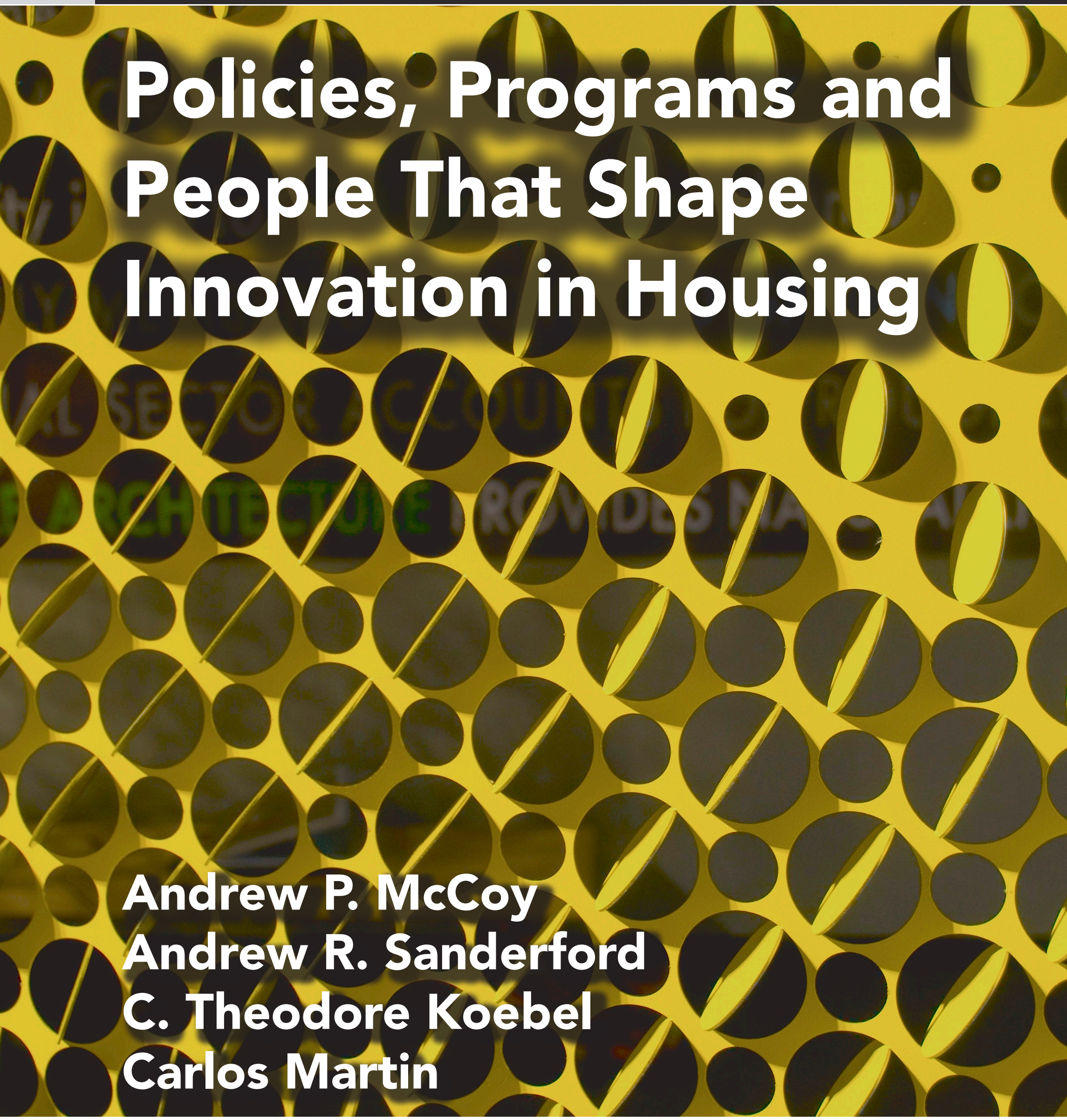
HOUSING INNOVATIONS COLLECTION
Andrew R. Sanderford, Andrew P. McCoy
and C. Theodore Koebel, *Editors*



Policies, Programs and People That Shape Innovation in Housing

Andrew P. McCoy
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MOMENTUM PRESS
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Abstract

Businesses, consumers, industry groups, and governments understand the importance of innovation and the innovation process for continued economic success and improvements in quality of life. However, innovation remains an opaque topic. A paradox exists in housing at-large; using innovation is vital yet accounting for the value to individual organizations remains a challenge. This paradox is supported by a landscape that includes a sizeable graveyard of failed attempts at innovation on grand and small scales.

