

TOWARDS ESTABLISHING DIFFUSION BARRIERS FOR INNOVATIVE GREEN BUILDING PRODUCTS: A SURVEY OF SIPS BUILDERS

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ABSTRACT

The aim of this paper is to propose and demonstrate an approach for exploring diffusion barriers specific to innovative green building products. Innovative green building products aim at reducing environmental impacts during a product's entire life-cycle, helping mitigate the substantial environmental degradation caused by current construction patterns. Few studies establish attributes that differentiate such products within the construction market, a key facet to increasing adoption. For key stakeholders, product attributes can affect the rate of adoption and the nature of use. Toward that end, this work: 1) Collects attributes common to all innovative building products through literature review in residential construction innovation, diffusion and adoption attributes, and green products; 2) utilizes a survey of certified green home builders as a sample population and Structural Insulated Panels as a "control" product to identify which product attributes specifically influence the use of green building products; and 3) Evaluates the relative influence of attributes on product adoption during initial trial of the product and for continued use of the product. Identifying attributes of green building products that influence adoption could enhance product development through reducing barriers to diffusion and commercialization across the residential construction industry. This work focuses on one specific product, Structural Insulated Panel systems (SIPS), from the standpoint of a population of green builders. As such, it attempts to serve as a scalable basis for future research.

KEYWORDS

innovation, green innovation, housing, product innovation, SIPS

INTRODUCTION

Estimates of environmental degradation stemming from the construction and operation of the built environment are staggering. In the United States alone buildings account for 48% of total energy consumption and its associated CO₂ emission (Architecture 2030), 38% of energy consumption for building operation (USDOE 2001; Scheuer and Keoleian 2002) and up to 24% of all municipal solid waste that enters landfills (Laquatra 2004). The residential

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construction industry makes up a large percentage of total construction in the United States, and is therefore responsible for a large part of this consumption and waste (Kibert et al. 2000). With renewed national interest in energy independence and growing concern over climate change and general environmental degradation, it is more important than ever to study innovations in green building that offer potential solutions to these problems.

Innovative green building products strive to reduce environmental impacts during a product's entire life-cycle, helping to mitigate the substantial environmental degradation caused by current construction patterns (Bernauer et al. 2006). These products reduce inputs from the manufacturing process, conserve natural resources during their service life, and can be reused or otherwise recovered at the end of their life cycle. However, the residential construction industry has been relatively slow in developing and adopting innovative green building products (Koebel 2007). Due to the relatively recent nature of innovation research in the residential building industry, it has tended to focus primarily on manufacturing characteristics and user innovativeness (McCoy et al. 2009). As such, specific product attributes of green innovations and their associated accelerators and barriers have not been sufficiently defined and analyzed and exist as a significant weakness in current product research (Bernauer et al. 2006).

The aim of this paper is to propose and demonstrate an approach for exploring diffusion barriers for innovative green building products. Few studies establish attributes that differentiate such products within the construction market, a key facet to increasing adoption. To that end, this work: 1) Collects attributes common to all innovative building products through literature review in residential construction innovation, diffusion and adoption attributes, and green products; 2) utilizes a survey of certified green home builders as a sample population and Structural Insulated Panels as a "control" product to identify which product attributes specifically influence the use of green building products; and 3) Evaluates the relative influence of attributes on product adoption during initial trial of the product and for continued use of the product. The initial work, while focused on SIPS in the context of residential construction, also attempts to serve as a scalable basis for future research that may be extensible to other types of products and other sectors of the industry. Identifying attributes affecting adoption of green building products could aid product development through reducing barriers of diffusion and commercialization across the residential construction industry.

BACKGROUND

Innovation

Innovation research is an established field covering product and process diffusion and adoption, the innovation commercialization process, and producer/consumer behavioral attributes. Czepiel (1974), Fichman (1992), Habets et al. (2006), Koebel et al. (2003), Rogers (2003), Atun and Sheridan (2007), and Langar (2009) similarly characterize innovation as *an idea, practice or object that is new or perceived as new by an individual or other unit of adoption*. Rogers (2003) further defines diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system". Rogers, both in his latest (2003) and earlier works, provides a broad synthesis of innovation diffusion and adoption theory, in which he identifies five general attributes of innovative products: relative advantage, compatibility, observability, complexity, and trialability. This and earlier versions of Rogers' work set the tone for future specialization of innovation research across a variety of fields, including the construction research field.

In addition to broad studies of innovation theory (e.g., van den Bulte 2000; Rogers 2003; Gladwell 2002), industry-specific innovation research exists in multiple areas, most notably marketing (e.g., Varble 1972), economics (e.g., Eaton and Dickinson 2006), and other specializations (e.g., Porter and Teisberg 2006, Scott et al. 2008), which seek to understand the development and diffusion patterns of innovation in a specific context to serve a particular sector. One such sector in which innovation adoption and diffusion has been significantly studied is the construction industry, discussed next.

Construction Innovation

In the construction innovation literature, Slaughter (1998) defines an invention as “a detailed design or model of a process or product that can clearly be distinguished as novel compared to existing arts.” She contrasts this with the notion of innovation, defined 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” (emphasis added). Further, that work clarified: “in contrast to an invention, an innovation does not require a detailed design or physical manifestation, and it does not have to be novel with respect to the existing arts, but only to the creating institution.”

Innovation research in construction in general and the residential building industry specifically has been slow to develop (Mitropoulos and Tatum 1999; Dewick and Miozzo 2004; Koebel 2007; Matar et al. 2008), with a shorter history than innovation research in other fields. This has been attributed to many factors including the fragmented nature of the construction industry, lack of research and development investment by firms, and lack of technology transfer initiatives by the federal government (Koebel 1999). Koebel (1999) examined failed government attempts at incentivizing construction innovation in the residential sector as well as the effects of the social system of homebuilding on the way innovations are adopted, stressing the importance of innovation in the building industry as a means to achieving sustainability.

Rogers' (2003) early work established what are considered to be the core attributes of innovation, namely characteristics of an innovation that contribute to its adoption: *Relative Advantage* with respect to the product or practice being superseded, *Compatibility* with existing infrastructure and habits, *Complexity* of use and function, *Trialability* without risk, and *Observability* of the product within the marketplace. These attributes have been accepted by many researchers across multiple domains of inquiry, including Black et al. (2001), Rogers (2003), Habets et al. (2006), Atun and Sheridan (2007), and Scott et al. (2008). Slaughter (1998) studied product attributes and added several for construction settings: *Incremental*, *Radical*, *Modular*, *Architectural*, *System*, *Timing of Commitment*, *Coordination*, *Special Resources* and *Nature of Supervision*. Others have expanded product attributes for the construction setting as well in an attempt to facilitate their acceptance (Koebel and McCoy 2006; McCoy 2009).

Slaughter (1993a) first studied risk and uncertainty associated with manufacturers and installers of specific products, looking at a supply chain of stakeholders operating at various levels technologically and politically. To understand barriers to adoption within the construction industry, Slaughter (ibid.) tracked the use of SIPS, an integrated building product with structural and enclosure/insulating functions, and analyzed the interaction between manufacturer product development and on-site implementation. Results showed that 82% of process innovation lay in the implementation of SIPS rather than in the development of the product, thus establishing a basis for the current study of product attributes as risks in the implementation process.

Similar to Slaughter's work on innovation models and Koebel's (1999; 2003; 2006) work on innovative builder attributes, significant contributions have been made in analyzing key

barriers for construction innovation (Blayse and Manley 2004) as well as the market barriers to innovation in the home building industry (HUD 2005). Blayse and Manley (2004) identified six possible barriers to Australian construction innovation as: clients and manufacturers; the structure of production; relationships between individuals and firms; procurement systems; regulations or standards; and the nature and quality of organizational resources. US Industry attributes have been reported in similar contexts by various academics but heretofore have failed to be identified in a comprehensive report.

In addition to Slaughter and Koebel, additional research has focused on the commercialization process barriers for innovative products and processes in residential construction (McCoy et al. 2007, McCoy et al. 2009). McCoy et al. (2009) focused on the various steps throughout the supply chain that are necessary in taking a product from invention to innovation and gaining acceptance in the marketplace. McCoy et al. (2010) recently mapped the commercialization process in the residential construction industry, offering a tool for linking barriers of process to a specific product.

