The developer/builder is the most reluctant participant in the supply chain of an innovative product, due to perceived risks of adoption. Due to the magnitude of their role, developer/builder reluctance highly influences product success in residential construction.

Hypothesis #2: Involvement of developers/builders early in the commercialization process mitigates the risks of adoption.

## ***Literature review***

### **Innovation Literature**

Our literature review rationalized and consolidated the terminology of three streams of research: innovation diffusion theory, construction innovation and commercialization strategy. Our research is guided by concepts developed in all three of these streams, consolidated in the coming sections of literature review. Before combining research, though, we should briefly identify differences. Diffusion theory is central to understanding innovation and attempts to explain the characteristics of social groups which affect the acceptance of a product. Innovation adoption theory attempts to further explain the characteristics of individuals within those social groups that affect the acceptance of a product (Rogers, 1995). Construction innovation literature draws on these existing theories. Unfortunately, scholarly literature in construction does not distinguish itself in the use of consistent terminology more than popular use (Koebel and McCoy, 2006). Commercialization literature is based on business theories. Sometimes confused with New Product Development, commercialization literature explains the actions and decisions required in getting a product to a given market (Clark and Wheelwright, 1993; Isabelle, 2004).

Commercialization models for innovation combine our three streams of research. These models describe the sequential decision process of coordinating and optimizing all of the technical and business decisions required by the successful introduction of a new product or service to the marketplace. Our previous work offered a framework for commercialization, shown in Table 1, in terms of phases (time) and functional areas (for technical and business best practices) in getting innovative products to market (McCoy et al., 2007). It is the decisions and actions where these phases and functional areas converge that are critical to the framework's efficacy. It is these areas that we attempt to better understand based on our literature review, our manufacturer interviews and our workshop surveys.

Table 1 here

### **Issues Facing Developers/Builders**

Confusion exists in the construction industry about the exact definition of the term “developer/builder.” A clarification of this term is therefore necessary for this work. We view the developer/builder as an entity that is positioned in the construction supply chain between distributors or retailers of products and the installers of products. Developers/builders deal in land inventories, the assembly process and procurement. The label “developer” is generally ascribed to managers of land inventories and subcontractors of the assembly process. Builders are distinguished by their core competency of

efficiently managing the assembly process. In many cases of home construction, the developer and the builders are the same business entity and the roles of both of these entities in adopting or refusing to adopt innovation in construction products are very similar. Hence, we define developer/builder as a single stakeholder group in a commercialization venture.

The world of developers/builders is characterized by de-centralization of resources, knowledge and projects, which often reinforces attitudes of risk aversion. Of importance is developer/builder's continued resistance to new technologies due to perceived risks of adoption. Reasons for this resistance are often attributed to uncertainties specific to the industry such as: *site variability*, *one-off nature*, *longevity of warranties*, *supply uncertainty* and *uncertainty inherent in the built environment*. Uncertainty is the source of risk. Uncertainty represents the likelihood of the occurrence of an event while risk represents the effects of this event (Pritchard, 1997).

*Site variability* in construction is typically described as a site-specific, project-based activity implemented by multi-party networks in which significant decision-making is decentralized closer to project sites and production procedures are standardized to achieve efficiency and quality control (Dubois and Gadde, 2002; Blackley and Shepard, 1996; Toole, 1998).

Housing's long lifecycle extends risks beyond those of many other industries, creating *longevity of warranties* (Blackley and Shepard, 1996; Koebel, 2003).

*Supply chain variability* or *uncertainty* in construction also resists innovation adoption. This path dependency is a developer/builder's resistance to change the processes that have worked well in the past (BTI, 2005; Toole, 1998).

Residential construction takes place in an environment that reinforces *uncertainty of technology adoption* (Koebel et. al, 2003; Ball, 1999; Slaughter, 1993).

Finally, *code compliance* of a product in a given building site can be uncertain as there currently exist multiple standards for codes and varying degrees of enforcement (BTI, 2005).

## **Risk**

Many publications discuss uncertainty in the residential construction industry and emphasize its impact on developer/builder firms, but do not identify and analyze risk metrics (Toole, 1998; Slaughter, 2000; Blackley and Shepard, 1996). Nevertheless, there is consensus in the industry about the importance of

successfully overcoming resistance to the adoption of innovative technologies (Koebel, 2004). We assert that understanding and mitigating risk in the commercialization of innovation will facilitate successful promotion of new technologies. Fisk and Reynolds (2006) considered many risks specific to construction sites without listing them. Koebel et al. (2003) placed developer/builder's sources of risk affecting the adoption and diffusion of innovation in residential construction into several broad categories. The National Association of Home Builders Research Center (NAHB, 2001) studied industry risks specific to the commercialization process. The Toolbase website of NAHB ([www.toolbase.org](http://www.toolbase.org)), in response to an initiative of the Partnership for the Advancement of Housing (PATH) to facilitate the adoption of innovative products, also categorizes risks for innovative, recently commercialized products. Koebel et al. (2003) and NAHB ([www.toolbase.org](http://www.toolbase.org)) together include broad categories of organizational, marketing, technical, supply chain, operational, environmental, financial and legal uncertainties or risks for such products.

We are not aware of any literature or resource that directly identifies the role of developers/builders and their sources of risk *during* the commercialization of residential construction products. Consequently, our research has distilled from the categories of uncertainty and risk defined by previous studies (in parentheses) a list of risks, which we later relate to the key decisions of our commercialization framework:

- *Consistency of installation* (based on supply chain, organizational and environmental risks)
- *Product lifecycle* ( Based on technical and legal risks)
- *Diffusion within/ across builder firms* (based on organizational and environmental risks)
- *Market awareness* (Based on financial and market risks)
- *Complexity* (Based on organizational and environmental risks)
- *Breadth of code compliance* (Based on operational and legal risks)

These categories consolidate previous research and industry resources and create a template for sorting our survey data. We define these dimensions in detail in Section 4 and further explain the distillation process in Table 2 of the results section.

We later advocate a special form of concurrent engineering (CE) for construction products, which we call concurrent commercialization (CC), based on our research data and review of literature. Concurrent engineering is a methodology for product design, which is founded on the close cooperation of stakeholders from marketing, engineering and the supply-chain in the design and marketing of a new product as well as the sourcing of its components (Miller, 1993).

The construction industry understands the concept of concurrent engineering and has made some strides to incorporate the concept in building design and assembly processes. CE for the construction site has historically been limited to “sample walls”. A recent advancement in project concurrency is the architect-sponsored extranet, an attempt to coordinate project information early in the process as well, which has largely failed to a lack of client buy-in (Barrow et. al, 2003). The industry still needs a broader view of CE to successfully commercialize products.

Quality Function Deployment (QFD) is a rudimentary application of a technique that has been long associated with CE. Fundamentally, QFD is a simple method for translating the requirements of one constituency of the supply chain into those of its immediate supplier. Since the 1980’s many companies have applied QFD to reflect the voice of the customer in the design of new products (Chase et. al. 2006).

## **Research Methodologies**

For this research, we base our case study methodology on Yin (1989) and Maxwell (1996). Case studies attempt to discover how and why real-life phenomenon occur, not relying on the ability to control these behaviors. For our purposes, the case study methodology best attempts to understand manufacturers actions and decisions during product commercialization as a result of documenting the actual process.

We also use the Delphi methodology for attempting to create consensus through surveying. Linstone and Murray (1975) advocate this methodology as best suited for removing ego and domineering personalities in developing consensus on a topic. We modify these techniques for use in a workshop setting, also where the pitfalls of ego could bias findings. Each survey’s results guide the construction of the succeeding survey and, when executed properly, produce a narrower diversity of opinions that converge on a consensus.

## ***Research Methodology***

### **Plan of the research**

The overall goal of this research is a prescription for overcoming the resistance of developers/builders to adoption of innovative products for residential construction. Our specific objectives are to test Hypothesis #1 and Hypothesis #2. We therefore find it pertinent to define the role of developers/builders within our commercialization framework through a consensus among various stakeholders of a commercialization project. This research uses a combination of methodologies to capture such data, as described in Figure 2 below. Our previous work, represented in Figure 1 and Table 1, motivated our hypotheses for the current research.

Figure 2 Here

The first stage of the research consisted of a literature review which served to operationalize the hypotheses through the identification of sources of risk and the involvement of builders within a product's commercialization process. This review was confined to US-based literature and these data, summarized in Tables 2, 3 and 4, are discussed later in this paper.

The second stage of the research identified opportunities within the commercialization process for mitigating builders' risk. Using the case-study methodology, we acquired the opinions of 15 US manufacturers. The analysis and interpretation of these data determined the steps within our commercialization framework in which developers/builders can participate in the commercialization process. These findings, summarized in Tables 3 and 4, are discussed later in this paper. We used the data from literature and case studies to create suggestions for risk-mitigating involvement by developers/builders, which we could validate through a survey of supply-chain participants.

The third stage of the research derived a consensus among a sample of stakeholders in the construction-products supply chain regarding the most beneficial roles of developers/builders in the commercialization process. We invited representatives from all supply-chain stages that are shown in Figure 1 and used the Delphi methodology for surveying the participants in the study. Through a sequence of surveys and discussions in a workshop setting a consensus was developed. Each survey's results were summarized and reviewed with the participants and the ensuing survey was tailored to pursue clarifications and agreement about basic issues of risk and involvement of developers/builders in commercialization.

The following sections further explain the specific methodologies used in this research.

## **Case-study Analysis**

The purpose of our case studies was to derive insights into the development process for manufacturers of innovative products. In order to investigate the commercialization processes of manufacturers, we used the four-step case-study methodology established by Maxwell's (1996):

1. *Establish a research relationship with those you will study*: we established supportive relationships with innovative product manufacturers with whom we continue to work. We identified innovative US product manufacturers through a National Association of Home Builders' (NAHB) designation, either at the International Builders' Show (IBS) or by through NAHB's toolbase.org database.
2. *Select sites and participants (the settings or individuals the researcher selects to observe or interview and other sources of information)*: we sampled manufacturers that cover a wide range of construction products and selected key personnel who were involved in new-product

development and commercialization. We made initial contact with these manufacturers through email and then conducted two interviews. These interviews were conducted in-person, if the manufacturer was within a few hundred miles of the researchers' home university, or over the phone.

3. *Collect data (how the researcher gathers the information that will comprise the case study):* we conducted two interviews of personnel who were experienced in new product development and obtained narratives of the commercialization processes that were used. The second interview pursued more depth to the answers given in the first interview.
4. *Analyze data (converting the data into useful information):* our research team, having experience and knowledge in research methods, business strategy and construction management, performed content analysis of the interviews. Each sentence of the transcripts of the interviews was carefully reviewed with respect to the commercialization framework of Figure 1. Specific attention was paid to those actions and decisions that considered the risks faced by developers/builders.

## **Delphi Method**

Having posited, from the case-study analyses of manufacturers, sources of risk and the potential for beneficial involvement of developers/builders in the commercialization process, we embarked on the third step in our research plan, which was to validate these assertions. Our research team performed this validation by applying the Delphi Method (Linstone and Murray, 1975).

The Delphi Method is a technique for estimating, forecasting or specifying a model through the opinions of a panel of experts in a field. The development of the Delphi Method was motivated by the fact that the judgment of experts is the best and, often, the only source of data when validating complex models of strategic plans, forecasts of technology development or industry evolution.

The Delphi Method acquires the opinions of experts through a series of surveys. The responses to each survey are returned to the researcher who summarizes them and reports to each panel member all of the opinions expressed by the panel. However, these reports are anonymous so that the pitfalls of ego, domineering personalities and the "bandwagon or halo effect" in developing consensus are avoided. After reviewing the opinions of all panel members, each expert is asked to complete a follow-up survey which is designed to refine his/her opinions and reconcile differences of opinion among the panel. The results of each survey guide the construction by the researcher of the succeeding survey. When designed

and executed properly, each round of surveys produces a narrower diversity of opinions. This process of survey, review and re-survey is repeated until consensus is achieved. Figure 3 summarizes the Delphi procedure.

Figure 3 Here

Some drawbacks of the Delphi Method include motivating panelists to participate in numerous rounds of surveys. Our solution to this problem was a workshop setting, which provided a convivial atmosphere without the distractions of the workplace. However, anonymity is not possible in a workshop setting; consequently, all discussions were carefully facilitated by the research team in order to avoid pitfalls that the method was designed to avoid.