This book seeks to decrease the opacity of innovation processes in residential construction and housing. Along with the next book in the collection, this book addresses key questions pertinent to the potential for widespread diffusion of green buildings and for improvements in community sustainability. The first several chapters will orient the reader to the concept of innovation in housing and residential construction. The later chapters will examine both the role of the Federal government in supporting innovation in housing and the commercialization pathway for residential building technology innovations.

The overarching purpose of this book is to provide context and foundation for later books in the collection and to assist readers in peeling back the complex layers of innovation in housing and residential construction.

KEYWORDS

adoption, construction, diffusion of innovation, housing, innovation process

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Preface

Residential primary energy consumption has declined significantly from 1950 to the present. Though housing units have grown larger over the same period, they are consuming less energy than similarly sized older homes. Such growth in efficiency suggests that higher performance housing technologies continue to be adopted by homebuilders and homebuyers. While noting that this technology diffusion has occurred is important in the broader conversation about sustainability and innovation, understanding how these principles play out at the local level sheds significant light on technology diffusion patterns in the industry as a whole.

Indeed, a substantial amount of research effort has focused on regulations, certifications, and consumer awareness as means to accelerate green building diffusion, but little is known about market behaviors with regard to diffusion: the distribution of early adopters, diffusion trajectories, or the characteristics associated with early adoption of green homebuilding technologies. This book and subsequent volumes in the *Housing Innovations* collection were conceived as follow up to the HUD funded research project, Impact of Market Behavior on the Adoption and Diffusion of Innovative Green Building Technologies (GRANT10814146). On this grant, primary investigators analyzed the diffusion of innovation among residential building firms. The *Housing Innovations* collection seeks to summarize this work and draw together a number of additional resources on innovation within residential construction. Specifically, this book examines high-performance technologies and their role as innovations in the residential homebuilding market.

Along with the next book in the collection, this book addresses key questions pertinent to the potential for widespread diffusion of green buildings and for improvements in community sustainability. The first few chapters will orient the reader to the concept of innovation in housing and residential construction. The later chapters will examine both the role of the Federal government in supporting innovation in housing and the commercialization pathway for residential building technology innovations.

The overarching purpose of this book is to provide context and foundation for later books in the collection that peel back the layers of innovation in housing. For example, in the second book in the collection, the authors report on and summarize the findings from a cluster of diffusion of innovation models focused on U.S. homebuilders and their decisions to adopt high-performance technologies over their traditional economic substitutes. Future books will examine case-specific instances of innovation as well as innovation commercialization and the relationship of innovation to residential construction safety.

While this book is the one of the first attempts to link together disparate components of the housing and construction innovation literature to inform a conceptual diffusion of innovation model, it is far from an exhaustive discussion and summary. However, it represents a significant step forward for those keen to continue the discussion. We hope that the book provides an introduction to the concept of innovation. Moreover, we hope that the book helps shed light on the unique dimensions of innovation within housing as well as the dimensions of innovation it shares with related and unrelated industries.

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ACKNOWLEDGMENTS

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CHAPTER 1

Innovating the House

Andrew Sanderford, Andrew McCoy, C. Theodore Koebel, and Carlos Martin

1.1 BACKGROUND

Scholars of innovation have, for some time, engaged in the process of identifying the role of innovation in economic growth. The study of innovation has produced an astonishing array of insights into the way firms create, individuals choose, and markets evolve. Today, the leading edge research notes that innovation is an agile process, arising from garages in Silicon Valley as well as laboratories of private and state sponsored firms in large metropolitan regions (Chesbrough, Vanhaverbeke, and West 2006; Christensen, Anthony, and Roth 2004; Fagerberg, Mowery, and Nelson 2006; Hall 1998; Koebel 2007; Rutten, Doree, and Halman 2009; Schumpeter 1939; Slaughter 1993a, 1993b). The evidence from the literature and practice is clear. Innovation can create competitive advantage, crack open new business opportunities, and define new categories of products, processes, and services.