“Green” Building Products

A working definition of what constitutes a “green building product” is necessary for this work, although it is not explicit in literature on green innovation. Differentiating between ecologically conscious consumer behavior (ECCB) and green innovation is important to this definition. ECCB is defined as the purchase of products and services that are perceived to have a positive impact on the environment, and/or avoidance of products and services perceived to have a negative impact (Roberts and Bacon 1999). In contrast, investigations of green innovation have focused on the marketing opportunities related to ECCB and product attributes that appeal to this segment of the market. Varble (1972), in his study on social and environmental considerations in new product development, argued for the inclusion of product considerations apart from sales and profit growth, in the context of heightened environmental awareness at the time. Kinnear et al. (1974) responded to this study with further research of ecologically conscious or concerned consumers, identifying key demographics and behavioral attributes associated with this demographic. This study was followed by numerous reports on product appeal (Schuhwerk and Lefkoff-Hagius 1995), personality variables (Balderjahn 1988), and green marketing (Baker and Hart 2008). Porter and Van der Linde’s (1995) seminal work argued that green innovation and its associated resource productivity gain was essential to lowering environmental impacts as well as lowering costs, improving product quality, and enhancing global competitiveness. According to the Organisation for Economic Cooperation and Development (OECD), “environmental innovation encompasses all innovations that have a beneficial effect on the environment regardless of whether this effect was the main objective of the innovation” (OECD 2008). Willander (2006) further qualifies an environmental innovation as “competitive in the marketplace and...profitable for the innovating firm”. Implications of green building product innovation, however, are currently in early stages of development and an emerging area of focus for innovation research.

Koebel (2008) and Bernauer (2006) broadly referred to green building as “involving innovative products, materials, or processes.” Bernauer (2006) defined green products as aiming to reduce “environmental impacts during a product’s entire life-cycle (cradle to grave)” and environmental innovation as “all innovation that has a beneficial effect on the environment regardless of whether this effect was the main objective of the innovation,” further stating that “organizational innovations do not reduce environmental impacts directly, but facilitate the implementation of technical

(process and product) innovations.” For this study, an innovative green building product is broadly defined as any building product that has a beneficial effect on the environment with respect to the life-cycle impacts of the product; contains salvaged, recycled, or waste content; conserves natural resources; avoids toxic or other emissions; and/or contributes to a safe and healthy work environment, regardless of whether these effects were the main objective of the product or not.

Studying Green Building Product Innovation

Previous attempts have been made to catalogue the factors affecting innovation diffusion for residential construction products (McCoy et al. 2009). Further innovation research has been primarily focused on product development from the perspective of the producer, called “market push”, or from the perspective of the consumer, called “market pull” (McCoy et al. 2009; Bernauer 2006; Langar 2009). While previous work has analyzed demographic, attitudinal, and behavioral correlates of green innovation, attributes of innovative green products as a basis for barriers to diffusion have not been systematically studied.

Risk along the supply chain plays a major role in determining the success of a product’s development, with individual stakeholders strongly influencing the success of product adoption through either veto or endorsement (McCoy et al. 2009). Key stakeholders in residential construction affected by these attributes are suppliers, manufacturers, distributors, retailers, Builders, installers, inspectors and end-users (McCoy et al. 2009). Nevertheless, according to Koebel (2007), in residential construction, “the builder, more than any other [stakeholder], decides how to balance the characteristics of supply against market demand. However, it is difficult for builders to appropriate the benefits of innovation for themselves, given their place in the production process.” For all stakeholders, product attributes can significantly affect the rate of adoption and the nature of use (Rogers 2003).

Koebel (2007) describes the national homebuilding market as typified by “small firms that produce only a few homes using their own crews or subcontractors”, although the homebuilding market is becoming more consolidated among large production homebuilders. In 1992, the four largest homebuilders captured 3% of the new home sales market (Slaughter 1993a) and in 2005, the top 100 national homebuilders captured 37% of the new home sales market (Koebel 2007). While this consolidation is projected to continue over time, small homebuilding operations still currently capture about 63% of the national market. Compared to large national firms, where diffusion often hinges on purchasing manager behavior and management buy-in, small firm diffusion often hinges on installers and owners who champion innovation with programs such as green certification.

As discussed in previous sections, earlier research has defined innovative product attributes in residential construction. To build on this base, the present study seeks to use these attributes as a control set of characteristics as the basis for a set of attributes specific to green building products. Attributes are then compared across two key differences in the nature of adoption: initial trial versus continued use. The ultimate goal of this investigation is to increase the diffusion of these products into the marketplace by identifying potential barriers to adoption that can be addressed to facilitate diffusion.

Innovation research as it applies to residential green building products focuses primarily on user behavior, termed ecological consumer behavior (Berger and Corbin 1992; Kinnear et al. 1974), producer/builder behavior (Koebel 2007; McCoy 2009; Slaughter 2000), and the performance characteristics of the product itself (Sani et al. 2005; Massawe et al. 2006; Akaranta 2000). Previous literature has focused on each of three environmental innovation types

described by Bernauer (2006)—organizational, product, and process—although construction products and specifically innovative green building products have not been addressed. Studying the attributes of these products across the nature of use, and how these can act as barriers to adoption, addresses a specific research gap through:

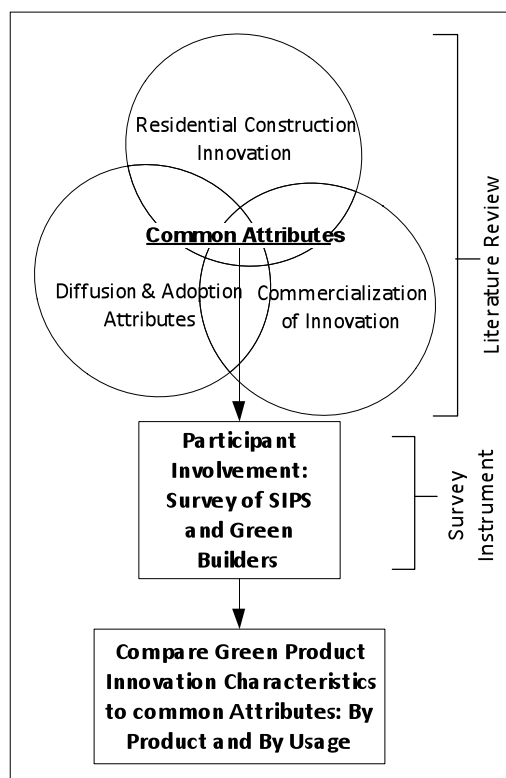
- Collecting attributes common to all innovative building products through literature review in residential construction innovation, diffusion and adoption attributes, and green products;
- Using a survey of certified green home builders as a sample population and Structural Insulated Panels as a “control” product to identify which product attributes specifically influence the use of green building products;
- Evaluating the relative influence of attributes on product adoption during initial trial of the product and for continued use of the product.

Specifically, the objective of this research was to identify product attributes that influence the adoption of green building products in the residential construction industry and evaluate their relative influence on initial adoption and ongoing use of green products. These observations can then be used as a basis to identify barriers to innovation diffusion that could be addressed through interventions to facilitate broader diffusion of green products.

METHODOLOGY

An investigation grounded in the practices of the construction industry is necessary to develop a deeper understanding of previously clustered innovation attributes as they apply to residential green building products. The authors therefore chose to implement a survey tool featuring these attributes for dissemination to a population of certified green residential homebuilders. A specific product, Structural Insulated Panels, was utilized in this study to focus data collection with respect to identified product attributes. The research team partnered with the EarthCraft Builder program, a regional program localized to the Commonwealth of Virginia, USA, to provide a means survey dissemination. Figure 1 outlines the research steps used in this study, described in detail in the following section.

FIGURE 1. Research Methodology.



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Literature Review of Innovative Building Product Attributes

The first task in this investigation was identifying a set of attributes known to affect innovative product diffusion in the residential construction industry. McCoy (2009) assembled a sample of attributes common to literature on diffusion, adoption, and commercialization of innovation, as well as innovation barriers spe-

cific to residential construction. These attributes were used as a starting point for a comprehensive review of the relevant literature pertaining to residential construction innovation, diffusion and adoption attributes, and green products.