In our application of the Delphi Method, the first survey was conducted via e-mail before the workshop. During the workshop we collected responses to the ensuing survey through laptop computers. The third and final survey was completed after the workshop via e-mail. The group reached consensus about the role of developers/builders in a product's commercialization and the sources of risk inherent in adoption of these products. Tables 3 and 4, explained in the next section, present these data from the Delphi study.

Since we were introducing the broad topic of commercialization to the panel, we decided to consolidate the phases of our model for the first survey in order to lessen initial confusion. Survey #1 asked questions regarding the barriers and accelerators present within the phases of our condensed framework and the importance of the phases and functional areas. A typical question asked was "How important is Product Design in the Design Phase," referring to the early phase of our commercialization framework. The respondents were asked to respond with a rating on a scale of 1 through 5, with 1= not important, 2= somewhat important, 3= important, 4= very important and 5= critical. In summarizing each question on a survey, we counted the number of panel members who responded to the question with a rank of 5.

Responses to Survey #1 were presented to the panel on the first day of the workshop. The discussion of the workshop centered on four functional areas within the commercialization framework: Product Design, Process Planning, Marketing and Supply-Chain Management. Survey #2 therefore sought specific details about these areas, as well the original areas of consensus, by asking about developer/builder decisions and actions within key steps of the commercialization framework. The survey also asked for the key performance indicators, decision variables and salient factors regarding the important commercialization decisions. Survey #2 was administered to panel members via a web site after the first day of discussion at the workshop. We discussed the results of Survey #2 on the second day of the workshop and then concluded our meeting. Again, discussion seemed to concentrate on the same steps of the

commercialization framework. The panel members requested time to process all of the discussion before entering into another survey.

Survey #3 was distributed online after the workshop and was based on the respondents' feedback from Survey #1 and Survey #2 and the workshop discussion. As our final evaluation of survey responses, we counted the number of respondents who ranked a statement with a score of 5 as an overall score for the question. If two-thirds of the panel responded with a rank of 3 or higher, we declared that a consensus had been reached on the statement.

## **Results**

### **Sources of Developer/builder Uncertainty**

This work consolidates different streams of research and fills gaps of previous work by identifying specific sources of risk to developers/builders in the adoption of an innovative residential construction product. We previously defined uncertainties as the sources of risks. Section 2 distilled the following list of uncertainties from literature and industry resources: *consistency of installation, product lifecycle, diffusion within/ across builder firms, market awareness, customize-ability and breadth of code compliance.*

Table 2 illustrates our distilling process for the above terms, combining sources of risk for developer/builders from current literature and industry resources. It also places them into our categories of uncertainties and into the context of our commercialization framework. Column one lists sources of uncertainties as previously described and column two references these uncertainties to the literature that reports sources of developer/builder risk. In an attempt to relate this information to the commercialization framework, column three associates sources of risk with a commercialization step from our framework, Table 1. The commercialization steps, represented by acronyms, are listed at the convergence of a phase and functional area in Table 1. For example, PD1 is the acronym for "Concept, Phase 1" and "Product Design." The sources of uncertainty and commercialization acronyms of Table 2 establish basic terms used in the following tables 3, 4 and 5.

Table 2: Sources of Risk

### **Developer/builder Risks**

We now present our findings about the location of developer/builder risk, and therefore uncertainty, in literature, case study interviews and the Delphi survey. Table 3 presents these findings by placing all three sources of data together. Column one is taken directly from the functional areas of Table 1. Columns 2

and 3 relate directly to Table 2 and its abbreviations, representing our distillation process of literature-based uncertainties and their location within the commercialization framework. Columns 4 through 7 count the number of instances in which developer/builder risk is specifically mentioned according to the other three columns.

Table 3: Location of Developer/builder Risks

According to the literature, risks are somewhat evenly spread around all functional areas and phases of the commercialization process. Technical attributes, market identification and organizational culture are the risks most mentioned in the literature. Product testing, prototyping and business strategy involve the second-most mentioned risks and advantages of commercialization. Product Development Phase 1 (PD1), Marketing Phase 2 (M2) and Human Resources Phase 1 (HR1) are the steps within a commercialization project which are most mentioned in the literature for risks and advantages. After that, PD2, PD3, PD4, PD6 and M3 are the steps with the second-most risks and advantages. As a functional area, Legal Management might be the least mentioned as containing risks and advantages.

Manufacturers do not report risks as evenly spread around all functional areas and phases of the commercialization process. Product testing, technical attributes and advertising are the most mentioned risks by manufacturers. Business strategy, market identification and distributor characteristics contain the second-most mentioned risks and benefits of commercialization. PD1, PD4, PD6, and M7 are the steps within the commercialization framework most mentioned for risks and advantages. After that, M2, M3 and SCM1 are the steps of the framework with the second-most mentioned risks and benefits. As a functional area, Financial Management is the least mentioned as containing risks and benefits.

Developers/builders report no functional areas and phases that have a large majority of risks. Advertising, financing and capital are the most mentioned risks by builders. The second-most mentioned risks and benefits of commercialization are spread among the phases in Product Design Process Planning and Marketing. M7, FM1 and FM2 are the phases within commercialization most mentioned for risks and benefits. After that, PD2, PD3, PD4, PD6, PP1, PP2, M1, M2 and SCM1 are the phases of commercialization with the second-most mentioned risks and benefits. As functional areas, Accounting and Information Systems and Legal Management are the least mentioned as containing risks and benefits.

For the architect and building code official (others), technical attributes present the most risks. Relative advantage and market identification contain the second-most mentioned risks and advantages of commercialization. PD1 is the step within the commercialization framework most mentioned for risks and advantages. M1 and M2 are the steps of the framework with the second-most risks and advantages. As

functional areas, Supply Chain Management, Accounting and Information Systems, Financial Management and Legal Management are the least mentioned as containing risks and advantages.

## **Survey of developer/builder involvement in commercialization**

We now present our findings about the involvement of developers/builders in a commercialization project. Table 4 presents these findings by again placing all three sources of data together, this time in the organizational context of the commercialization framework. Similar to Table 1, Table 4 contains functional areas of commercialization along the y-axis and phases of commercialization along the x-axis. Commercialization steps from our framework are now divided into 4 columns that represent literature, interview and survey data. As shown in the table legend, L stands for literature, M represents the manufacturer case studies and B and O represent the builders' and others' survey responses. The counts in these columns report the number of times in our content analysis that the role of the developer/builder is mentioned by each source for each step in the commercialization framework.

Table 4: Builder Involvement in Commercialization Framework (Table 1)

According to literature, developer/builder involvement is not evenly spread around all functional areas and phases of the commercialization process. Concept, Feasibility and Planning are the most mentioned phases of commercialization framework while Product Design is the most reported functional area of developer/builder involvement.

For manufacturers, developer/builder involvement is not evenly spread around all functional areas and phases of the commercialization process either. Concept, Feasibility and Standardization and Market Release are the most mentioned phases of commercialization while Marketing is the most reported functional area of developer/builder involvement.

Developer/builders see themselves involved in all functional areas and phases of the commercialization process. Concept and Feasibility are the most mentioned phases of commercialization while Marketing and Supply Chain Management are the most reported functional areas of developer/builder involvement.

Others view the developer/builder involvement in commercialization as limited to Concept and Feasibility phases and the marketing functional area.

## ***Analysis***

### **A Concurrent Engineering Approach to Commercializing Building Products**

The success of a new product requires the establishment of a complete supply chain (see Figure 1), which is possible only if every member of the chain foresees net benefits in joining the chain. Our case-study data and literature review reveal that the construction-products supply chain is marked by the endemic reluctance of developers/builders to adopt innovative products readily. Follow-up interviews of developers/builders exposed the reasons, obvious in retrospect, for their inertia. The home-building industry is competitive mainly in terms of land ownership. Once a developer/builder has acquired a prime piece of real estate, the most significant competitive battle has been won. The developer/builder's dis-incentive to innovation is also supported by the lack of awareness among home buyers of the relative merits of many construction products, which are not visible to home occupants. These two characteristics of the housing market conspire to create in the minds of developers/builders sensitivity to the risks of adopting innovation. We are compelled by these results to suggest that a successful commercialization of a home-building product requires creative approaches to mitigating the perceived risks of developers/builders or to share these risks with other members of the supply chain.

In common with classic concurrent engineering, our prescription of CC requires the involvement of all supply-chain parties in the design and development of a new product in the earliest stages of a commercialization project. However, CC broadens the scope of product-development decisions beyond the considerations of technology and product performance to all of the business decisions within the framework of Table 1. In effect, CC is directed at designing a commercialization venture as opposed to only designing a product. One point of view of CC, which draws a direct correlation to CE, is that CC expands the definition of the market to include all supply-chain participants, not just the end users.

Since our previous research indicates that the developer/builder is the most reluctant customer in the supply chain, CC applied to construction products emphasizes the influence of mitigating developer/builder risks in the design of a commercialization project. In general, risk management is implemented through three types of interventions: buffering, contingency planning and hedging. CC allows the incorporation of any and all of these three approaches to risk mitigation in the design of a product and the design of the supply-chain relationships.

### **Understanding Concurrent Commercialization: An example**

In this section we provide an example of a rudimentary application to CC of a technique that has been long associated with CE -- Quality Function Deployment (QFD). Our purpose in presenting this example

is three-fold. First, we wish to emphasize the origin of CC in the tried and proven methods of CE for coordinating a cross-functional design team and maintaining the focus of design efforts on key strategic goals. The pedigree of CC supports our assertion that CC is a practical extension of the conceptual framework of CE. Second, we wish to show the reader a concrete example of the process of CC. Finally, we wish to propose a modified version of QFD as a practical tool in CC.

QFD implements concurrent-engineering principles through the construction of a table known as the “House of Quality”. This table is a simple device through which customer requirements that are entered into the rows of the table are translated into supplier requirements, which are entered into the columns of the table. Traditionally, the House of Quality translates end-user requirements into product performance requirements in support of a new product design initiative. Once this translation is made, other translation tables are spawned, which translate product performance requirements into process performance requirements and material supply requirements. Our use of QFD for CC modifies the primary translation table in accordance with the goals and needs of commercializing an innovative construction product. We begin with the needs of developers/builders, as these members of the supply chain are most influential in the adoption of new products. Specifically, we consider the mitigation of the perceived risks of these supply-chain partners as the requirements that the design of the commercialization plan must meet. The design of the commercialization plan is expressed not only in terms of the technical performance of the new product, but more broadly in terms of the uncertainties, identified in Section 4, which influence the key functional-area decisions that comprise a successful commercialization plan. As a rudimentary, illustrative example, we have prepared in Table 5 a simplified representation of the primary QFD table for the commercialization of I-joists.

Table 5 here

In order to provide basic examples of commercialization risks, we define the rows of the QFD table in terms of developer/builder risks from exiting studies -- Fisk and Reynolds (2006) and NAHB (2001). These rows are an adaptation of risks a developer/builder who is considering the adoption of an innovative structural product such as I-Joists might encounter. For example, “material shortages” risk represents a combination of risks previously stated as “more efficient use of wood fiber resources translates into the ability to produce a great variety of larger, more structurally sound lumber products out of smaller, younger-growth trees, eliminating resource constraints imposed by the scarcity of larger, older trees (Fisk and Reynolds, 2006; NAHB, 2001).” Our “subcontractor resistance” risk combines previous risks stated as “Framers’ skill levels inadequate for successful installation of I-Joists (Fisk and Reynolds, 2006; NAHB, 2001).”

The sources of risk are uncertainties; features of a commercialization plan can address some of these uncertainties. Our CC QFD table is designed to translate efforts to reduce uncertainties into mitigation of the risks faced by the developer/builder. We derive the columns of Table 5 from the list of key uncertainties presented in our literature review and explained in Table 2. The arrows below each category refer to the desired direction of efforts to reduce risk and increase product success. For example, a higher “consistency of installation” will increase product acceptance in the market.

The numbers of Table 5 that have been entered at the convergence of a column and a row indicate the effect of the uncertainty reduction represented by the column on the risk represented by the row. A negative number indicates that a reduction in the column’s uncertainty reduces the row’s risk. The magnitude of the number indicates the strength of this cause-effect relationship, which is measured on a scale of 0 to 10.