Within the research on the transformative nature of innovation, scholars have examined how and why individuals and firms adopt innovations in particular places at particular times (Porter and Stern 2001; Porter and Van der Linde 1995). There are many competing and complementary theories that have emerged from this work. One, the theory of the city as an innovative milieu, suggests that the city (or region) serves as the physical or social setting in which innovation occurs (Hall 1998). Such a theory contends that there have been places in time and space where giant advances in innovation have been made possible by unique clustering of opportunities, people, capital, infrastructure, resources, and public policy. While attempting to replicate the conditions for success in those places, Hall cautions that "building innovative milieu is not something that can be done either easily or to order" (Hall 1998). Among many things, Hall's argument highlights the opportunity to investigate the nature of innovation in the residential construction industry, an industry where place and location are drivers of value.

Researchers and policymakers have struggled with the lack of technological innovation in the construction industry. More specifically, the U.S. homebuilding industry has been considered resistant to innovation given a number of structural and market factors. However, green building technologies are innovations in the residential construction space and appear to have diverged from prior adoption and diffusion patterns. In place of path dependency and resistance to innovation, the literature points toward a widening awareness and likely use of innovative practices and techniques that support environmental goals. Where homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies exhibit accelerated patterns.

This transformation presents an opportunity for federal research advocates seeking to institutionalize long-term innovation in the industry in general and further promote private-sector investments in energy-efficient, sustainable technologies in particular. The Federal government has been pursuing both broad research and innovation goals for American industry, and the Department of Housing and Urban Development (HUD), especially, is concerned with the incorporation of these into the current and future affordable housing stock.

The potential to widely diffuse sustainable building and development practices is critical to the future viability and impact of the sustainability movement. Structures, particularly residential structures, are the new frontier for sustainability. Given the durability of the built environment, new additions to the housing inventory have long-term implications for resource consumption and for the creation of sustainable communities. Successful sustainability requires a shift from the current low-level of market penetration to widespread diffusion and market saturation. Without better knowledge of commercialization, adoption, and diffusion of sustainable housing, it could remain a *boutique* good that is unaffordable and unappealing to the majority of consumers.

Though there have been some investigations into sustainability in housing, as yet, little is known about the commercialization, adoption, and diffusion of innovative green building products, product clusters, or practices. Previous interventions—particularly from the U.S. Departments of

Energy (DOE), HUD, Environmental Protection Agency (EPA), and the National Science Foundation (NSF)—utilized strategies borrowed from other industries and policy efforts; for example, federal attempts to promote homebuilding technology diffusion have included advocating regulations that required innovation (i.e., DOE's energy-efficient building codes), direct funding of technological research (NSF), demonstrations of research products (DOE's Building America and EPA's Energy Star), and public products or subsidies for their adoption (such as federal energy-retrofit tax credits and HUD's Recovery-funded green capital resources). Further, attention has been paid recently to a broad understanding of industrywide adoption processes to design efficient and effective future public interventions. Some of these interventions successfully contributed to federal and local capacity for investing in green technology diffusion strategies.

1.2 GREEN BUILDING TECHNOLOGY DIFFUSION

The advent of green building technologies has diverged from prior adoption and diffusion patterns. Where the commonly accepted *time-to-market* of homebuilding innovation has been 10 to 25 years from concept, some green building technologies have experienced accelerated diffusion. This transformation presents an opportunity for federal research advocates seeking to institutionalize long-term innovation in the industry in general and to further promote private-sector investments in energy-efficient, sustainable technologies in particular.