Table 1 shows the results of the literature review, a list of the common product attributes affecting diffusion of innovations in residential construction. The degree to which an innovative product exhibits a particular attribute influences the attraction or resistance of residential construction stakeholders to adopt the product. For example, *trialability* is defined as a product's ability to allow experiment without risk. If an innovative product is deemed by stakeholders to exhibit high *trialability*, they are more likely to engage in a user trial of the product,

TABLE 1. Common Product Attributes Affecting Diffusion in Residential Construction.

Attribute	Reference	Definition
Timing of Commitment	Slaughter 1993b, Slaughter 1998; Toole 1998	Timing or flexibility with implementation of the product during the construction schedule
Compatibility/Special Resources	Cagan et al. 2003, Holmen 2002, Rogers 2003, Slaughter 1993a; Toole 1998	Congruency with the habits of users or existing products
Supporting Innovation	Flood et al. 2003; Slaughter 1998; Toole 1998	Innovations that require other innovations to make them compatible
Complexity/Simplicity	Cagan et al. 2003, Flood et al. 2003; Holmen 2002; Rogers 2003; Toole 1998	The product's ability to be understood by users
Trialability	Cagan et al. 2003, Flood et al. 2003; Holmen 2002; Rogers 2003; Slaughter 1993a, 2000; Toole 1998	Ability to experiment without risk
Observability	Cagan et al. 2003; Holmen 2002; HUD 2005; Rogers 2003; Toole 1998	Product visibility within the marketplace
Relative Advantage/ Cost	Cagan et al. 2003, Eaton et al. 2006, Flood et al. 2003; Holmen 2002, HUD 2005, Rogers 2003, Slaughter 1993a, 2000; Toole 1998	Cost/relative benefit to using the product as opposed to traditional products
Risks	Eaton et al. 2006; HUD 2005; Koebel and McCoy 2006; Slaughter 1993a	Impact of negative consequences for using the product
Supervision Competency	Blackley and Shepard 1996; Slaughter 1998; Toole 1998	Experience or education/training required to use or install the products
Consumer Resistance (End User)	Flood et al. 2003; Koebel and McCoy 2006	Opposition that originates from the consumer (individual based)
Trade Resistance	Blackley and Shepard 1996; Koebel and McCoy 2006; Slaughter 1993a, 2000; Toole 1998	Opposition that originates from the trades (organization based)
Regulatory Resistance	Blayse and Manley 2004, Blackley and Shepard 1996; HUD 2005, Koebel and McCoy 2006, Oster and Quigley 1977; Slaughter 1993b; Toole 1998	Opposition that originates from government organizations (authority based)
Coordination with Project Team	Blackley and Shepard 1996; HUD 2005, Slaughter 1998; Toole 1998	Synchronization of various stakeholders required for implementation

leading ultimately to a higher rate of adoption by individuals and diffusion throughout the marketplace.

Survey of Green Residential Builders

The second step in the research was to conduct a survey of industry practitioners to determine the relevance of each identified green building product attribute in influencing the adoption of green building products. For the purpose of this study, a single product was used to provide a frame of reference for respondents in rating the various product attributes in terms of their role in influencing product diffusion. The following subsections describe the survey design and implementation.

Selection of a Frame of Reference: Structural Insulated Panel Systems (SIPS)

An important decision in the research was the selection of an appropriate study product. While green products often range based on use or disposal (rather than production), they aim at reducing environmental impacts during the product's entire life cycle (Bernauer 2006). Green innovations range from hybrid vehicles (reducing use of fossil fuels and emissions) to commercial off the shelf (COTS) water recycling systems, which reduce disposal amounts. In residential construction, Slaughter (1993a) emphasized the need for studying innovation related not only to manufacturer processes, but also "actual construction methods." The use of SIPS, in this work, was an attempt to narrow the field of the many green building products into a frame of reference from one with a history of study not just at the manufacturer level, but also the construction site.

Another reason for using a green specific product was to provide a frame of reference for the industry practitioners completing the survey. In this way, respondents could consider their own experiences with a product in reflecting upon the role of each attribute in product adoption. Although this study was limited to a single product, the methodology employed in the survey was designed with application towards other green products in mind, as part of future research.

Structural Insulated Panel Systems (SIPS) were selected as the reference product in this study. Toolbase, which also contains other green building products, (www.toolbase.org) defines SIPS as:

panels made from a thick layer of foam (polystyrene or polyurethane) sandwiched between two layers of Oriented Strand Board (OSB), plywood or fiber-cement. As an alternative to the foam core, SIPs are available with a core of agriculture fibers (such as wheat straw) that provides similar thermal and structural performance. The result is an engineered panel that provides structural framing, insulation, and exterior sheathing in a solid, one-piece component.

SIPS meet the working definition of a green product innovation for this investigation, aligning with Koebel (2008) and Bernauer (2006), and have also been categorized as innovative by leading researchers (e.g., Slaughter 1998) as well as industry associations. The Partnership for Advanced Technologies in Housing (PATH) includes SIPS among other products in its database of innovative residential building materials on its innovative materials website Toolbase.org. According to the Structural Insulated Panel Association, SIPs are currently incorporated into 1-2% of new residential construction projects nationally, classifying its current market as innovative on the adopter categorization scale developed by Rogers (2003). Slaughter's work has also extensively studied SIPS as a construction innovation (Slaughter 1998), which provides a point of reference for this product as a starting point.

Survey Population

Another important consideration for the survey was to select an appropriate population sample. The survey population for this study consisted of 150 residential builders who have been certified as trained through the EarthCraft builder program, which serves the southeastern region of the United States. Earthcraft Virginia is an affiliate of Southface, a regional and national leader in green building and certification specification, widely recognized as one of the leading residential green building rating systems in the United States. All 150 green builders were solicited via email through a list provided by the nonprofit organization that manages and administers the EarthCraft Virginia system. This population was specifically targeted to increase the likelihood of familiarity with green building product innovations such as SIPS. Of the 150 contacts, the survey yielded a response rate of twenty-three percent (23%), or 35 individuals (on behalf of firms). All survey respondents were either based or had significant operations in the Commonwealth of Virginia, but were certified as part of the larger Southface community.

The decision to focus on EarthCraft-certified home builders in the state of Virginia stemmed from discussions on how to solicit a statistically significant response rate from a sample population that is representative of the larger home building community in the United States and has experience with the subject product, Structural Insulated Panel Systems. EarthCraft Virginia keeps a comprehensive record of contact information for their registered builders and agreed to provide this information to the research team. These builders have demonstrated interest in green building products through their EarthCraft training and certification and tend to exhibit demographic attributes similar to the larger green building community.

Survey Instrument

With common attributes of innovative green building products in mind, the research team developed a survey to validate any correlation between common innovative product attributes and those of Structural Insulated Panel Systems. The survey was designed using a tailored design method, involving “development of survey procedures that create respondent trust and perceptions of increased rewards and reduced costs for being a respondent, which take into account features of the survey situation and have as their goal the overall reduction of survey error” (Dillman 2000). For the survey contained in this work, such a design entailed systems for a quick understanding of definitions, which were explained in fundamental terms, simple rating scales for questions, and on-line delivery. In trying to reach residential builders, who often are in the field or busy in the office, such a method increased the chances of conducting a successful survey. All respondents were also offered the ability to receive anonymous results as a reward for their time.

Survey Implementation

After providing basic demographic information and information about their adoption and present use of SIPS, respondents were asked to rate identified green product attributes using a Likert scale response model (Robson 2002) in terms of the degree to which each attribute affected innovation adoption. Based on the responses of builders to the selected product attributes, a pattern emerged that identifies which product attributes are significant barriers to diffusion and, by implication, which offer opportunities to accelerate adoption through a reduction of barriers. The questions on the survey were divided into three sections: general demographic information, SIPS adoption and use information, and product attributes influencing adoption.

Data Analysis

The research team conducted demographic analysis to measure the dimensions and dynamics of populations. Paired t-tests were performed to compare values between the first trial and continued usage, in keeping with the central hypotheses of the work. A correlation matrix was constructed among attributes and nature of product use, based on Pearson's correlation coefficients for significance. Prior to the paired-sample t-test and correlation, all assumptions were checked including univariate normality and linearity. Data were analyzed using SPSS version 17, and the level of significance was set at 0.05, two-tailed.