The “roof” of the QFD table is used for indicating tradeoffs among the key performance measures of the commercialization plan. A plus sign in a cell of the roof indicates that performance measures of the two columns which intersect in the cell are mutually supportive (antagonistic). For example, improvements in the consistency of installation of a product enable more rapid diffusion across building firms, so we entered a plus sign in the cell of the roof that represents the dependency of these two performance measures. Reductions in the complexity of a product are likely to reduce the number of codes with which it complies, so we entered a minus sign. This sign represents the dependency of these two performance measures.

The column called “Competitive Benchmarks” indicates the level of competition in the product’s market. In preparing a commercialization plan, a review of major competitors reveals the levels of performance that developers/builders have come to expect in each dimension of risk. In Table 5 we illustrate this competitive analysis with a list of terms that express the standards set by the competition on each dimension of developer/builder risk.

Finally, the bottom of the QFD table produces the targets for the design of the commercialization plan. After studying the cause-effect relationships between the key performance measures of the plan and the dimensions of developer/builder risk, the relative importance of these risks to the developer/builders and the standards set by the competition, the commercialization team derives targets which will guide the key decisions of the commercialization process which are identified in our framework in Table 1.

## ***Conclusions and future research***

Developer/ builders are the supply chain members most influential in determining commercialization success. We found out that addressing the developer/builder risk along the entire supply chain is one key determinant to a successful commercialization project. We also found that commercialization involves more than just technical product design; commercialization cuts across all functional areas. Addressing risk for developer/builder adoption requires solutions in all of these functional areas. Through these findings, we propose the extension of concurrent engineering to concurrent commercialization as a strategy for meeting the challenge of developer/builder adoption.

Successful concurrent commercialization requires risk sharing among all members of a product's supply chain. We advocate concurrent management in commercialization, which requires information sharing and knowledge transfer among supply-chain members early in a commercialization project. BIM could be a technology that enables this transfer of knowledge within the members of the supply chain. Future research should develop the specification of concurrent commercialization in more detail in order to influence the development of BIM standards.

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## TABLES AND FIGURES FOR INSERTION

**Table 1: Commercialization Framework Reprinted by permission of Emerald Literati Network (UK)**

		PHASE							
		Concept	Feasibility	Planning	Review Planning	Early Production	Review Early Production	Standardization	Market Release
		1	2	3	4	5	6	7	8
FUNCTIONAL AREAS	Product Design	PD1: Problem Identification	PD2A: Conceptual design, technical research	PD3: Detailed design, internal testing	PD4: Prototype, external testing.	PD5: Field testing	PD6: Design revision	PD7: Standardize product	PD8: Next generation of product designs
	Process Planning	PP1: Process research	PP2: Select processes	PP3: Design processes	PP4: Test, review process performance	PP5: Measure process times, quality, costs	PP6: Early production results, redesign	PP7: Standardized processes	PP8: Process improvement
	Marketing	M1: Market research	M2: Market fit & segmentation	M3: Demand forecast & marketing plan	M4: Review marketing plan	M5: Test marketing	M6: Revise marketing plan	M7: Manage sales	M8: Discover new markets
	Supply Chain Management	SCM1: Configure supply chain	SCM2: Identify sourcing options	SCM3: Detailed design of supply chain	SCM4: Model supply chain performance	SCM5: Execute production run	SCM6: Adjust supply chain controls	SCM7: Standardize sourcing	SCM8: Improve supply chain management
	Human Resource Management	HR1: Identify project leaders & stakeholders	HR2: Create leader positions, project team	HR3: Create staffing plan	HR4: Review & adjust staffing plan	HR5: Recruit, create, train, & supervise for production run	HR6: Review staff costs, performance, adjust staffing & training	HR7: Manage human resources.	HR8: Update human resources plan for next generation of products
	Accounting & Information Systems	AIS1: Research information technology	AIS2: Design accounting system	AIS3: Design information systems	AIS4: Install & test IS	AIS5: Audit production run	AIS6: Revise auditing procedures	AIS7: Standardize accounting systems	AIS8: Improve IS
	Financial Management	FM1: Identify sources of capital	FM2: Prepare capital plan	FM3: Acquire Capital	FM4: Estimate capital costs & risks	FM5: Finance production run	FM6: Revise capital plan	FM7: Manage capital resources	FM8: Update capital plan
	Legal Management	LM1: Identify liabilities & regulatory requirements	LM2: Establish patents, regulatory standards, incorporation	LM3: Design contracts, warranties	LM4: Review protections & standards by external certifiers	LM5: Monitor & production run	LM6: Revise contracts & standards	LM7: Monitor & control claims	LM8: Adapt contracts & standards to changing environment

**Table 2: Sources of Risk Reprinted by permission of Emerald Literati Network (UK)**

<b>Distilled Sources of Risk</b>	<b>Literature References</b> (For developer/builder risks)	<b>Commercialization Framework Impact</b> (From Table 1)
<b>Consistency of Installation</b> (site variability and project variability):	<ul style="list-style-type: none"> <li>– Inconsistency between construction costs and land costs creates risk (Slaughter, 1993a);</li> <li>– Complex products and subsystems are risky (Toole, 1998);</li> <li>– Poor land acquisition might reduce profit (Koebel, 1999; Ball, 1999);</li> <li>– Integrative innovations are prohibitively risky (Slaughter, 1993a )</li> <li>– industry fragmentation affects profit (Blackley and Shepard, 1996);</li> <li>– Firms view subcontractor dependability and reducing call-backs as more important than reducing costs and liabilities through investment in innovative products (Koebel, 2003);</li> <li>– Reliability of suppliers reduces risk most (Koebel 2003);</li> <li>– Product variability creates risk in lifecycle costs (Toole, 1998);</li> </ul>	PD1: Problem identification PD2: Technical research and Concept design PP1: Process research PP2: Selecting processes SCM1: Configure supply chain SCM2: Identify sourcing options SCM3: Detailed design of supply chain FM1: Identify sources of capital FM2: prepare capital plan FM7: Manage Capital resources
<b>Product Lifecycle</b> (Includes durability, serviceability, maintainability, reliability and disposability)	<ul style="list-style-type: none"> <li>– Lack of ample field-testing and demonstration of results increases risk in adoption (Toole, 1998, Slaughter, 1993);</li> <li>– Product variability creates risk in lifecycle function and costs (Toole, 1998);</li> <li>– Firms view aesthetic improvements, total quality practices, subcontractor dependability and reducing call-backs as more important than reducing costs and liabilities through investment in innovative products (Koebel, 2003);</li> <li>– Lack of established companies that stand behind their products increases risk (Koebel, 2003);</li> <li>– Many technical information sources reduces risk (Toole, 1998);</li> </ul>	PD1: Problem identification PD2: Technical research and Concept design PD3: Detailed design and Internal testing PD4; PD6: Prototype and External testing LM2: Establish patents and regulatory standards
<b>Diffusion within and across Builder Firms</b> (knowledge transfer between builders, i.e. small, independent builders)	<ul style="list-style-type: none"> <li>– Knowledge transfer more difficult in large, multi-party networks (Toole, 1998);</li> <li>– Other builders, sales and supplier representatives, trade publications, in-house testing and subcontractors are less risky as sources of information (Toole, 1998);</li> <li>– Architects, homeowners, manufacturers, universities, technology transfer programs and subcontractors are more risky as sources of information (Toole, 1998);</li> <li>– Reliance on tacit knowledge less risky and more resistant to innovation adoption (Toole, 1998);</li> <li>– Larger firms have greater capacity to innovate (Blackley, Shepard, 1996; Oster and Quigley, 1977; Koebel, 2003);</li> <li>– Small firms lack capital for innovation including costs of implementation and require returns more quickly (Slaughter, 1993a);</li> <li>– Owner/president most influential followed by project manager in influencing decisions about new products/materials (Koebel 2003)</li> <li>– Owner/president almost exclusively responsible for final decisions about new products/materials (Koebel 2003);</li> <li>– Owner/CEO technology champion increases adoption (Koebel,2003);</li> <li>– Pro-innovation technology champion and emphasis on cooperation associated with higher innovation (Koebel, 2003);</li> </ul>	SCM2: Identify sourcing options HR1: Identify project leaders and stakeholders HR2: Create leader positions and project team HR3: Create staffing plan AIS2: Design accounting system FM1: Identify sources of capital FM2: Prepare capital plan LM3: Design contracts
<b>Market Awareness</b> (knowledge of end-user preferences or influence within the building process)	<ul style="list-style-type: none"> <li>– Innovation more necessary in lower-price houses (Oster and Quigley, 1977)</li> <li>– High-income consumers prefer custom houses, not necessarily innovation (Koebel et al, 2003);</li> <li>– Firms rely on marketability more than on reducing costs and liabilities through investment in innovative (Koebel, 2003);</li> </ul>	M1: Market research M2: Market fit and segmentation M3: Demand forecast and Marketing plan M7: Manage Sales AIS2: Design accounting system FM7: Manage Capital resources

	<ul style="list-style-type: none"> <li>- Consumer prefers visible benefits (aesthetics) to invisible building improvements, unless they provide short-term payoff (Koebel, 2003);</li> <li>- Increased quality seen as main benefit to innovation (Koebel 2003);</li> <li>- Creating image as innovative builder is secondary benefit (Koebel 2003);</li> <li>- Innovative product demand seen as risky (Slaughter, 1993, 2000);</li> <li>- Innovative product price volatility seen as risky (Slaughter, 1993, 2000);</li> <li>- Inadequate knowledge management and technology scanning seen as risky (Slaughter, 1993, Toole, 1998);</li> <li>- Increasing productivity was positively associated with innovation (Koebel 2003);</li> <li>- Increasing profit was negatively associated with innovation (Koebel 2003);</li> <li>- purchasing, design, and marketing departments have limited influence on adoption (Koebel 2003);</li> <li>- Pro-innovation business strategy associated with higher innovation (Koebel, 2003);</li> <li>- Higher cost presents most risk in adoption of innovations (Koebel 2003);</li> <li>- Operating in multiple markets reduces risks (Blackley and Shepard, 1996);</li> </ul>	
<b>Customizability</b> (complexity of product)	<ul style="list-style-type: none"> <li>- Complex product and subsystems increase uncertainty of adoption (Toole, 1998);</li> <li>- Lack of systems integrator increases risk (NAHB Research Center, 2001);</li> <li>- Complexity of establishing relative advantage increases risk (NAHBRC, Toole, Koebel);</li> <li>- Long time frame for production contributes to innovation resistance (Toole, 1998);</li> <li>- Integration of products creates less risk (Slaughter, 1993a);</li> </ul>	PD1: Problem identification PD2: Technical research and Concept design PP1: process research PP2: electing processes M1: Market research HR3: Create staffing plan
<b>Breadth of Code Compliance</b> (extent of local and regional regulation)	<ul style="list-style-type: none"> <li>- Operating in multiple markets increases opportunities for regulatory acceptance (Blackley and Shepard, 1996);</li> <li>- Codes and regulations increase costs and uncertainty associated with innovation (Blackley and Shepard, 1996; Slaughter, 1993a; Toole, 1998)</li> <li>- Builders do not necessarily see codes and regulations as a barrier to technology diffusion (Koebel et al., 2003);</li> <li>- Code barriers to innovation reduce risk in adoption of bad ideas (BTI, 2005);</li> </ul>	LM1: Identify liabilities and Regulatory requirements LM2: Establish patents and regulatory standards

**Table 3: Location of Developer/builder Risks Reprinted by permission of Emerald Literati Network (UK)**

Functional Area (From Table 1)	Sources of Risk (From Table 2 & Literature)	Commercialization Step (From Table 1 & 2)	Number of times developer/builder risk is mentioned			
			Lit. Review	Manuf. Case Studies	Delphi Experts (Builder)	Delphi Experts (Other)
<b>Product Design</b>	Product Lifecycle; Consistency of Installation; Customizability	PD1, PD2: Problem identification, Technical research and Concept design	5	18	3	7
	Product Lifecycle	PD3: Detailed design and Internal testing	4	4	3	0
	Product Lifecycle	PD4; PD6: Prototype and External testing	4	13	3	0
<b>Process Planning</b>	Consistency of Installation; Customizability	PP1; PP2: Process research and Selecting processes	2	6	3	0
<b>Marketing</b>	Market Awareness; Customizability	M1: Market research	2	1	3	3
	Market Awareness	M2: Market fit and segmentation	5	8	3	3
	Market Awareness	M3: Demand forecast and Marketing plan	4	8	2	1
	Market Awareness	M7: Manage Sales	1	10	6	0
<b>Supply Chain Management</b>	Consistency of Installation	SCM1: Configure supply chain	6	9	5	0
	Consistency of Installation; Diffusion within Builder Firms	SCM2: Identify sourcing options	1	5	0	0
	Consistency of Installation	SCM3: Detailed design of supply chain	2	3	0	2
<b>Human Resources</b>	Diffusion within and across Builder Firms	HR1: Identify project leaders and stakeholders	7	6	1	1
	Diffusion within and across Builder Firms	HR2: Create leader positions and project team	3	3	2	1
	Diffusion across Builder Firms; Customizability	HR3: Create staffing plan	1	6	1	0
<b>Accounting &amp; Information Systems</b>	Diffusion across Builder Firms; Market Awareness	AIS2: Design accounting system	3	2	0	0
<b>Financial Management</b>	Consistency of Installation; Diffusion among Builder Firms	FM1; FM2: Identify sources of capital and prepare capital plan	1	1	4	0
	Consistency of Installation; Market Awareness	FM7: Manage Capital resources	2	1	0	0
<b>Legal Management</b>	Breadth of Code Compliance	LM1: Identify liabilities and Regulatory requirements	1	5	1	1
	Product Lifecycle	LM2: Establish patents and regulatory standards	1	1	0	0
	Diffusion across Builder Firms	LM3: Design contracts	1	3	1	0