There is a large, established literature on the adoption and diffusion of innovation (see, for example, Baumol 2010; Fagerberg, Mowery, and Nelson 2006; Meeus, Oerlemans, and Hage 2004; Rogers 1995) that provides excellent substantive and methodological context for this book. A substantial body of work also exists on policy diffusion, including a recent focus on energy and environmental policies and regulations (Boushey 2010; Jefferson 2008; Matisoff 2008; Simons, Choi, and Simons 2009). Boushey (2010) examines rapid and widespread adoption by states of policies influenced by significant contagion effects that could provide useful insights into the diffusion of green building. Although the literature on innovation, adoption, and diffusion is very extensive, there has been little empirical work on innovation and diffusion of technology in housing (Blackley and Shepard 1996; Kale and Arditi 2009; Koebel 2007; Oster and Quigley 1977; Slaughter 1993a; Toole 1998). The residential construction industry (and the construction sector broadly) has been identified as persistently resistant to innovation (Martinez and Polo 1996; McCoy et al. 2010; Rhee et al. 2010;

Seaden et al. 2003). Despite this resistance, anecdotal evidence and early research on diffusion of sustainability and green building practices indicate a possible shift toward an accelerated diffusion pattern for green building.

This book builds on and describes recent research on innovation adoption and diffusion in residential construction. Further, this book and others in the collection examine the role of better data coverage and inclusion of the following factors external to the firm that have been previously ignored or addressed in isolation: public organizations (Boushey 2010), codes and regulations (Manseau and Shields 2005), key stakeholders (De Bruijn and Heuvelhof 2008; Manseau and Shields 2005; McCoy et al. 2010), product attributes (McCoy et al. 2010), and industry complexity (Gann and Salter 2000; Gann, Wang,and Hawkins 1998), to name some. One recent example of this broader variable approach is Kale and Arditi (2010), who introduced flexibility to diffusion modeling around certifications for Building Information Modeling (BIM). In addition to being one of the first studies to apply a Rogers based diffusion of innovation model to the construction industry, it significantly influenced recent analyses of homebuilder's adoptions of high-performance building innovations.

Additionally, the impact of certification on the diffusion of green building more broadly has not been explored; anecdotal evidence suggests that certification systems themselves could be irrelevant to or even hinder overall diffusion. Location biases have been noted in the literature (Koebel and McCoy 2006) but not examined empirically for green building.

This book has several goals. First, we hope to introduce and orient practitioners, researchers, and regulators to the conversation about innovation in U.S. housing. Second, the book will summarize key research on innovation in housing and from allied disciplines that could provide guidance. Third, the book will discuss the history of Federal interventions in housing innovation and provide insight into the people, policies, and programs that shaped the government's role in building technology. Finally, the book will provide a summary and framework of the commercialization pathway for new residential construction technologies and describe the stakeholders in that process.

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CHAPTER 2

Understanding Innovation and the Challenges of Innovation in Housing

C. Theodore Koebel

2.1 INNOVATION PARADOXES

Businesses, consumers, industry groups, and governments understand the importance of innovation for continued economic success and improvements in the quality of life. Innovation is the prominent theme found in articles and commentary in the popular press, research and scholarship, and government reports. In today's economy and society, it seems everyone—whether country, business, or consumer—wants to be seen as an innovator or at least as *being* innovative. The very terms we use reflect the positive values associated with innovation (creative, contemporary, inventive, new, original, avant-garde), and the negative values associated with its opposite (old-fashioned, worn, traditional, outmoded, uncreative, Luddite). Innovators are *leaders* and *creators*; if you are not an innovator, you are a *follower*, or worse, a *laggard*.

Favorable valuations of the idea of innovation undoubtedly reflect the positive impact of innovations and the pace of innovation since the mid-20th century. Technological innovations have transformed our lives, mostly for the better. We expect continuous improvements in products affecting our lives, particularly associated with technology and biomedical innovations, with a rapid pace of commercialization bringing new and improved products to the intermediate or end-user. However, innovation is inherently risky, not just to the older, progressively obsolete systems replaced by radical innovation but also to the innovator. Although our attention is biased toward innovations that succeed, many innovations and innovators fail. The negative terms associated with the positive attributes of innovation include foolish, risky, rash, unwise, while the positive attributes of the noninnovative can be described as tried-and-true, proven, trustworthy.