FINDINGS

The data collected in this study offers insights into the diffusion factors associated with Structural Insulated Panel Systems in particular, and sets the stage for better understanding residential green building product innovation in general. The survey population provided a rich set of data that paints a picture, albeit limited in size, of the adoption attributes of SIPS in Virginia and the southeastern U.S., discussed in the following subsections.

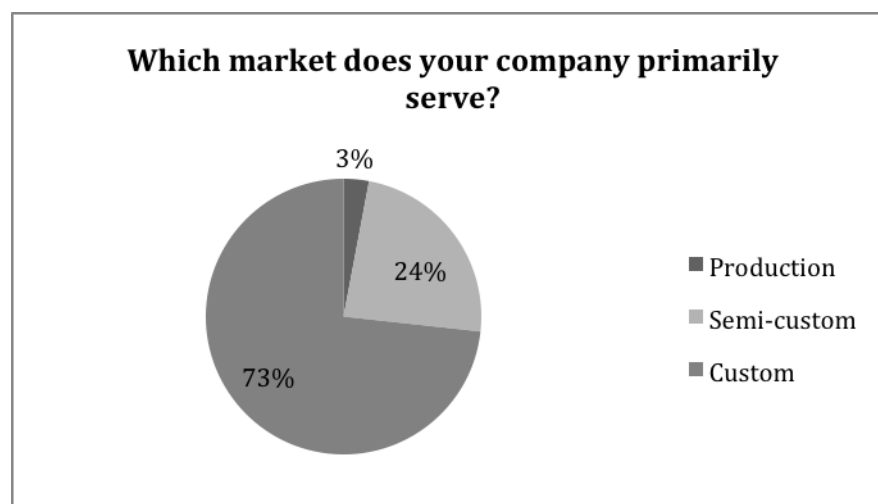
Demographics

Respondents to the survey represented the larger population of custom and semi-custom builders of single-family detached homes (see Table 2). Respondents were primarily custom and semi-custom builders of single-family detached homes (Figures 2 and 3). Single family

TABLE 2. Respondent Demographics.

Demographic Attribute	Average Descriptor
Company Size	<5 employees
Market Segment	Custom to semi-custom single family detached
Housing Units Constructed Per Year	<25
Years of Experience	6–35 years

FIGURE 2. Respondent mix by market served.



custom and semi-custom home builders represent a large portion of the residential construction market, but in general do not have the individual capacity for research and development and tend to be more sensitive to market fluctuations than the production builders that are diversified across geographic locations (Koebel 2007). Custom and semi-custom homebuilders also tend to have closer working relationships with their clients, and are able to respond more quickly to changing consumer demands (ibid.). These builders tend to be small “mom and pop” organizations and often have very small payrolls: 57% of survey respondents had five or fewer employees (Figure 4). The survey data consisted primarily of responses from project managers, owners, or presidents of the companies represented (Figure 5).

Accordingly, the respondents in this study represent this significant segment of the residential construction market in the U.S.

FIGURE 3. Respondent mix by housing type.

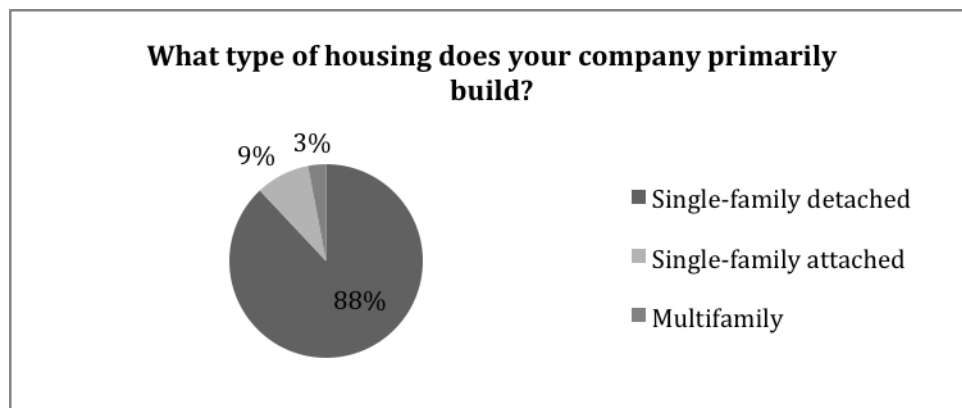


FIGURE 4. Number of Full Time Employees.

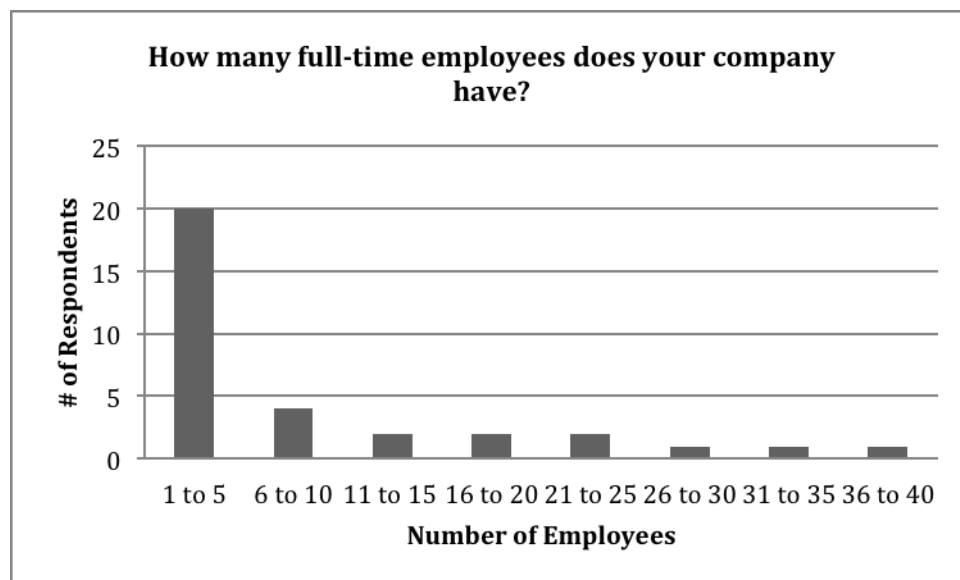
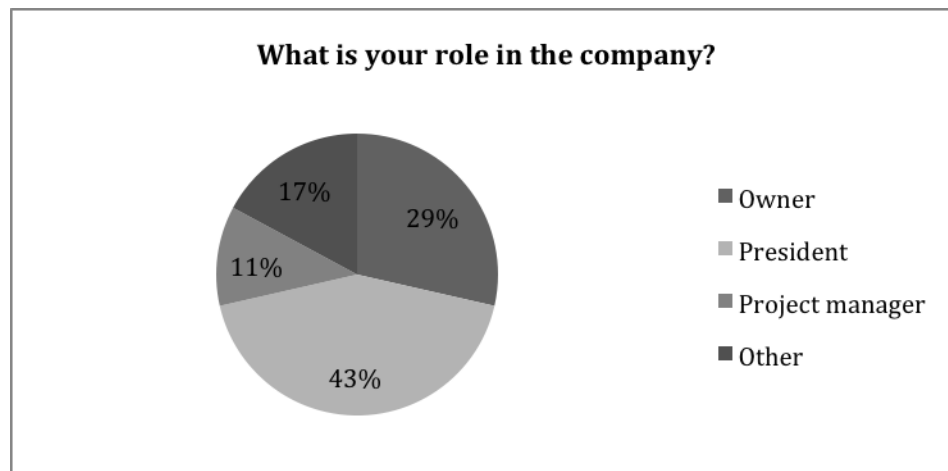


FIGURE 5. Respondent's role in company.



The builders represented in the survey have varying degrees of experience in the residential construction industry ranging from 1–40 years (Figure 6), and have often worked at their respective companies for numerous years: 37% of respondents had from 21–35 years of experience with their current employers (Figure 7). Most respondents build less than 25 housing units per year, and often build considerably fewer (Figure 8). All survey respondents considered themselves as those who would “Pursue, value or consider new technology” making them *innovators*, *early adopters*, or *early majority* on Rogers’ (2003) innovativeness index (Figure 9). None of the survey respondents “saw little value or resisted new technology,” which would place them into Rogers’ (2003) *late majority* or *laggard* categories, in terms of the adoption of innovative products. While new technology was not specified here, the preamble to the survey defined green building innovation as the purpose of the study. This predisposition to the adoption of new products is characteristic of the entrepreneurial spirit embodied by small business owners.