**Table 4: Builder Involvement in Commercialization Framework (Table 1); Reprinted by permission of Emerald Literati Network (UK)**

	Concept				Feasibility				Planning				Review Planning				Early Production				Review Early Production				Standardization				Market Release				Total				
	Phase 1				Phase 2				Phase 3				Phase 4				Phase 5				Phase 6				Phase 7				Phase 8								
Functional Areas	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	L	M	B	O	
Product Design	2	1	1	0	1	0	1	0	1	0	0	0	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	12
Process Planning	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Marketing	0	12	2	2	1	6	2	2	0	1	2	0	0	1	2	0	0	3	0	0	0	3	0	0	0	6	0	0	0	4	1	0	50				
Supply Chain Management	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	8				
Human Resources	2	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6				
Accounting & Information Systems	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3				
Financial Management	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2				
Legal Management	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3				
<b>TOTAL</b>	30				21				6				5				4				6				7				7								

**Legend:**

L = Counts of the literature-reported role of the developer/builder in the commercialization framework (Table 1).

M = Counts of the manufacturer-reported role of the developer/builder in the commercialization framework (Table 1).

B = Counts of the builder-reported role of the developer/builder in the commercialization framework (Table 1).

O = Counts of the other-reported (Code official, architect, engineer) role of the developer/builder in the commercialization framework (Table 1).

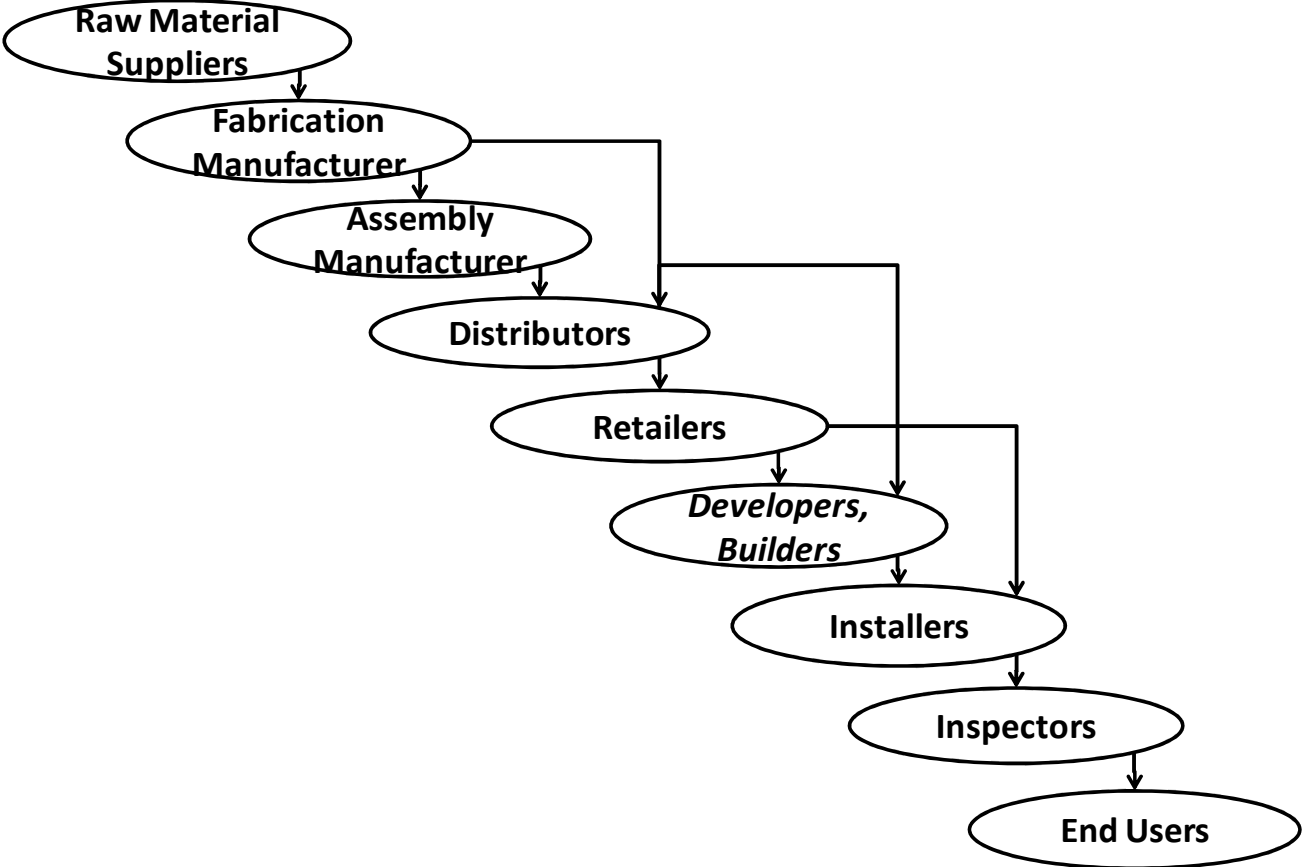
**Table 5: I-joist QFD Example Reprinted by permission of Emerald Literati Network (UK)**

\*\*\*Example here: I-Joists (NAHB, 2001)

Sources of uncertainty	Consistency of Installation	Product Lifecycle	Diffusion within/across Builder Firms	Market Awareness	Complexity	Breadth of Code Compliance	Competitive Benchmarks
	↑	↑	↑	↑	↓	↑	
Developer/ Builder Risks							
Material shortages	High	- 8		+2	- 5		Moderately Challenging
Decentralized decisions	Medium		- 5		+ 5	- 5	Extremely Challenging
Market Price	High			- 5	- 7		Un-challenging
Project Delays	Medium	- 6	- 4		- 8		Moderately Challenging
Loss of reputation	Medium		- 6			- 5	Un-challenging
Labor cost variance	Medium	- 5	- 5	- 7			Extremely Challenging
Labor unrest	Low	+ 5	+ 3	- 5	+ 5		Un-challenging
Subcontractor resistance	Low	- 5	- 3	- 5	- 8	- 4	Extremely Challenging
Warranty costs	Medium		+ 6		- 3		Moderately Challenging
Remediation costs	Low		+ 6	- 2	- 5		Moderately Challenging
Substitution costs	Low		+ 6	- 2	- 5	- 5	Moderately Challenging
U/M		Variety of Lengths (1)	Time before failure (2)	Promotional Installations (3)	Cost of competing product (4)	Hours of additional education(5)	Number of codes product is in compliance with (6)
Targets		5 Each	12 Months	78 Each	+/- 5%	10 hours	10
Competing product #1		6 Each	18 Months	50 Each	+10%	15 Hours	6
Competing product #2		4 Each	10 Months	45 Each	+ 2%	11 Hours	8
Gap analysis		2 Each	6 Months	5 Each	8%	4 Hours	2

- (1) Target for “Variety of Lengths” based on the total number of standard lumber lengths available on the market as of 2007: i.e. 2x4 x8, x10, x12, x16, x20.
- (2) Target for “Time before failure” based on the typical warranty period for a home builder’s work as of 2007: One year.
- (3) Target for “Promotional Installations” based on the implementation of one promotion per Metropolitan Statistical Area (MSA) as of 2007: 78 total MSAs.
- (4) Target for “Cost of competing product” based on the ability for a new product to cost plus or minus 5% of existing product most similar as of 2007.
- (5) Target for “Hours of additional education” based on the typical amount of continued education expected for supervisors in construction per year as of 2007.
- (6) Target for “Number of codes product is in compliance with” based on the International Building Code 2003 edition.

Figure 1: Supply Chain Reprinted by permission of Emerald Literati Network (UK)



**Figure 2: Research Plan Reprinted by permission of Emerald Literati Network (UK)**

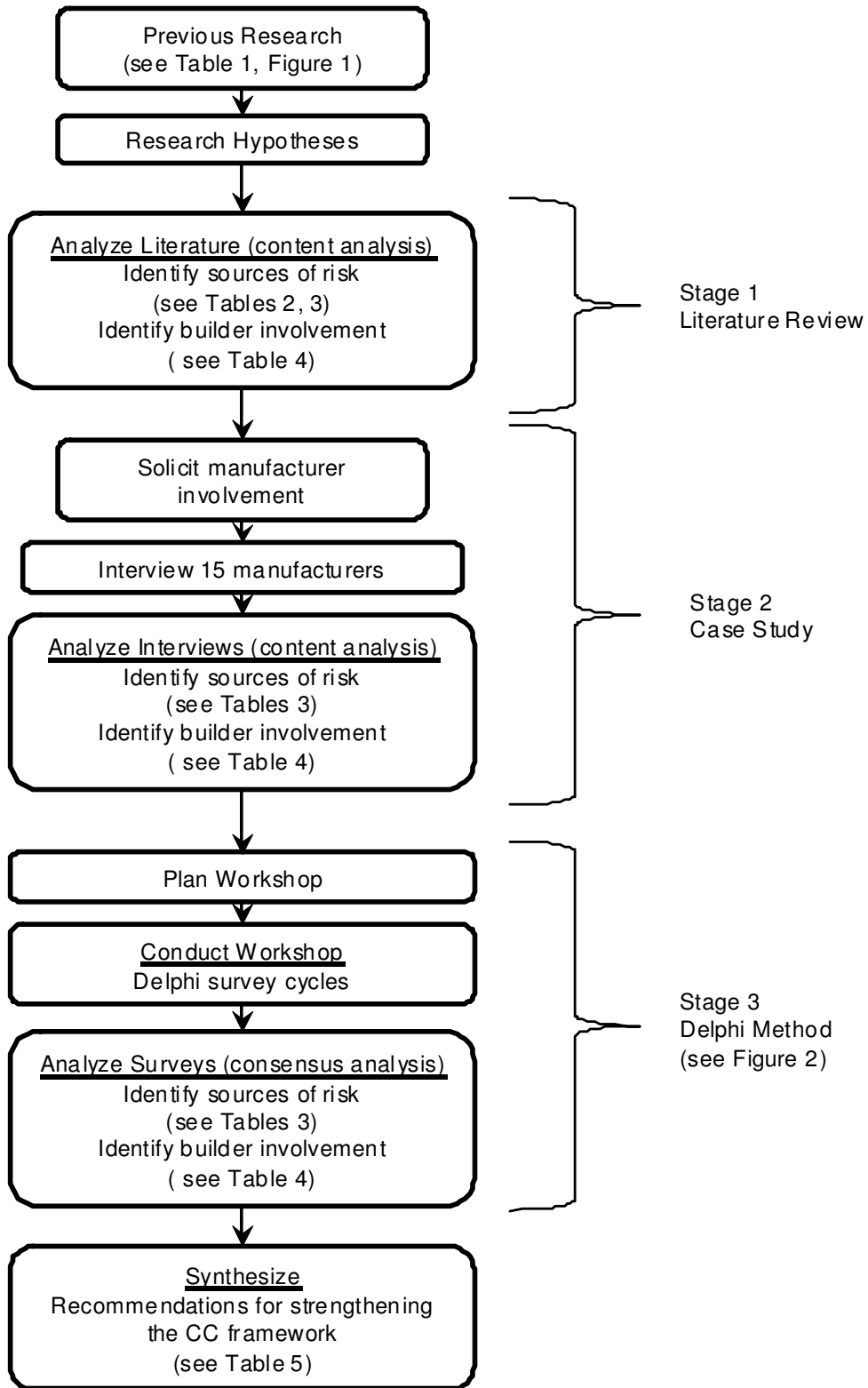
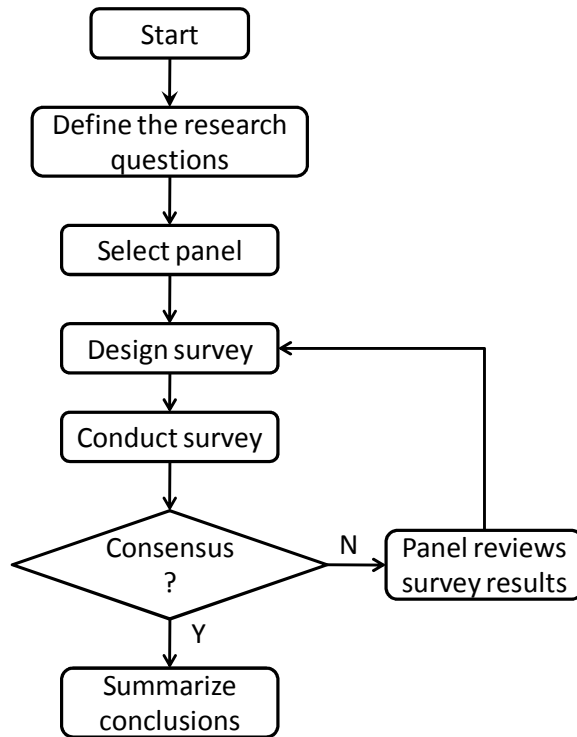