The innovation paradox in housing is that we cannot easily tell when innovation is good and when it is bad, which is the inherent risk of taking chances with something new. The landscape of the housing industry includes a sizeable graveyard of failed attempts at innovation on grand and small scales, including George Romney's Operation Breakthrough (which failed to produce any breakthroughs), the exterior-insulation-finishing system (EIFS), which failed in many residential applications prior to improvements in moisture control, and Pulte Home Sciences' factory panelization venture. Making the innovation terrain even more challenging, failure can be a precursor of success. But there are attributes of housing that make the risks of failure more costly than in many other consumer products, as well as attributes that present barriers or impediments to innovation.

There are also three different (and sometimes overlapping) types of innovations in housing. Cost-efficiency innovations result in building homes of light quality for less cost and expanding demand by making the product more affordable. Quality-functionality innovations improve on the performance of existing products and help sustain their continued use. Radical innovations introduce entirely new products or materials that create new markets. Innovations in housing generally involve improvements in the cost and functionality of established products and processes; however, few innovations have succeeded in driving down housing costs. Radical housing innovations are less common and are frequently prompted by innovations and shocks outside of the housing sector. The chemical discovery of vinyl occurred decades before its use as an exterior siding material in housing. The first building insulation code in the United States was mandated during World War II in an effort to conserve oil for military use. The shock of the 1973 Oil Embargo led to increased use of fiberglass and rigid polymer foam as insulation although these products were introduced many years before. New materials are historically adapted for use in housing very slowly and often only in response to governmental mandates, scarce supply of a previously dominant material, or shifts in consumer demand associated with external economic shocks.

In navigating the difficult terrain of innovation in housing, it is useful to address the basics. What is innovation? What are the attributes of housing that act as barriers to innovation? What are the major models and concepts for understanding innovation?

2.2 WHAT IS INNOVATION IN HOUSING?

Identifying innovation is not as easy as it might seem. At the simplest level, it is the new or improved product or process, but it is often not clear what constitutes *new*. Completely new products are fairly easy to identify due to entirely new functions or means of achieving existing functions, the cell phone, for example. As a product, housing can hardly be considered to be new. Functionally, housing is a shelter built for human habitation for protection against the elements, security from intruders, and accomplishment of daily activities of bathing, cooking, and sleeping. Housing has gained importance since the time humans moved out of caves and its functions have remained fairly consistent, albeit those functions are fulfilled differently as technology and materials have changed (Schoenauer 2000).

No time traveler spanning even several centuries would find contemporary housing completely incomprehensible. Foundations, frames, roofing, exterior cladding, windows, doors, plumbing, and kitchens would be fairly easy to recognize. Although modern appliances and home entertainment systems would surely baffle our time traveler, he would mainly be impressed by the improvements in the home's functions rather than dumbfounded in recognizing entirely new functions. Housing has been improved mainly through continuous innovation and improvement in its materials, processes, and functional systems, rather than being redefined by radical innovations (Koebel 2012). The simple nail has progressed from hand produced to *cut* (manufactured), and square nails have evolved to wire nails designed for specific purposes, while the hammer has progressed from the traditional tool to the nail gun, which integrates the hammer and the nail into an automatic process with greater uniformity, quality, and speed. And many *innovations* in the housing industry are adaptations of earlier innovations from other industries or government labs—NASA created many of our current insulation innovations in the 1960s space race. Similarly, the advanced innovations in other industries in the use of computer modeling, simulation, testing, robotics, lasers, and computer-driven production now have the potential to achieve a highly efficient and quality-controlled industrial assembly for housing either in mobile on-site factories or in centralized factories.

The continuity of housing's functions and their incremental improvement make it harder to recognize innovations in housing, and also make it easier to identify something as an innovation even if the *innovation* is not truly new. This has probably led to more confusion among researchers studying innovation than among companies or consumers, particularly when researchers define innovation as anything new to the user even if the user is using old technology. For example, a builder might be using vinyl siding for the first time, but would hardly consider this as an innovation unless there was something significantly new about the product.

Innovation adoption refers to the decision of an intermediate or end-user to try the innovation. Adoption can be continuous or discontinuous. The first group of adopters is often classified as innovators, but this terminology can be confusing; the terms *testers* or *experimenters* are more accurate descriptions (beta-testing has become a standard phase during introduction of new products in many industries). These experimenters decide to try new products and then to continue or reject use, providing important signals to others about the performance and competitive advantage of the new product. Of interest, some in our industry have learned to avoid taking risks as experimenters in favor of second-mover advantage—monitoring the successes of experimenters and seizing the lower risk opportunities presented. This second-mover stance, however, is severely constrained if the pool of experimenters is small.