FIGURE 6. Respondent years of experience.

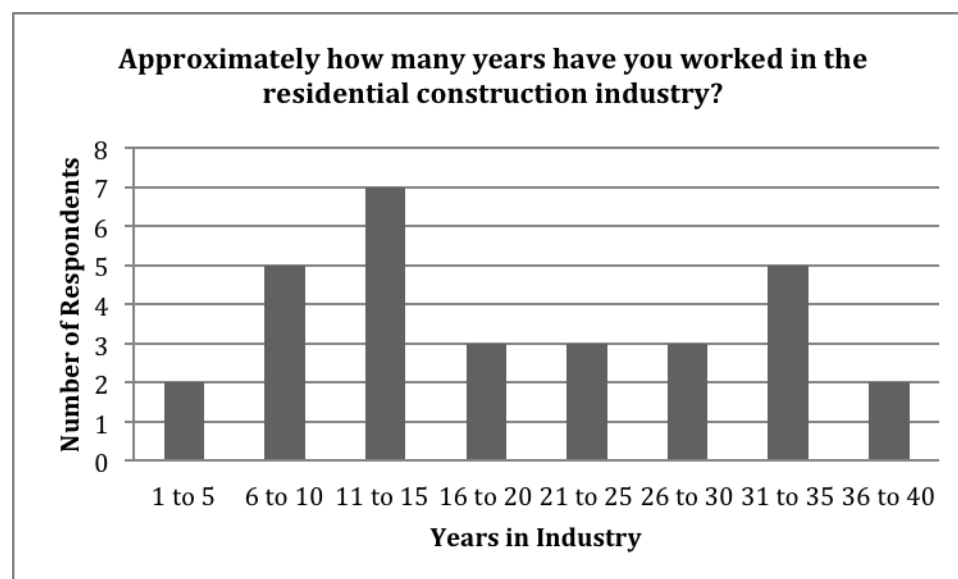


FIGURE 7. Respondent years with company.

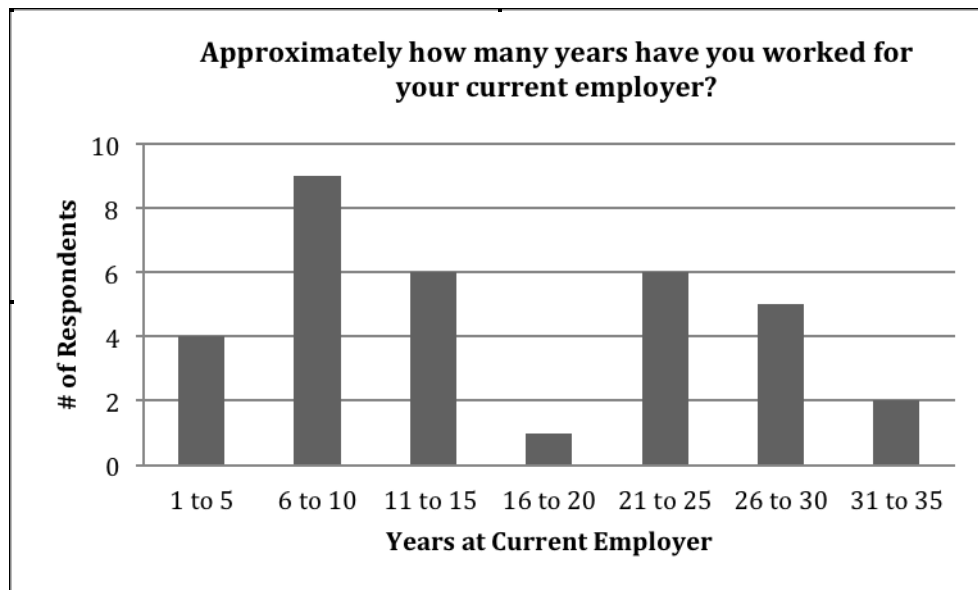
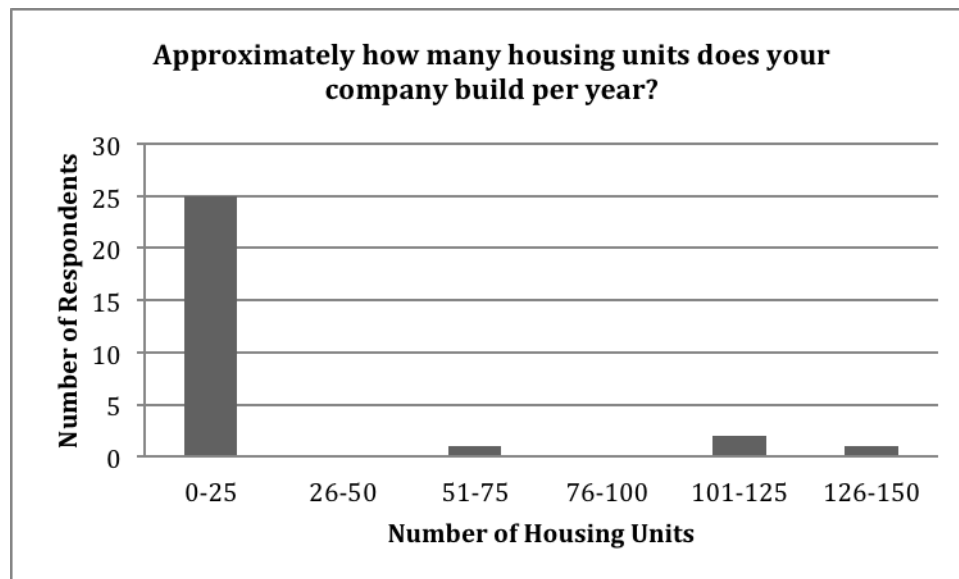


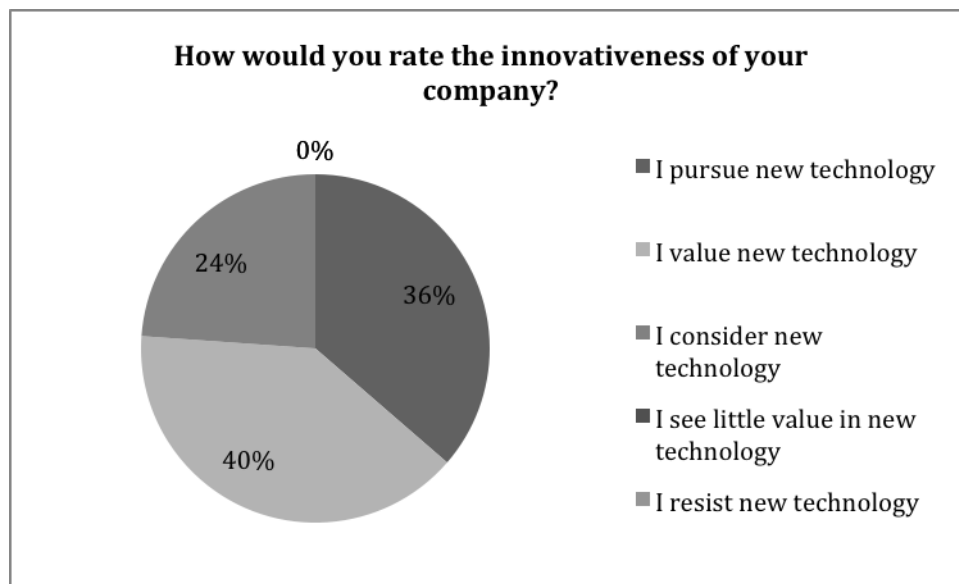
FIGURE 8. Houses built per year.