Figure 3: The Delphi method Reprinted by permission of Emerald Literati Network (UK)



# Chapter 7 - Concurrent Commercialization and New-Product Adoption for Construction Products

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**ABSTRACT:** This work is part of continuing research on the impact of sound commercialization practices on innovative product adoption. Studies of product-development practices of manufacturing firms and adoption patterns of installation firms in the construction industry reveal high uncertainty in the success of new-product development. Product-adoption reflects a market's *innovativeness*, the tendency of some individuals to adopt a new product before other members of a social system. Rogers (1995) categorizes market segments in terms of adoption thresholds. Many studies attribute delayed adoption to improper product-development or a lack of observable benefits of a new product. No studies, however, have assessed the effect of best practices for commercialization on adoption rates for residential construction products. Our previous work defined Concurrent Commercialization (CC) as a strategy for improving product adoption performance (McCoy et al., 2008). The current paper presents the basis for testing the effectiveness of previous CC research on adoption rates of products for the US residential construction industry.

**KEYWORDS:** ADOPTION, DIFFUSION, INNOVATION, COMMERCIALIZATION, RESIDENTIAL CONSTRUCTION, BUILDING TECHNOLOGY AND CONCURRENT ENGINEERING

## ***Introduction***

This work is part of continuing research on the impact of sound commercialization practices on innovative product adoption. Research to date of new-product development has revealed a high degree of uncertainty in product adoption and frustrating market resistance to innovations that, from the standpoint of technological value, deserve rapid adoption. A key factor in adoption is the *innovativeness* of a market, measured in terms of the tendency of some individuals to adopt a new product before other members of a social system. Many studies attribute delayed or limited adoption to improper product-development or a lack of observable benefits of a new product. However, no studies of residential construction products have empirically measured the effectiveness of best practices for commercialization on adoption success. Our previous work defined Concurrent

Commercialization (CC) as a strategy for improving product adoption performance (McCoy et al., 2008). The current paper presents the basis for testing the effectiveness of previous CC research on adoption rates of products for the residential construction industry.

In order to clarify the confusion which surrounds interpretations of the terms product invention, innovation and commercialization, we posit the following definitions. Product *inventions* are novel ideas or concepts in a developable state which represent real change to the adopting institution. Product inventions involve resources to establish intellectual property, therefore legal protection. Product *innovations* are novel ideas or concepts representing real change to the adopting institution which have been implemented. Inventions become innovations through the process of *commercialization*.

We define commercialization as the coordinated technical and business decision processes (and resulting actions) required for successful transformation of a new product or service from concept to market adoption. Commercialization is often considered a process within new-product development, not an expansion of it (Christensen, 2004 and Clark and Wheelwright, 1993). Much of the new-product development business literature focuses on individual best-practice steps of manufacturers or departments such as R&D (Souder, 1987, Clark and Wheelwright, 1993 and Kuczmarski, 1988). The current research considers commercialization as the coordinated execution of all processes required for product innovation success from a developed state to implementation within a given market.

The process of commercializing a product is often represented through a model of commercialization. Commercialization models describe the process of coordinating and optimizing all of the technical and business decisions required by the successful introduction of a new product or service to the marketplace (McCoy et al., 2006). Our previous work offered such a model, as seen in Table 1, in the form of a framework for implementing a strategy for improving adoption performance (McCoy et al., 2008). The current paper extends that contribution by advocating that CC practices lead to a higher adoption rate sooner in the commercialization process of products for the residential construction industry.

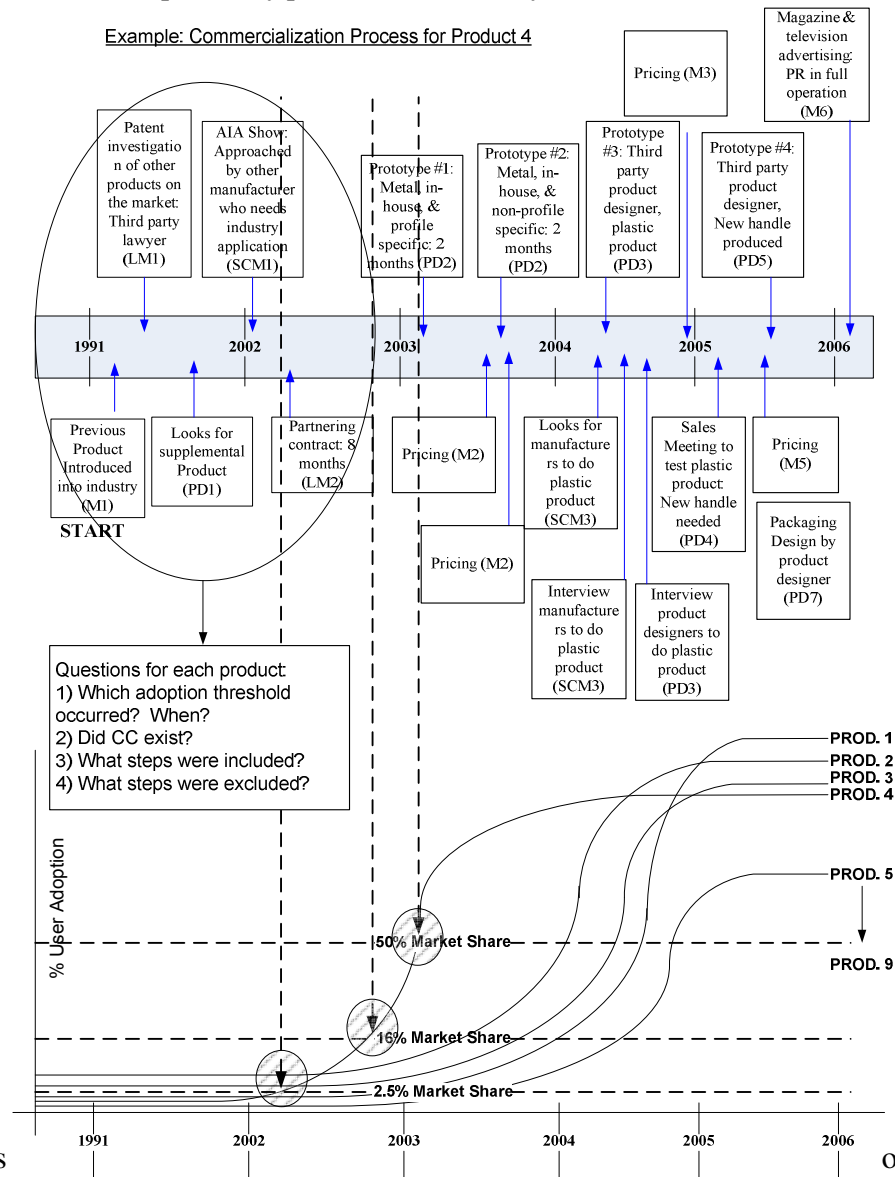
**Table 1: Concurrent Commercialization Model Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**

		PHASE							
		Concept	Feasibility	Planning	Review Planning	Early Production	Review Early Production	Standardization	Market Release
		1	2	3	4	5	6	7	8
<b>FUNCTIONAL AREAS</b>	<b>Product Design</b>	PD1: Problem Identification	PD2A: Conceptual design, technical research	PD3: Detailed design, internal testing	PD4: Prototype, external testing,	PD5: Field testing	PD6: Design revision	PD7: Standardize product	PD8: Next generation of product designs
	<b>Process Planning</b>	PP1: Process research	PP2: Select processes	PP3: Design processes	PP4: Test, review process performance	PP5: Measure process times, quality, costs	PP6: Early production results, redesign	PP7: Standardized processes	PP8: Process improvement
	<b>Marketing</b>	M1: Market research	M2: Market fit & segmentation	M3: Demand forecast & marketing plan	M4: Review marketing plan	M5: Test marketing	M6: Revise marketing plan	M7: Manage sales	M8: Discover new markets
	<b>Supply Chain Management</b>	SCM1: Configure supply chain	SCM2: Identify sourcing options	SCM3: Detailed design of supply chain	SCM4: Model supply chain performance	SCM5: Execute production run	SCM6: Adjust supply chain controls	SCM7: Standardize sourcing	SCM8: Improve supply chain management
	<b>Human Resource Management</b>	HR1: Identify project leaders & stakeholders	HR2: Create leader positions, project team	HR3: Create staffing plan	HR4: Review & adjust staffing plan	HR5: Recruit, create, train, & supervise for production run	HR6: Review staff costs, performance, adjust staffing & training	HR7: Manage human resources.	HR8: Update human resources plan for next generation of products
	<b>Accounting &amp; Information Systems</b>	AIS1: Research information technology	AIS2: Design accounting system	AIS3: Design information systems	AIS4: Install & test IS	AIS5: Audit production run	AIS6: Revise auditing procedures	AIS7: Standardize accounting systems	AIS8: Improve IS
	<b>Financial Management</b>	FM1: Identify sources of capital	FM2: Prepare capital plan	FM3: Acquire Capital	FM4: Estimate capital costs & risks	FM5: Finance production run	FM6: Revise capital plan	FM7: Manage capital resources	FM8: Update capital plan
	<b>Legal Management</b>	LM1: Identify liabilities & regulatory requirements	LM2: Establish patents, regulatory standards, incorporation	LM3: Design contracts, warranties	LM4: Review protections & standards by external certifiers	LM5: Monitor & production run	LM6: Revise contracts & standards	LM7: Monitor & control claims	LM8: Adapt contracts & standards to changing environment

This research concentrates on the discreet moment of use over ten years for thirteen innovative products included in the United States-based organization National Association of Home Builders' (NAHB) *Builders' Practices Survey* (BPS): Glazing Laminates, Panelized Light-frame Walls, Structural Insulated Panels, Steel Wall Headers, Composite Siding, Composite Decking, Floor Sheathing, Insulated Concrete Forms (ICF), Pre-cast Concrete Walls and four types of Oriented Strand Board (OSB).

Rogers' (1995) seminal work on innovation diffusion categorizes market segments in terms of adoption thresholds, and the time required to achieve each threshold serves as a measure of innovativeness. Adopter categories describe the individual characteristics of product adopters and their corresponding market percentages as: Innovator (2.5%), Early Adopter (13.5%), Early Majority (34%), Late Majority (34%) and Laggard (16%). Christensen (1997) placed emphasis on the threshold of 16% as the level of market penetration at which a product's adoption can be considered successful. Moore (2002) referred to this threshold as a *chasm* that required proper market identification early in the commercialization process for success. Our work relies on similar thresholds of BPS product adoption to test the effectiveness of concurrent commercialization practices. Figure 1 illustrates our comparison of adoption patterns for the innovative products in the BPS survey from the years 1996 to 2005 and the salient commercialization steps of a typical commercializing firm.