The aggregation of adopters over time from the point of market introduction establishes the diffusion trajectory (or cycle) of the product. As the number of adopters increases, communication and network effects produce a contagion-like spread of adoption. These network and *bandwagon* effects can result in a rapid acceleration of adoption. As the saturation level is reached, the rate of adoption slows, and the product reaches its maximum market share. The maximum share can only be speculated when an innovation is introduced and can shift (upward or downward) due to changes in competitive products, commercialization and marketing, and the pace of obsolescence.

The diffusion curve plots the cumulative number of adopters over time and frequently approximates a normal distribution. Innovations have an inherent timeline and remain as innovations only for a period of time. This temporal aspect of innovation is dynamic, as implied by the diffusion curve, which shows the progression of adopters (users) over time. Frequently this curve approximates normality and is symmetric around its mean (which is also its median and mode), hence the popularity of the S-curve in illustrating cumulative diffusion patterns. The use of the standard normal curve in describing innovation diffusion (Figure 2.1) was popularized by Rogers (2003, first published in 1962) and has

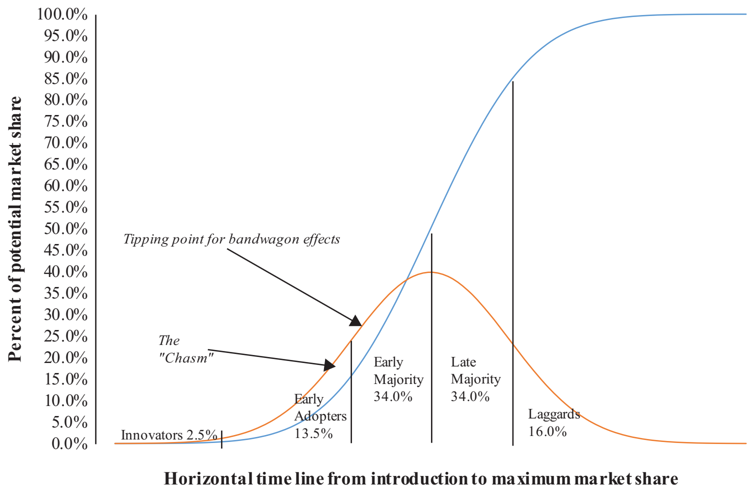

Figure 2.1. The standard normal curve and innovation adopter categories.

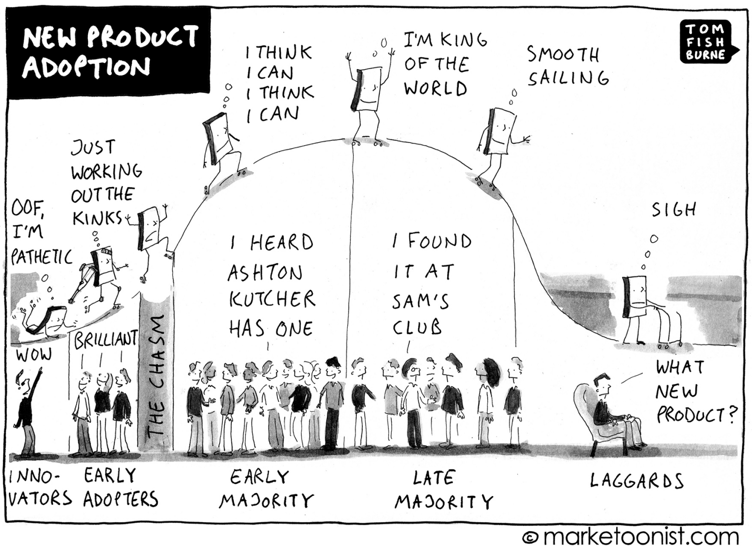

Figure 2.2. New product adoption cartoon.

since become the iconic picture of innovation even for a cartoonist (Figure 2.2).