Innovative Product Adoption: Structural Insulated Panel Systems

The second section of the survey focused on respondents' adoption of SIPS. 44% of survey respondents reported having experience with implementing SIPS in a building project. These fifteen respondents were subsequently asked to rate product attributes related to the diffusion of SIPS in the third section of the survey. Respondents who reported *never* having used SIPS in a building project were asked in a free response question to list reasons why not. These respondents listed "higher cost" (36.8%), "client resistance" (31.5%) and "lack of product

FIGURE 9. Perceived Innovativeness.



information” (21%) as the primary barriers to adoption. Other mentioned reasons for resistance cited were “lack of prevalence in a local market,” “lack of properly trained subcontractors,” and “lack of push by local sales representatives.”

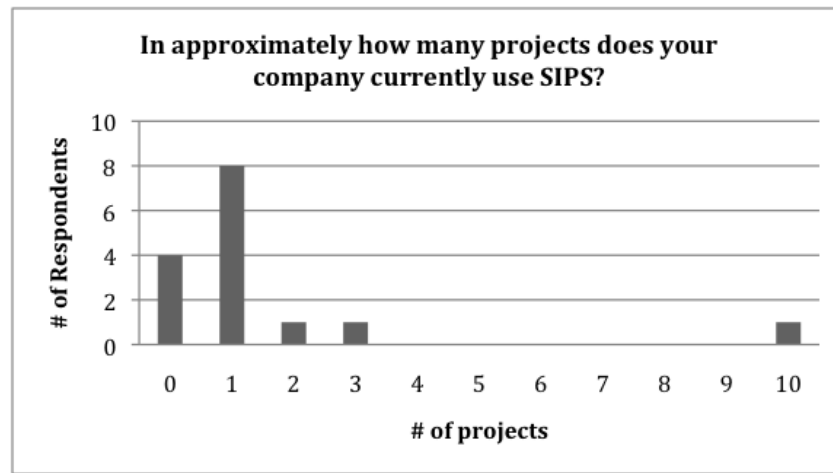
Respondents who had experienced at least one project with SIPS but discontinued their use in subsequent projects were also asked to list reasons why they had discontinued use of SIPS in a free response question. The primary reasons cited by this segment of respondents were *cost* and *lack of client demand*. Other reasons were associated with the market slowdown, including *no new starts*.

The majority of respondents with SIPS experience (12 out of 15) reported using SIPS in one or fewer current building projects (Figure 10), reflecting the small market penetration that SIPS have achieved despite many years and versions on the market. Only 20% of respondents with SIPS experience were currently using SIPS in more than one project.

Significance of Product Attributes for Initial/Continued Adoption of Structural Insulated Panel Systems

The third part of the survey was presented only to those respondents indicating prior experience with SIPS. In this part of the survey, respondents were asked to recollect their company’s *initial* experience with SIPS, then separately consider their experience with this innovation after the firm decided to incorporate SIPS as part of their construction methods on a continued basis. Differences in the importance of attributes between first adoption and ongoing or continued adoption could indicate a need for possible variations in interventions to increase diffusion of SIPS in the market.

The survey asked respondents to first agree to a diffusion attribute’s existence and then rate the effect of that attribute on adoption for both first use and continued use using a Likert scale, with 1 indicating “does not affect adoption” and 5 indicating “strongly affects adoption”. Table 3 presents descriptive statistics for responses with respect to each product attribute.

FIGURE 10. Use of SIPS in Current Projects.**TABLE 3.** Participant Responses Describing Attribute Importance for Innovation Adoption.

Attribute	Type	(Range)	Mean (sd)	Interquartile Value	P-value
Timing of Commitment	First Trial	(1–4)	2.44 (1.13)	2.00	0.51
	Continued Usage	(1–4)	2.67 (1.22)	2.50	
Compatibility	First Trial	(2–5)	3.67 (1.00)	1.25	1.00
	Continued Usage	(2–5)	3.67 (0.87)	1.00	
Supporting Innovation	First Trial	(2–5)	3.56 (0.88)	2.00	1.00
	Continued Usage	(2–5)	3.56 (0.88)	1.00	
Complexity	First Trial	(2–5)	3.33 (0.71)	1.00	0.45
	Continued Usage	(2–5)	3.56 (0.88)	1.00	
Triability	First Trial	(1–5)	3.00 (1.12)	0.50	0.81
	Continued Usage	(1–5)	3.11 (1.17)	1.50	
Observability	First Trial	(1–4)	3.33 (1.00)	1.00	1.00
	Continued Usage	(1–5)	3.33 (1.22)	1.50	
Relative Advantage/ Cost Advantage	First Trial	(2–5)	3.78 (0.97)	2.00	0.59
	Continued Usage	(2–5)	3.67 (1.12)	2.00	
Risks	First Trial	(1–5)	4.38 (0.52)	1.50	0.18
	Continued Usage	(3–5)	3.75 (0.89)	1.75	
Supervision Competency	First Trial	(2–5)	3.50 (1.07)	1.50	0.60
	Continued Usage	(2–4)	3.25 (0.89)	1.75	
Consumer Resistance	First Trial	(1–5)	3.63 (1.19)	3.00	0.76
	Continued Usage	(2–5)	3.75 (0.89)	0.75	
Trade Resistance	First Trial	(1–5)	3.00 (1.20)	2.00	0.56
	Continued Usage	(1–5)	2.75 (1.39)	1.50	
Regulatory Resistance	First Trial	(1–5)	3.38 (0.92)	1.50	0.45
	Continued Usage	(2–5)	3.13 (0.99)	1.50	
Coordination within Project Team	First Trial	(3–4)	3.63 (0.52)	1.00	0.08
	Continued Usage	(2–4)	3.25 (0.71)	1.00	

Notes: *sd*=Standard Deviation

Statistical Results

As reported in Table 3, none of the thirteen attributes, as compared between first trial and continued usage, were statistically different (Table 3). While Table 3 lists participant responses as to the importance of attributes across different types of use, the following section provides further exploratory data analysis techniques used for better understanding differences among responses.

Results from the correlation analyses are shown in Table 4. There were diverse relationships identified in all attributes. Only Compatibility and Relative Advantage/Cost Advantage had statistically significant, strong, positive associations between the first trial and continued usage. Respondents who reported higher levels of *Compatibility* ($r = 0.87, P = 0.003$) and *Relative Advantage/Cost Advantage* ($r = 0.84, P = 0.004$) in the first trial also significantly reported a higher level of the two attributes for continued usage. *Timing of Commitment* and *Coordination within Project Team* were the next two attributes with high levels of correlation. Such a correlation would suggest that these attributes, while present at initial trial, remain as a risk in continued use. On the other hand, *Risk* (as a quantifiable uncertainty) was reported as a negative association between the first trial and continued usage, unlike for other attributes. This indicates that respondents, who acknowledged a high level of risk at the first trial, tended to report a decreasing level of risk for continued usage.

Figures 11 and 12 present box plot comparisons of the Likert Scale responses on the importance of innovation attributes for product adoption, for initial trial and continued use from the survey. Box plots are a quick way of examining one or more sets of data graphically, typically based on five number sets, as opposed to a histogram (shown in figure 13) or other descriptive analysis tool. Figure 11 shows the relative importance of factors for the *initial trial* of SIPS by respondents, and Figure 12 shows relative importance for *continued use*. These box

FIGURE 11. Relative importance of Innovation Attributes for *Initial Trial* of SIPS.