**Figure 1: CC Threshold Process Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**



The rest of this paper is organized as follows. We first explain our research methodology and provide an overview of the US-based NAHB Builders'

Practices Survey (BPS) and the case-studies which, together, provided the data for our research. We then propose, as results, our basis for statistical and case-study analyses for one of the thirteen products in the BPS between the years 1996 to 2005: Insulated Concrete Forms (ICF). We specifically aim to validate the effectiveness of the application of Concurrent Commercialization on US residential construction adoption data. We finally propose directions for future research.

## ***Literature Review***

Some solutions to disjointed product development incorporate concepts from Concurrent Engineering (CE). More recently developed concepts of CE advocate the establishment of “user-centric” manufacturing, where installer preferences drive product development and thus directly benefit both manufacturing and the installer (von Hippel, 2005). We define manufacturers as those who expect to benefit from *selling* a product or service to installers (Von Hippel, 2005). Installers are those firms or individual consumers that expect to benefit from *using* products or services provided by manufacturers (Von Hippel, 2005).

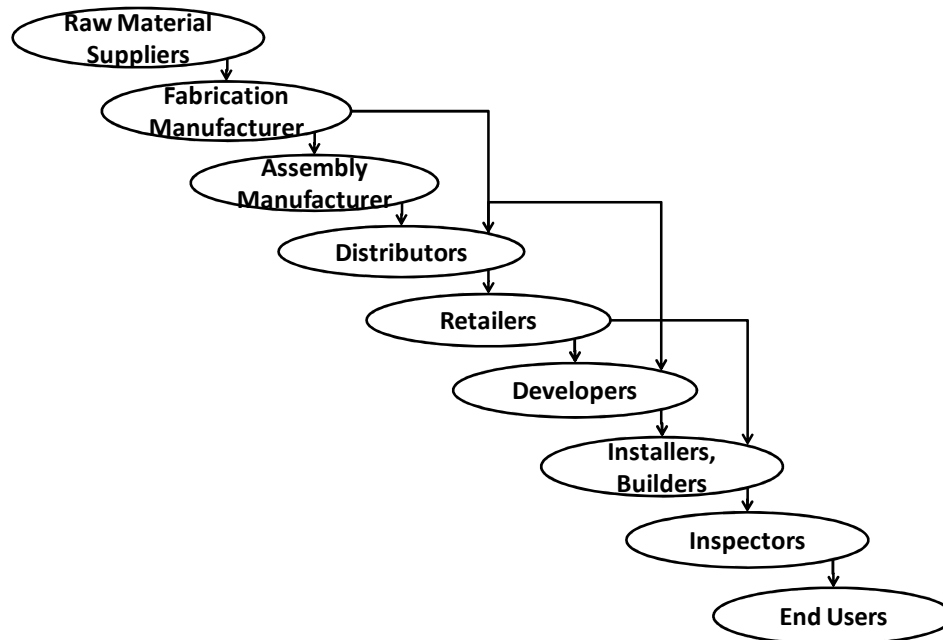
CE has become an established methodology in many industries over the last few decades for successful product development. CE dictates a parallel process among a product’s stakeholders in marketing, engineering and the supply-chain, as well as the sourcing of its components. Discovery of viable markets as an early basis of the product’s design is integral to CE; the emphasis is on achieving a product design that will be competitive in the marketplace.

The construction industry understands the concept of concurrent engineering but remains largely unaffected by it. Recent strides to incorporate CE have focused on the process in building design and assembly. McCoy et al. (2007) discussed historic examples of CE on the construction site as mostly physical models of work constructed during initial site preparation to resolve future issues of process and quality. These “sample walls” were a test panel of the final product’s assembly, built early in the construction process by all parties involved. Lansley (1987) and others discussed the need to respond to these physical, technical or human resource constraints for the rapidly changing construction industry through properly developed skill sets, a problem CE might solve. Other CE solutions include an understanding of construction markets and their needs (David, 1991, Yisa, 1996). Kalfan et al. (2001) found a lack of readiness for CE in the construction industry due to insufficient supply-chain planning. Hence, Vaidyanathan and O’Brien (2004) advocated IT as a solution to supply-chain readiness in the construction industry. A recent AEC study used extranet software to coordinate project information early in the design process and nevertheless reported failure due to lack of client buy-in

(Margulies, 2003). Successful product commercialization in the construction industry therefore needs a broad scope for CE that emphasizes the early, parallel coordination of technical and business functions for all value-chain entities.

Our previous research defined an expanded form of concurrent engineering for construction products, which we termed Concurrent Commercialization (CC) (McCoy et al., 2008). Similar to classic concurrent engineering, CC requires parallel involvement of all parties in the design and development of a new construction product in the early stages of a commercialization project. CC broadens the scope of product-development decisions beyond the considerations of technology and product performance to all of the business decisions. CC is essentially directed at designing a commercialization process, as opposed to designing a product, which benefits the product development from exposure to all members along the construction supply chain of Figure 2. CC, drawing on CE, expands the definition of the market to include all supply-chain participants, not just the installers and advocates the establishment of a complete supply chain, possible only if every member of the chain foresees net benefits to joining. In strengthening the commercialization process, the product might experience better probability of success.

**Figure 2: Construction Supply Chain Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**



A review of current adoption literature reveals the risks associated with adoption are somewhat evenly spread around all functional areas and phases of Table 1 (BTI, 2005; Ball, 1999; Blackley and Shepard, 1996; Dubois and Gadde, 2002; Koebel, 2003; and Toole, 1998). Technical attributes, market identification and

organizational culture contain sources of risk most often mentioned in the literature. Product testing, prototyping and business strategy involve the second-most mentioned sources of risks. CC is designed to mitigate the risks of adoption for all members of the supply chain.

To study the effect of CC on new-product adoption rates by installers, we assembled data from the National Association of Home Builders' (NAHB) Builders' Practices Survey (BPS) for the years 1996 through 2005. The Builders' Practices Survey (BPS) is the instrument for our view into innovation adoption for these years. The BPS survey collected data from 1956 firms for 1996, 1656 firms for 1997, 1931 firms for 1998, 1821 firms for 1999, 2202 firms for 2000, 2777 firms for 2001, 2034 firms for 2002, 2241 firms for 2003, 2049 firms for 2004 and 2003 firms for 2005. These data were collected on the "establishment" basis, meaning a national firm might have 2 local offices answering the same survey in the same year. The BPS survey had a total of 20,670 inputs for the years 1996 through 2005, acting as the basis for this research. The survey was distributed through the internet, then printed and mailed. Firms' responses received a "record number," thus keeping the data anonymous. The BPS limits its possible respondents to those who completed single or multifamily housing units for the year of the survey.

Blackley and Shepard (1992) offered a similar study in that it considered BPS data. Their work examined a sample of 417 builders for one year, while ours considers adoption data over several years. In defining adopters, Blackley and Shepard (1992) included only single-family detached home sites in the continental United States whose respondent reported revenue from new construction. Based on the BPS respondent characteristics, these parameters might eliminate several potential areas of our products' market: those homebuilders whose most-important operation is not detached, single family homes for sale and those whose focus is not on homebuilding, as opposed to property development (Blackley and Shepard, 1992). Still, it is important to note that our study follows commercialization success, not individual homebuilder success.

Toole (1998) also studied firm adoption success for homebuilders, while basing his work on products' relative advantage that increased the organization's performance. According to the toolbase website, NAHB and PATH, all of the products included herein provide relative advantage and organizational performance incentives, either through efficiency of installation or durability of the product. Based on the BPS respondent characteristics, these parameters might further eliminate several potential areas of our products' market: those homebuilders whose most-important operation is not speculative development of detached, single family homes for sale. However, our study aims to measure commercialization success.

Much of the innovation diffusion modeling literature considers product adoption as a discreet moment during the life cycle of the product or technology, usually the point of first purchase (Sexton and Barrett, 2004). The BPS does not measure adoption in the sense of when the product is first used, instead it measures use as a discrete variable and degree of use as a continuous variable. Repeat purchase diffusion models, however, reflect the fact that each consumer makes many purchases of the product during the life cycle of the product, or frequently tries the product before committing to adoption. Koebel et al. (2003) studied the declining rate of diffusion and the point at which the number of adopters in time has peaked, calling it an inflection point.

## ***Methodology***

Our thesis is that CC is a collection of sound principles for guiding the commercialization process. We posit the following null hypothesis in order to test this assertion.

Null Hypothesis: The implementation of principles of CC in a commercialization process does not improve market penetration.

Our data collection was executed in two phases. Our explanatory variables were measured through case studies. Our measure of market penetration was obtained from the BPS Survey data. While the BPS contains hundreds of product types overall and close to fifty that are specifically named, we limit our study of the commercialization process to 13 products for which we obtained case-study data. This limited view nevertheless offers previews to a larger study that will incorporate more case studies of named products.

## **Measuring Concurrent Commercialization through Case Studies**

We used case studies, specific to the construction industry, to obtain qualitative data aimed at determining the extent to which innovators applied the principles of CC in their commercialization efforts. Maxwell's (1996) four main components for case-study research acted as the basis of our collection strategy:

1. Establish a relationship with the manufacturer of ~~nine~~ thirteen innovative products in the BPS
2. Sample these manufacturers and their products through interviews
3. Collect these interviews as case studies
4. Analyze these interviews through expert panel consensus about the timing and sequence of actions of the commercialization process that are important to success.

McCoy et al. (2008) established the case study methodology for the process of capturing interviews for this work. Previous work justified our standards for measuring the extent of CC implementation through collection of information about the specific steps in a commercialization project in order to add domain-specific features to the commercialization framework (McCoy et al., 2007). Our sampling selected persons with proprietary knowledge that could not be obtained elsewhere and obtained the interview narrative data in their own words (Maxwell, 1996). The research team performed content analysis by examining the interview transcripts line by

line, at first independently, and then as a team. The team identified each action or decision described by a respondent in terms of its location in the commercialization framework of Table 1. Group discussion resulted in consensus about the placement in the commercialization framework of technical and business decisions and actions identified by a respondent.

Based on the definitions of commercialization and classic concurrent engineering, a concurrent commercialization requires the parallel development of technical and business decisions through the involvement of all supply-chain parties in the earliest stages of the commercialization model. We define the early stages as Phases 1 and 2, the Concept and Feasibility phases, before moving to the next stage of commercialization. McCoy et al. (2008) found this point in commercialization as a critical juncture, as moving a product farther along the commercialization process requires a larger commitment of resources. Improper preparation towards the commitment of these resources often proves fatal for a commercialization project. Therefore, a checklist for a successful CC project would include the sixteen steps listed in the first two columns of Table 1.

The consensus regarding the implementation of CC requirements for each of the thirteen BPS products in our sample is shown in Table 2. The evaluation of interview data found the commercialization plans for Engineered Oriented Strand Board (OSB), Fiber-cement Siding and Plastic Composite Decking to contain parallel development and coordination of all steps within a phase of the commercialization framework before moving to the next phase. Precast Concrete Walls, Insulated Concrete Forms (ICFs), Structural Insulated Panels (SIPs), Cold-formed Steel Wall Headers and Glazing Laminates did not contain parallel development in the earliest stages of the commercialization process. Table 2 lists early commercialization decisions which were included or omitted in each commercialization plan as well as the percentage of the sixteen key CC decisions from the first two phases of commercialization which were included.