The key portion of the diffusion trajectory is the point when adoption accelerates as it moves from the innovators (testers) and early adopters to appeal to the majority of the market. The chasm (Moore 1991) occurs at this stage when success depends less on the motivations of experimenters and increasingly on the expectations of the next group of adopters who value the benefits of increased functionality, reduced cost, and ease of use. Beyond these second-stage adopters, marketing can rely increasingly on bandwagon or herd effects influencing early and late majority adopters. Consequently, the largest and most critical challenges for commercialization occur in the early phase of diffusion, although the production, supply chain, and delivery problems in the middle of the diffusion curve are clearly significant. As the saturation level is reached, the rate of adoption slows, and the product reaches its maximum market share.

Over time, an innovation becomes the tried-and-true, or languishes in the chasm (aka *failure to launch*). This dynamic, temporal nature of innovations presents a challenge for how we describe, name, and understand them since the *innovation* progressively loses its innovativeness over time. This is not merely a problem of semantics, as it can lead to the mistake of defining innovation as something new to the user rather than as a time-bound characteristic of a product or process. Even if we have yet to find easily understood descriptions, it is important to keep in mind that the innovativeness of a product changes over its life cycle and diffusion cycle.

Although typically depicted with the standard normal curve, innovation diffusion only approximates standard normality and could have faster or slower acceleration (a smaller or larger variance) and longer tails to the distribution (Figure 2.3). Innovations can also deviate significantly from symmetry in their diffusion. Some products spend a longer time in incubation and have a prolonged period before acceleration (first point of inflection). Usually this reflects an improvement in the product or a change in the market that eliminates the deficiencies that obstructed acceleration (launch) and underscores the importance of the commercialization process that brings an innovation to the market (McCoy, Thabet, and Badinelli 2009). Some housing innovations have low levels of adoption and diffusion until their competitive advantages become clearer, the market changes (prices, preferences, incentives, regulations), or the product has been modified. Structural insulated panels (SIP) and insulated concrete forms (ICF) were introduced in the 1930s and 1950s, respectively, but had very little share of the residential construction market until recently. The competitive advantages of these products have been enhanced by a shift toward production builders, increases in energy costs, marketing of green housing, and improvements in the supply chain. Tax credits, deductions, or discounted prices can provide important incentives for experimenters and early adopters during the launch phase of new products. Although government incentives and regulations can be very important in promoting the

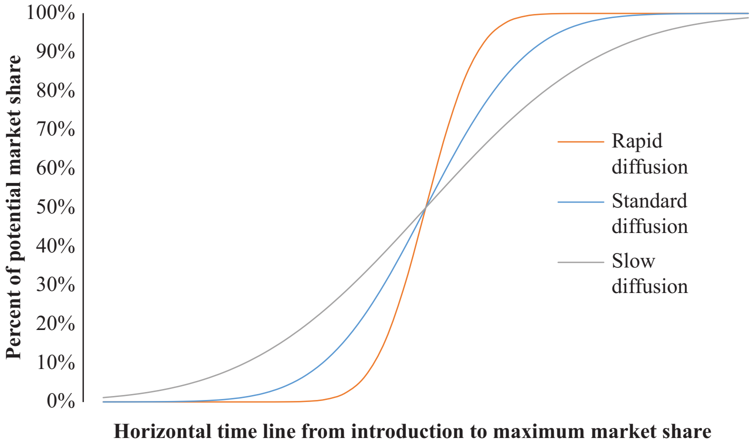

Figure 2.3. Alternative normal diffusion curves.

diffusion of green building innovations (Koebel et al. 2014), very little is known about the impact of government interventions on the acceleration of diffusion trajectories or the maximum potential of market shares.

Patents for inventions are a traditional means of identifying innovations and can be used to create a time stamp for the introduction of an innovation but there is an important distinction between invention and innovation. Invention is the initial creation of a new idea, product, or process, whereas innovation involves the delivery of the invention into practice (e.g., through product development and commercialization). There is seldom a clear separation between invention and innovation as the processes are interactive and repetitive, often over a long period of time. The chemical discovery of vinyl occurred decades before its use as an exterior siding material in housing. The mixture of sand, cement, and cellulose fibers to create fiber-cement materials dates back to the 1950s, but fiber-cement siding is still considered by many as an *innovative* product. Thus innovation does not necessarily mean *new* and *newness* (time from first creation or introduction) can change due to reinvention, modification, and time of commercialization.