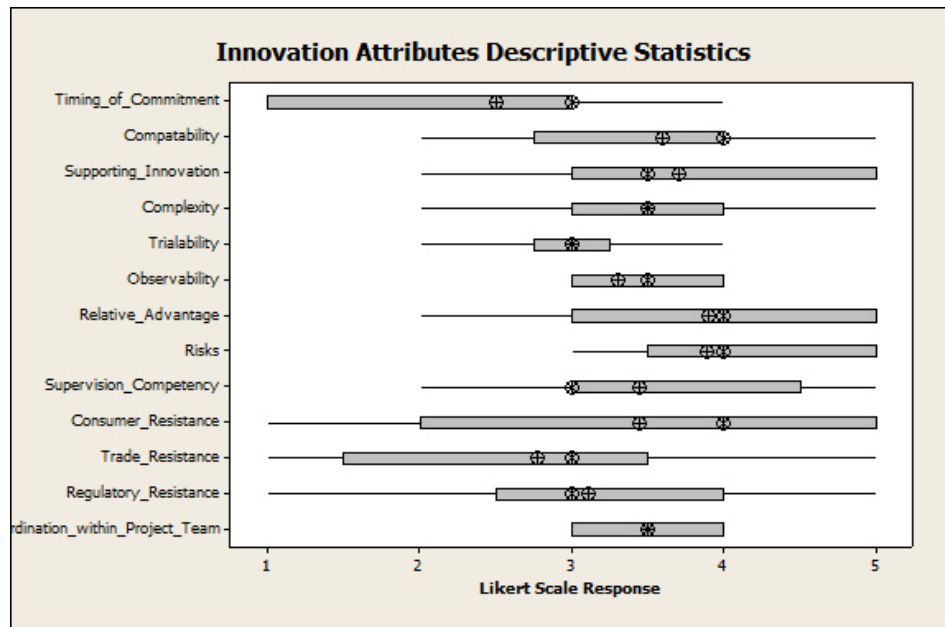
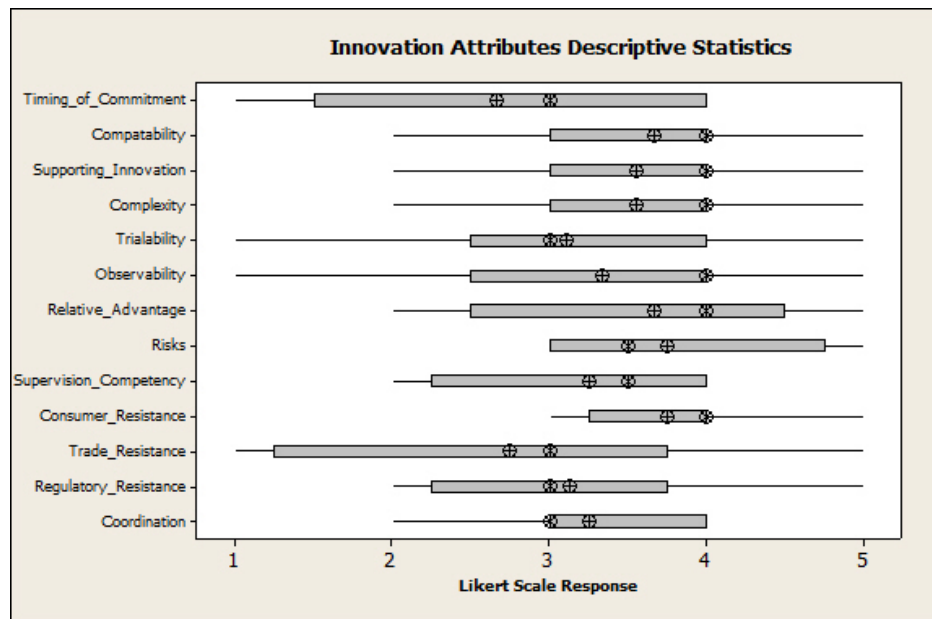


TABLE 4. Pearson's Correlations for Attributes Between the First Trial and Continued Usage.

Attribute	Continued Usage												
First Trial	1	2	3	4	5	6	7	8	9	10	11	12	13
Timing of Commitment	0.66												
Compatibility		0.87**											
Supporting Innovation			0.31										
Complexity				0.47									
Trialability					0.29								
Observability						0.41							
Relative Advantage/Cost Advantage							0.84**						
Risks								-0.39					
Supervision Competency									0.15				
Consumer Resistance										0.44			
Trade Resistance											0.60		
Regulatory Resistance												0.57	
Coordination within Project Team													0.68

FIGURE 12. Relative importance of Innovation Attributes for *Continued Use* of SIPS.



plots provide the ability to see the distribution of survey responses, indicating a measure of consensus among respondents.

In the box plots of Figures 11 and 12, the gray box represents the range from 25 to 75 percent of value reported in the survey. The gray area is considered the interquartile value, which demonstrates variability in consensus around the reported attribute among respondents. The circle symbol with a plus represents the mean value and the circle with a star represents the median value (50th percentile).

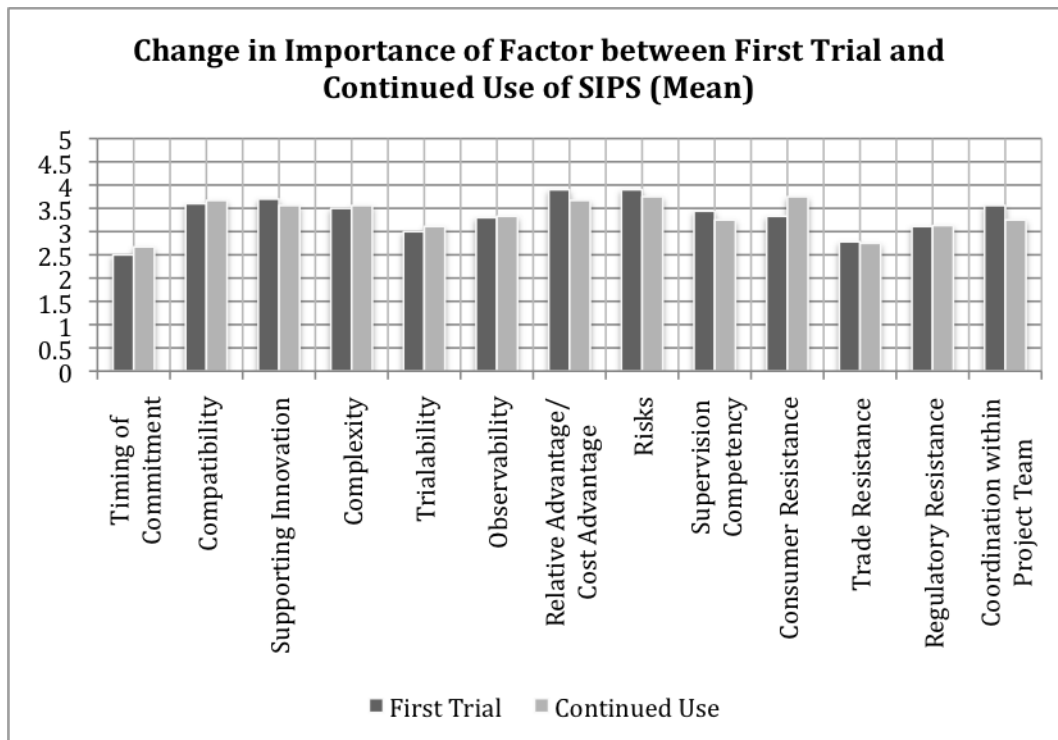
Figure 13 shows, through a histogram, the change in reported importance between first trial and ongoing use for each of the innovation attributes, based on the mean Likert response for each attribute.

Most factors had relatively little change in importance between first trial and continued use. However, the *direction* of change (shown in figure 13), i.e., whether each factor became *more* or *less* important after a respondent's initial experience with the product, provides an interesting perspective on the role each factor may play in adoption, and how interventions might be designed to increase adoptions. The next section describes these and other conclusions that can be drawn from this study.

CONCLUSIONS

The sample population of EarthCraft VA builders (in the state of Virginia) is similar in green certification and demographic makeup to others in the green residential building industry in the southeastern US region (as Earthcraft and Soutface) and in the United States in general. Therefore, the results of this study may be generalizable on a broader basis to the larger certified community of these programs, and not just the population of respondents solicited for the survey.

FIGURE 13. Change in Importance of Factor over Time (Mean Likert Response).



To begin, the work proposed an approach through a list of the common product attributes affecting diffusion of innovations in residential construction (table 1), but not necessarily for green products. Short answer responses to the survey did not suggest a need for additional attributes when testing green products. Further, the survey tool generally appears to provide a valid means to identify perceived barriers to adoption of Structural Insulated Panel Systems, one green product. Further study would need to test this tool across the portfolio of green products.

SIPS are being used by those in the first 50 percentile of normal distribution of innovativeness, i.e. innovators, *early adopters*, and *early majority*, which is expected. Interestingly, the same groups are *not* using SIPS as well. Meaning, level of *innovativeness*, or the propensity to adopt, might not affect SIPS and attributes are therefore an appropriate level of study.