**Table 2: BPS Product Concurrent Commercialization Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**

<b>Product</b>	<b>CC Steps Included Early</b>	<b>CC Steps Omitted</b>	<b>% of CC Cells Performed</b>	<b>CC Implemented?</b>
Cold-formed Steel	PD1;PD3;M1;M2; FM1;HR1	PD2;PP1;PP2;SCM1; SCM2;FM2;HR2; AIS1;LM1;LM2	38	No
Precast Concrete Wall below grade	PD2;PD3;PD4;PP3;M3; FM1;LM3	PD1;PP1;PP2;M1; M2;SCM1;HR1;HR2; FM2;AIS1;LM2	44	No
Precast Concrete Wall above grade	PD2;PD3;PD4;PP3;M3; FM1;LM3	PD1;PP1;PP2;M1; M2;SCM1;HR1;HR2; FM2;AIS1;LM2	44	No
Glazing Laminates	PD1;PD2;PD3; M1;M2;HR1;LM1	PP1;PP2;SCM1;SCM2; HR2;FM1;FM2;AIS1; AIS2;LM2	44	No
Structural insulated panels	PD1;PD2;PD3;PD4; PD7;PP7;M1;HR2; FM2;LM4	PP2;M2;SCM1;SCM2; HR1;AIS1;AIS2;FM1; LM1	63	No
Insulated Concrete Form below grade	PD1;PD2;PD3;PD4; PP1;M1;M2;M3;SCM1;HR1; HR2;FM1;FM2	PP2;SCM2;IS1;AIS2	81	No
Insulated Concrete Form above grade	PD1;PD2;PD3;PD4; PP1;M1;M2;M3;SCM1;HR1; HR2;FM1;FM2	PP2;SCM2;IS1;AIS2	81	No
5/8" Engineered OSB-1st	All Cells Phases 1, 2, 3 & 4		100	Yes
3/4" Engineered OSB-1st	All Cells Phases 1, 2, 3 & 4		100	Yes
5/8" Engineered OSB-2nd	All Cells Phases 1, 2, 3 & 4		100	Yes
3/4" Engineered OSB-2nd	All Cells Phases 1, 2, 3 & 4		100	Yes
Fiber Cement Siding	All Cells Phases 1, 2, 3 & 4		100	Yes
Plastic Composite	All Cells Phases 1, 2, 3 & 4		100	Yes

Table 3 shows a typical question on the survey that collects adoption information on exterior wall types. In this example, “Types of Exterior Wood and Steel Walls” is the initial product cluster. Panelized light-frame (factory-built panels) and Structural insulated panels (SIPs) are considered to be the innovative technologies within this cluster. Recent light frame steel technologies have made factory-built panels a viable alternative to on-site shear wall construction. SIPs have been around in principle since the 1930s, but not until recently has glue and extruded polystyrene technology allowed them to be used extensively throughout the exterior of a home.

**Table 3: Typical BPS Question Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**

<i>What <b>percent</b> of your dwellings with wood and steel walls used the following types of construction?</i>	
<b>Types of Exterior Wood and Steel Walls</b>	<b>% Homes</b>
Site-built light-frame (2x4s, 2x6s)	
Panelized light-frame (factory-built panels)	
Modular (factory-built structure)	
Structural insulated panels	
Post and beam or “timber frame”	
Logs	
	<b>100%</b>

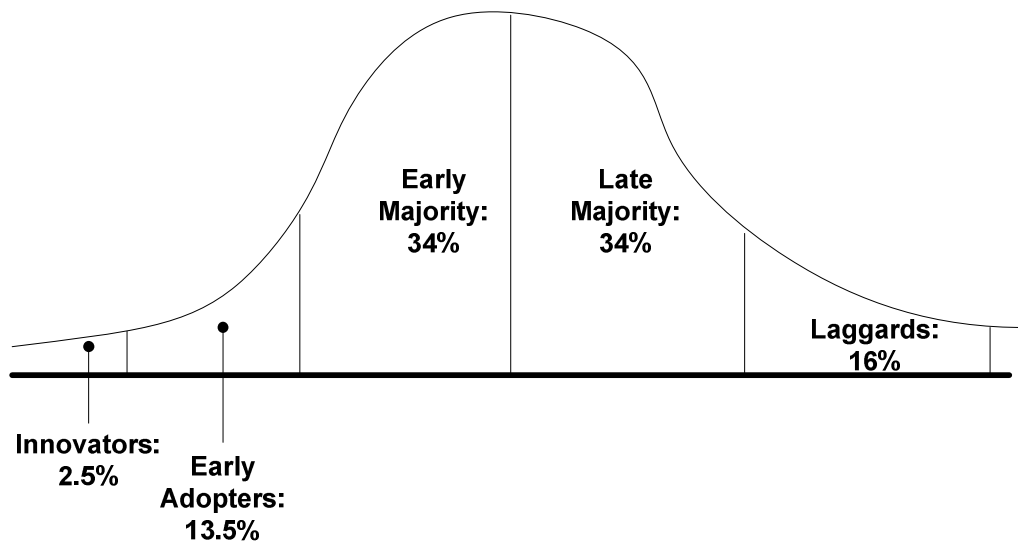
It is also important to describe the innovative nature of the products included in this study, as it might affect the probability of adoption. We identified each product in the BPS as either “traditional” or “innovative,” based on their inclusion in the NAHB PATH innovative technology database and our previous definition of innovation (Toolbase, 2008). NAHB and PATH, through the Toolbase website, provide a standard definition for each product as either “innovative Products or Processes” or not. Precast concrete walls studied here have been present as a concept since 1908. Still, no previous products established the interlocking design that provides a structural, insulated and waterproofed exterior wall space, either below or above grade, as this new generation of products. Structural Insulated Panels also were investigated in the early 1900’s, only to recently incorporate technology that offers proper exterior durability. Insulated Concrete Forms use this same technology to provide below-grade insulation and strength through interlocking extruded polystyrene forms. No similar ICF technologies existed in the past. Engineered OSB products use recent chemical technology to improve previous OSB products, thus making the new generation nearly impervious to moisture. Cold-formed steel headers allow the easy installation of curvilinear openings, previously difficult due to intricate wood framing. Glazing laminates improve previous light filtration systems through increased safety functions that deter theft and protect during natural disasters. Fiber cement siding and plastic composite decking improve on existing natural products that prematurely deteriorate and reduce maintenance issues, while fiber cement siding is additionally fire resistant.

## Results

### Measuring Market Penetration

Product adoption improvement is often measured in terms of discreet moments of use when market penetration reaches certain thresholds. These thresholds in use reflect key points in the cumulative distribution of demand across a market. Using a normal distribution of adopter behavior as a guide (see Figure 3), Rogers (1995) separates the adopter characteristics of a social system into the following five categories: Innovator (2.5%), Early Adopter (13.5%), Early Majority (34%), Late Majority (34%) and Laggard (16%). Precast concrete walls, SIPs, fiber-cement siding and plastic composite decking were developed commercially in the 1980s. ICFs, Engineered OSB, steel wall headers and glazing laminates were commercially developed by the mid 1990s. All products were nationally available from the years 1996 through 2005, with the possible exception of products developed in the 1990s, whose data we might limit to after the year 2000. BPS data for all products nevertheless shows consistency in adoption rates over the time period 1996 – 2005, leading us to conclude that each of the thirteen products in our study reached terminal market penetration by the year 1996. In comparing the commercialization success across these products, we therefore average the adoption percentages for each product over this ten-year period.

**Figure 3: Normal distribution of Innovation Adoption Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**



In order to measure the degree of product adoption at any time, two pieces of data are needed: the number of adopters to date and the number of potential adopters in the market. The BPS provides yearly data of the percentage of homes on which a product is used by each builder who responded to the survey, which provides the first piece of necessary data.

The BPS also acquires general data regarding demographics and the type of construction that is performed by each respondent. These data provide a basis for measuring the potential market for each product. Precast concrete walls serve as a foundation for the housing unit. The potential market for this product cannot include responses of the following general characteristic “foundation types:” crawl space continuous wall, concrete slab on grade or pilings and piers or raised pilings. The nature of precast concrete walls also requires one side to remain unfinished, usually the exterior face. Precast concrete wall systems are less likely to be adopted by builders of homes that contain common walls, those that require a finish on two sides. While it is possible to integrate the two systems, precast concrete walls and a separate interior common wall, it is unlikely. Precast concrete wall systems and ICFs do not apply to respondents who report only one story of home (i.e. no basement). ICFs have a potential foundation market limited to full basement, partial basement and crawl space, partial basement and slab and crawl space continuous wall. Engineered OSB does not have a potential market of builders with concrete slab on grade and one story, as there is no place for a wooden sub-floor. Composite decking’s potential market is limited to those builders who build off of the ground, as suggested by foundation types full basement, partial basement and crawl, partial basement and slab, crawl space continuous wall and piers or raised pilings. Cold-formed steel wall headers are a decorative product, thus making it unlikely that a builder for rental units would spend the extra cost. Finally, all exterior wall systems with SIPs should be excluded from the potential market for fiber-cement siding. The weight of the product requires its fastening to wall studs, which are unavailable in the SIPs wall system. While fiber-cement siding websites allow for the possibility of this connection, the use of the product with SIPs is unlikely. Only glazing laminate have no potential limits to their market. No other products may apply to any house type or market in which they were widely available.

In analyzing the BPS data, we need to use the considerations described above in order to estimate the potential market for each product in each year of the survey. Table 4 shows a summary example for Below and Above Grade ICFs. Table 4 summarizes the number of adopters of each product type as well as the potential market for the product cluster. The potential market is listed per year beneath the counts for each cluster. In order to measure market penetration in terms of percent adoption, we divide the number of respondents who have tried the product by the potential market and multiply this number times 100. For example, based on the sample information in Table 4, the 1996 adoption percentage for Above Grade ICFs is calculated as:  $(17/350) \times 100 = 4.86$ . These percentages of product adoption based on trials for the potential market are then listed in Table 5. Of specific interest are those products whose adoption rates grow the most during the years of the survey, as in this example of Above Grade ICFs. In contrast, other products’ adoption rates might remain relatively constant, or lessen, in their trials.

**Table 4: Product Counts Summary by Year Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**

Cluster Name	Product Type	Year									
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Below Grade Exterior Walls	Insulated Concrete Form	29	32	52	32	81	115	89	82	98	89
<i>Total Potential Market</i>		<i>1577</i>	<i>1302</i>	<i>1534</i>	<i>1065</i>	<i>1840</i>	<i>2362</i>	<i>1572</i>	<i>1740</i>	<i>1569</i>	<i>1430</i>
Above Grade Exterior Walls	Insulated Concrete Form	17	16	32	15	49	50	49	38	42	57
<i>Total Potential Market</i>		<i>350</i>	<i>316</i>	<i>373</i>	<i>282</i>	<i>414</i>	<i>382</i>	<i>318</i>	<i>360</i>	<i>358</i>	<i>367</i>

More important to this study are thresholds at which the percentage of trials moves a product into different adopter innovativeness categories. Some products might stay pretty much within the realm of the *innovator* adopter category. Based on the example provided Tables 4 and 5, Below Grade ICFs have started to push past the threshold of *innovators* (2.5%) to the adopter category of *early Adopter*. Above Grade ICFs obtained more significant adoption, within the next 13.5% of adopters, and is a product close to *crossing the chasm*, the threshold of 16% into *early majority*. Products strongly rooted in the *early majority* would be fully accepted by the market based on the definition of market acceptance for this study. Finally, some product adoption might signify *late majority* or *laggard* threshold status.

**Table 5: Potential Market Adoption Summary by Year Reprinted by permission of The Royal Institute of Chartered Surveyors (UK)**

Cluster Name	Product Type	Year									
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Below Grade Exterior Walls	Insulated Concrete Form	1.84	2.46	3.39	3.00	4.40	4.87	5.66	4.71	6.25	6.22
Above Grade Exterior Walls	Insulated Concrete Form	4.86	5.06	8.58	5.32	11.84	13.09	15.41	10.56	11.73	15.53

## Conclusions

### BPS Product Concurrent Commercialization

Based our case-study interview data of Table 2, the Insulated Concrete Form manufacturer reported 81% of CC steps performed for their product development. Of those products without 100% CC development, the ICF development requires mentioning as its percentage comes closest to parallel early development and is therefore very close to our definition of CC. This product success suggests that the closer one might have come to achieving CC, the better one's chances are of commercial success. ICF's market penetration in the Above

Grade cluster is especially supportive of this claim, while both applications of the product indicate significant increases in market share per year. Further product adoption rate analysis will better explain this hypothesis.

Below and Above Grade ICFs are mostly contained within the threshold of *early* adopter over the ten years of this study. Below Grade ICFs have stayed closer to the 2.5% threshold and Above Grade ICFs have not quite been able to make it past the 16% threshold. This might suggest that the early adopter category has challenging thresholds: the lower percentages just after entering this category and the higher percentages near crossing the threshold into the next category of early majority. Above Grade Exterior ICFs were able to quickly move past lower percentages, but we do not have access to adoption data before 1996. Thus, it is difficult to suggest conclusions for Above Grade Exterior ICFs, while Below Grade Exterior ICFs continues to be a product not quite integrated within the social group needed for it to have full market acceptance. Below Grade Exterior ICFs interestingly has stalled around a 6% trial level. This might suggest that a traditional product in its cluster is too strongly rooted. For ICF this might mean that CMU are preferred for basement applications, while that is not the case with above ground applications.