Survey respondents provided meaningful feedback on their choices to adopt or not adopt SIPS, and were candid in their reasoning through the free response sections of the survey. The specific barriers that exerted the largest effect on adoption were *supporting innovation*, *relative advantage* and *risks*, while the barriers that exerted the smallest effect on adoption were *regulatory resistance*, *trade resistance* and *trialability*. Timing of commitment also scored relatively low on the diffusion factors chart, indicating a lack of concern by builders over when the SIPS product is adopted during the home production process. Product manufacturer/suppliers and builders can learn from these perceived barriers (or lack thereof) to inform the SIPS commercialization process and increase diffusion across the industry.

First Trial Conclusions

Regarding the attributes of innovation of SIPS upon first use, several trends can be derived from the descriptive statistics. The first observation is that *timing of commitment*, *consumer resistance*, *trade resistance* and *regulatory resistance* have the lowest rated effect on adoption. *Trade* and *regulatory resistance* is not much of a factor in the assembly of SIPS as both parties are often reactive and might not affect the decision to adopt. *Timing of commitment*, however, is a surprise. The *timing of commitment* of SIPS is important in the building process as SIPS must be specified as early as possible to avoid affecting the structure of the home and the work of key stakeholders, such as electricians and plumbers. The fact that initial trial builders rated it as having a relatively small effect on adoption is a substantial discovery. While SIPS might have a relatively low rate of initial adoption, after many years in the market, builders seem less worried about its role in the building process as a factor of resistance, which is counter to the case with a previous innovative product such as I-Joists. According to the data, timing of commitment is one of the smallest barriers to adoption of SIPS.

Supporting innovation, relative advantage and risks show the highest effect on adoption according to the survey results. *Supporting innovation* for SIPS was discussed by Sarah Slaughter as one of the primary sources of builder innovation on the jobsite due to the necessity to incorporate the panels into existing building systems (Slaughter 1993). *Risks* and *relative advantage* are identified as barriers to adoption for general green building innovation by Ted Koebel (Koebel 2008). These innovation attributes can be thought of as the largest barriers to adoption of SIPS, which have been identified through the literature review and validated through the survey results.

Finally, an interesting clustering of data has emerged around *trialability*, *observability* and coordination within the project team. The interquartile range for each of these attributes is 1 or less, indicating a consensus on the degree to which each attribute effects adoption. The mean score for *observability* was 3.33 and coordination within the project team was 3.5 while the mean score for *trialability* was 3. This clustering indicates that a large portion of survey respondents agree that these attributes relatively strongly affect adoption while not presenting as strong a barrier to adoption as the attributes discussed in the previous paragraph.

Interestingly, *consumer resistance* collected the widest range of responses from the survey pool. However, the mean of 4 indicates that it is considered to strongly effect adoption by a large portion of survey respondents. Several builders separately identified “lack of consumer demand,” which could be interpreted differently than resistance, as a reason for not trying SIPS. This data seems to indicate that builders perceive consumer uncertainty, either through a market “pull” or market resistance, as a large barrier to the adoption of SIPS. Such a distinction could also indicate a need for the attribute to be re-defined for green products, or those innovations that have been on the market for some time without high saturation.

Continued Use Conclusions

Survey respondents were also asked to rate the same list of innovation attributes for continued use of SIPS, in contrast to initial trial. Comparing the descriptive statistics from each set of responses reveals some interesting trends. Some attributes reveal more clustered responses while other attributes trend upwards or downwards in regards to their effect on adoption. *Timing of commitment*, *compatibility*, *complexity*, *risks*, *supervision competency*, *trade resistance*, *regulatory resistance*, and *coordination within the project team* all demonstrated little variance from their first use responses.

Supporting innovation and *consumer resistance* both exhibited a tighter clustering of responses, although both mean scores remained within 0.5 of their first use responses. *Trialability* and *relative advantage* both exhibited a shift in interquartile range, pointing to a more scattered response, but the mean response remains close in both instances. In general, the innovation attributes appear to have relatively similar effects on adoption for first trial and continued use applications.

In addition, from the correlation matrix in Table 4, *Compatibility* and *Relative Advantage / Cost* contain a positive correlation between initial trial and continued use. *Compatibility* was also addressed in the literature by Slaughter (1993) as a barrier to adoption due to the need for congruency between manufactured products and industry habits. Interestingly, this barrier seems not to have been reduced by SIPS manufacturers, at least according to builders, a key stakeholder in the supply chain. Further, builders tend to increasingly identify it as a barrier after continual use. *Relative Advantage / Cost* also contains increasing risk through continued use. If such advantages are not understood fully through initial trial, it seems evident that such issues would be more and more pressing through time. Finally, the correlation of *Risk* was a negative association between initial trial and continued use. This result indicates that Earth-Craft VA builders can reduce general risks associated with adopting Structural Insulated panel systems through continuous use.

Limitations

The conclusions that can be drawn from this study have potentially far-reaching effects on the adoption of innovative green products in the construction industry. However, a commentary of the limitations of this material is necessary to provide full disclosure and analysis of the research. The description of these limitations is not meant to challenge the validity of the work or the robustness of the conclusions and future work, but rather to fully disclose the nature of the work.

One limitation of the study is the survey tool itself. The development of surveys is a complex art that involves in-depth knowledge of research methodology, question structuring, and a healthy dose of people skills. The authors used their expertise to create a detailed survey with as few ambiguities as possible and piloted the survey to a small pool of academics. However, once the response collection began a few obvious weaknesses of the survey were uncovered. The primary issue facing the survey became the wording of the specific questions asked of the sample population. Although definitions of each innovation attribute were provided upon invitation to complete the survey, the definitions themselves leave room for some degree of ambiguity in response, as previously mentioned in the conclusions. For example, coordination within the project team is defined as “synchronization of various stakeholders is required for implementation”. Are stakeholders restricted to the builder’s project team (i.e. project manager, superintendent and subcontractors), or is a broader interpretation including the owner, architect, and end user more appropriate? This definition does not accurately define which stakeholders are in question and can therefore be interpreted in different ways by different survey respondents. In response to this concern, the survey tool did allow for open response as to suggested changes, none of which disagreed with the attribute definitions provided.

Another drawback of the survey design was the decision to exclude builders who had not *ever* tried SIPS in the analysis of the innovation attributes. These builders were prohibited from rating the attributes of SIPS after a negative response the question: “has your company ever implemented SIPS in a building project?” These builders are likely aware of SIPS usage in

the industry and could have, therefore, contributed meaningful feedback to the attributes of SIPS. In fact, the builders who have chosen not to use SIPS may be the best identifiers of barriers to adoption for the product. Future surveys should include these respondents in all sections of the survey. Further, the use of Earthcraft certified builders within the larger Southface community does not offer findings as general as needed for a more robust study.

Finally, although some results showed statistical significance, small size of samples is a study limitation. In this study, statistical interpretations should be drawn very carefully. Based on Cohen Convention (1992), at least 64 samples for paired t-tests and 85 samples for correlation tests are required to achieve power =0.80 for $\alpha=0.05$ and medium effect size. Thus, a further study using larger sample size is necessary to produce precise estimates of reliability and generalizable findings (Cohen, 1992).

IMPACTS AND FUTURE WORK

"Using the attributes of the magnitude of the change and the linkages to other components and systems, companies can predict and plan for different types of activities depending upon the type of innovation involved." (Slaughter 1998)

Expanding Slaughter's logic to the comprehensive list of innovative green building product attributes developed in this study allows deeper understanding of the barriers to adoption of Structural Insulated Panel Systems. Each product attribute can be considered independently or as part of the whole. Identifying the barriers to adoption such as consumer resistance to SIPS will help identify which attributes of an innovative product are hindering its diffusion in the market. This information can be distributed throughout the product supply chain to realize a smoother transition from invention to innovation.

This study has established a framework for evaluating the role of innovative product attributes in the adoption decisions of a specific stakeholder group, and has shown that barriers (or accelerators) of innovative products can be identified and quantified. Applying this study methodology to other green and non-green products will allow the comparison of attributes across products. This comparison will allow conclusions to be drawn as to whether innovative green building products demonstrate different barriers to adoption than other products, or if they are basically perceived as the same by builders. The reproduction of this study methodology is planned for future research projects at Virginia Tech. A comprehensive picture of barriers and accelerators to innovative green building products will ultimately shorten the diffusion period for environmentally friendly building products and help reduce the massive ecological footprint of the residential construction industry.

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