Finally, our interpretations of the data analysis described above aim to support the claim that implementation of CC principles in a commercialization plan for a construction product will significantly improve market penetration. In order to perform a statistical test of our null hypothesis we will further divide the group of 13 products in our sample into two subgroups: those products that implemented 100% of the CC steps in the first two phases of commercialization and those that implemented less than 100% of these steps. These sub-group identities are indicated in Table 2 by the labels “yes” and “no”, respectively. For each product we will measure the maximum market share over the years 1996 – 2005 as a measure of market penetration. Using this datum as our measure of market penetration is most beneficial to those products that may have experienced a decline in market share after reaching a peak during the ten years of the study. Comparing the average maximum market share for these two subgroups using a t-test will reject or support our claim, beyond reasonable doubt, that implementing CC in a commercialization process does improve market penetration.

### ***Acknowledgements***

The authors acknowledge the assistance of the National Association of Home Builders (NAHB) in the preparation of the BPS dataset, specifically Indroneil Ganguly, Randy Cantrell and Chris Steuble. This paper was supported by research projects funded through the NSF-PATH program and HUD’s Building Technology and Affordable Housing Program: NSF Grant # CMS-0533322, *Facilitating Supply Chain Support for the Commercialization of Innovative Products in the Residential Construction Market* & NSF-PATH Modeling

*Diffusion of Innovation in Residential Construction.* All opinions are those of the authors and neither HUD nor PATH.

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## **Chapter 8 - Innovation Commercialization Framework: Conclusions and Future Work**

### ***Summary***

Innovation commercialization is a long process the success of which is not guaranteed through sound technology or willing markets. However, a proper development process for innovative products can better prescribe the requirements of commercial success. This work posits that commercial success can be facilitated through the use of a framework that properly identifies all technical and business decisions or actions required from the concept of a product to its maturation into the market. No such frameworks exist in the residential construction industry.

The overall goal of this research was to develop a commercialization framework for innovation commercialization in residential construction and test its validity. This research tested the framework with manufacturers, builders and others involved in the supply chain through identifying roles, risks and benefits specific to the industry. This work achieved its goal through objectives that involve various stakeholders of the construction supply chain. It first established consistent terminology for innovation commercialization for the purpose of proposing a standard definition in this work. Through literature review and case study interviews, it created a framework of commercialization for innovation in residential construction. This framework was then specified to manufacturers as to the important risks, benefits and tasks within a commercialization process. The framework was then further specified to builder/developers as to their important risks, tasks and benefits within a commercialization process. Finally, this work mapped the commercialization process leading up to and during the use of thirteen products in the NAHB Builders' Practices Survey. The commercialization process was then compared to product use within the BPS survey specifically to better predict manufacturer processes within the framework that ensure product success.

Studies lacking standard terms continue to confuse the larger body of innovation research, which this work avoids. In achieving the first objective, this work develops standard terminology for innovation commercialization in residential construction by comparing the worlds of innovation theory, NPD and commercialization through literature review.

While no previous commercialization framework exists for the residential construction industry, this work creates one. Construction products will benefit from the development of a specific framework for

construction industry commercialization. The framework presented herein outlines phases and functional areas for technical and business best-practices in getting innovative products to market.

Since a framework alone would not contain much of the industry's needs for innovation development success, this work uses case study interviews based on this framework to identify areas of manufacturer commercialization risks, benefits and tasks of importance. It specifies the commercialization framework through data obtained from manufacturer interviews, and then analyzing their experiences in the residential construction industry. Each interview solicits descriptions of key decisions that were made during the successful commercialization of innovative products. Expert Panel data analysis through Delphi methodology identifies the critical decisions for successful commercialization and also diagrams sequences and timelines of these critical decisions among different types of products and business environments.

Similarly, the framework must also reflect the role of residential builders/developers, defined as users, in the commercialization of innovative products. Workshop and survey data further develop this side of the framework for residential construction products. Through three surveys, workshop data indicate consensus on the implications of important risks, tasks and benefits for these stakeholders within commercialization. These data first create consensus about the risks of builders within the commercialization process and then draw consensus on their role.

Finally, no other work compares innovative technology use thresholds with commercialization best-practices for manufacturers in residential construction. This work therefore argues that commercialization best-practices for manufacturers in residential construction lead to higher adoption thresholds sooner in the commercialization process of products for the residential construction industry. It locates thirteen products in the NAHB Builders' Practices Survey (BPS) between the years 1996 to 2005 and assembles their data. It uses case studies to record the commercialization process before and during the adoption thresholds for these BPS products and then compares these two forms of data specifically to derive the effects, interpreted as benefits, of sound commercialization practices on product use.

## ***Conclusions***

Innovation is not invention. It is the implementation of a novel idea, product or process, for the firm or individual utilizing it, into actual use. Manufacturers are at the beginning of this implementation process and users, as installers, towards the end. Integral to the residential construction implementation process, developer/builders are a single stakeholder along the supply chain in a commercialization venture. This

work therefore sees developers and builders as the same business entity and the role of this entity in adopting or refusing to adopt innovation in construction products as very similar.

Innovation commercialization is the process of developing a product from concept, through feasibility and implementation, to its acceptance into a given market. An innovative product's acceptance is the point at which it enters the market, while other studies include more of the product's durability lifecycle after its market acceptance. This study sees commercialization, with a larger context than previous work, as the coordinated technical and business decision processes (and resulting actions) required for successful transformation of a new product or service from concept to market adoption. Commercialization is therefore the coordinated execution of all processes required for product innovation success from a developed state to implementation within a given market.

In creating a framework that predicts the required steps of commercialization for innovative products in the residential construction industry, this work consolidates industry frameworks from research literature and then further adjusts its preliminary framework from case study interview feedback. It exists herein as a matrix of eight phases in time and eight technical and business functional areas. The eight phases in time are: Concept, Feasibility, Planning, Review Planning, Early Production, Review Early Production, Standardization and Market Release. The eight functional areas are: Product Design (PD), Process Planning (PP), Marketing (M), Supply Chain Management (SCM), Human Resource Management (HR), Accounting and Information Systems (AIS), Financial Management (FM) and Legal Management (LM). Framed as a matrix, the framework's architecture accepts the various data inputs of this work, those of literature review, product case study interviews and surveys. These data then further specify and modify the content and structure of the framework. Each input establishes portions of commercialization important to construction industry products through noted areas, actions, and sequences and could indicate the importance of localized processes that require additional attention when taking a product to market.

Initial testing of the framework from case study data supports claims in literature that steps in the early stages of a commercialization project are most important. No new phases or functional areas for the framework were suggested by the data, establishing that the commercialization framework is not under-specified. Also, the current version seems to have steps that can be removed, not steps that need to still be added.

The case-study data on manufacturers' development processes further emphasize areas of importance within the commercialization framework. First, the commonly used sequences of commercialization steps validate a concurrent-engineering approach. The data also support our commercialization framework with respect to the scope of commercialization phases and this work's claim that the first phase is an essential starting point for any commercialization project. While seemingly obvious, literature often starts product development in later phases. The findings further specify the need for early integration of marketing within a product's design.

Although all phases of the commercialization process are essential, phases 1-4 of our commercialization framework are *more* critical to success than phases 5-8. Early missteps largely *increase* the possibility of later risks.

Among functional areas, PP, HR and AIS, are relatively routine for commercializers of residential construction products. Compared to commercialization in other industries, the construction industry delays the heavy investments in process development and capacity expansion to a late stage of a commercialization project and proceeds cautiously in these functions.

An intriguing hypothesis from the findings in manufacturer case studies is that construction products present such significant challenges in other functional areas that financial management (FM) issues, which generally play a critical role in any commercialization, are somewhat routine. Financial management therefore, by comparison to other construction-specific commercialization actions, might be perceived as less of a barrier to success.

These 15 manufacturer case studies offer interesting anecdotal views into the role of champions as well. The data reinforce evidence from literature on new product development that champions are important to the development process. In some firms, the president of the company develops the product and is, therefore, the champion. In other firms the champion is a process-planning group which meets often to discuss the progress of the product development and to ensure obstacles are cleared. Still other firms assign key individuals to oversee each product's development, depending on whether it is inside or outside the company. Since larger companies often assign individuals, we assume that these firms allocate the resources of a full-time champion and, consequently, foster an atmosphere of encouraging innovation. Based on these case studies, this work posits the hypothesis that a key function of corporate champions is to coordinate successfully all corporate and departmental entities involved in a commercialization project. Coordinating supply chain entities, for example, would produce a clear

financial benefit for all involved. In a contrasting example within our studies, one firm had no clear champion, which reduced its ability to create builder awareness and distribute properly. Once this position was later established the product achieved success through better distribution, suggesting the importance of the role. The role of the product champion as commercialization coordinator should be the subject of future research.

Developer/ builders are the supply chain members most influential in determining commercialization success. This work finds that addressing the developer/builder risk along the entire supply chain is one key determinant to a successful commercialization project. Commercialization also involves more than just technical product design; commercialization cuts across all functional areas. Addressing risk for developer/builder adoption requires solutions in all of these functional areas. Through these findings, this research proposes the extension of concurrent engineering (CE) to concurrent commercialization (CC) as a strategy for meeting the challenge of developer/builder adoption. Further, successful concurrent commercialization requires risk sharing among all members of a product's supply chain, which requires information sharing and knowledge transfer among supply-chain members early in a commercialization project.

Based on thirteen products included in the NAHB BPS survey, this work finally concludes that CC is a significant predictor of commercial success. First Floor ¾" Engineered OSB, Second Floor ¾" engineered OSB, fiber cement siding and plastic composite decking are examples of products which benefited from CC and achieved the adoption thresholds of late or early majority – market shares universally accepted as commercial success. Insulated Concrete Forms' 80% CC achievement, along with its threshold status of early adopter/majority, suggests that the closer one comes to achieving CC, the better one's chances are of commercial success. Those products with lower CC percentage did not achieve commercial success, suggesting directions for future research.

In testing CC, this research finds significance in specific thresholds within the adoption process. The initial threshold of innovator seems to play an important gateway role within adoption. Only certain products pass beyond this threshold easily and all have CC in their development. Similarly, the early adopter threshold seems difficult for a product to successfully cross at both the early and later part of the threshold. Therefore, many products in this study remained for some time either at the beginning or end of this category. Once the threshold of early majority is obtained by a product, though, commercial success seems certain.

## ***Future Work***

Many future extensions of this work are available. One future research goal is a classification scheme of construction products based on the optimal sequence of steps for different product types. New innovators might benefit from an initially-prescribed interface for commercialization that such a classification scheme would provide.

Future study might pursue the role of champions in innovation commercialization for residential construction. Current literature thoroughly looks at the important role of these key players, while not in respect to commercialization.

Future research might further the implications of important early steps to “inventors” versus “innovators.” Inventors move a product far enough along the commercialization process for patenting and selling/licensing of rights. Innovators carry a product through the entire commercialization process. This idea directly relates to findings for salient processes and sequences, as they heavily favored early, risk-limited actions. For limited-resource inventors, financial constraints often dictate the contractual involvement of an innovator. Therefore, this juncture of the commercialization process remains a key decision point, especially for small business enterprises.

Future work should also investigate the design and coordination of the supply-chain entities (players) in terms of financial risk-sharing. These supply-chain solutions might distribute risk, while also promoting cost benefits for all players involved. Building Information Modeling (BIM) could be a technology that enables this transfer of knowledge within the members of the supply chain. Future research should develop the specification of concurrent commercialization in more detail in order to influence the development of BIM standards.

Finally, no current work attempts to quickly view the behavior of construction firms or projects in terms of innovation commercialization. Development of an evaluation tool, such as Figure 1 below, that establishes quick views into project or firm-based behavior would be beneficial to our understanding of adoption progress for innovation in the construction industry<sup>4</sup>. Understanding the behavior of individual settings should offer a better view into the behavior of the entire industry as well. In defining individual

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<sup>4</sup> In *Blink, The Power of Thinking Without Thinking*, Malcom Gladwell advocates the use of “thin slicing” techniques. Thin slicing is the ability to find patterns in situations or behavior based on narrow experiences. Dr. John Gottman at the University of Washington is using similar techniques for psychology studies that predict success of marriages based on quick, verbal exchanges between spouses. Samuel Gosling performs similar studies that predict job performance based on narrow exposures to a student’s dorm room.

settings, behavioral analysis traditionally tries to recognize observable characteristics through quick profiles. An innovative-behavior quick-profiling tool for construction would utilize a large amount of questions that reflect the complex nature of construction industry products and settings.

Figure 1: Innovativeness Quick Behavior Evaluation Tool