2.3 DIFFUSION MODELS

The Gompertz and Bass models of diffusion are frequently used to project the adoption–diffusion trajectory by estimating (or guessing) the size of the experimenter group, the rate of acceleration in adoption, and the maximum level of adoption. The Gompertz model (Mas-Machuca, Sainz, and Martinez-Costa 2014) reflects the time of introduction, the time of acceleration, the rate of acceleration, and the saturation level.

The Bass model (Bass 1969) is a first-order ordinary differential equation used to model the aggregated diffusion curve. The model is a variant of contagion models where current adopters interact or communicate with potential adopters. The diffusion curve reflects the speed and timing of adoption based on the degree of imitation among adopters. The Mansfield (1968) model retroactively examines the diffusion of industrial innovation, using parameter estimates that reflect profitability, the adaptability of innovations, industry size and growth, and other economic criteria as determinants of the rate of diffusion.

These mathematical models of aggregate diffusion provide little or no knowledge of the underlying factors affecting the behavior of adopters, which must be separately and continuously studied in order to gain greater accuracy in predicting whether the product will only reach small *niche* markets (low point of saturation or market share) or will have more widespread adoption (high point of saturation or market share). Although they rely on assumptions about the communication of information within social networks, they provide little insight into those networks. The effect of social networks on innovation and diffusion are widely recognized, but have been rarely studied in the construction industry. The diffusion of innovation is analogous to contagion and the advances in mathematical modeling of the contagion process offer opportunities to integrate individual adoption decisions and aggregate diffusion patterns in innovation research (Hill et al. 2010). Applying contagion modeling to innovation diffusion in construction could lead to better prediction of expected diffusion and better interventions to accelerate diffusion trajectories.

Behavioral models of diffusion focus on the variables that affect adoption over time by individual users rather than modeling the aggregate diffusion curve. Koebel et al. (2003; Figure 2.4) developed a more comprehensive, behavioral model for innovation diffusion in housing. McCoy et al. (2010) and Koebel et al. (2014; Table 2.1) have refined this model in their work.

Other models have been used to analyze technology acceptance (Davis 1989; Venkatesh 2000). The technology acceptance model (TAM) is used to model adopters' intentions to accept new computer technologies and technology acceptance in medicine and other fields. The TAM emphasizes the perceived usefulness and ease of use of the technology

Table 2.1. Variables influencing innovation adoption

Adopter's human resources	**Adopter's organizational structure**	**Adopter's organizational culture and decision process**
• Skills • Motivation • Commitment • Specialization and professionalism • Technical knowledge resources • Managerial attitudes and support	• Size and resources • Centralization • Flexibility • Communication and administrative intensity • Complexity • Formalization	• Innovation proneness • Organizational support for innovation • Technology champions • Cooperation and openness • Orientation (outward versus inward) • Organizational position and role of decision maker
Adopter's market context	**Industry characteristics**	**Communication channels and social networks**
• Location • Competitive strategy • Market scope • Growth strategy • Knowledge of competitors' behavior • Unionization	• Regionalization • Concentration • Heterogeneity • Inter-firm competitiveness • Growth rate • Wage rates • Government regulation	• Mass media • Word-of-mouth • Opinion leaders • Professional and trade associations • Boundary spanners • Informal and indirect links
Technical attributes of the innovation	**Economic attributes of the innovation**	**Supplier or vendor characteristics**
• Divisibility • Learning by doing • Complexity-crudeness • Type of innovation (process or product) • Complementarities required	• Profitability • Uncertainty and risk • Expectations about future prices • Expectations about future tech trajectory of innovation	• Technical capabilities and support • Communications skills

(*Continued*)

Table 2.1. Variables influencing innovation adoption (*Continued*)

Technical attributes of the innovation	Economic attributes of the innovation	Supplier or vendor characteristics
• Relative improvements in old technologies • Compatibility (values and practice) • Communicability • Relation to innovator product class schemas • High, medium, and low tech • Radical versus incremental	• Labor saving versus materials saving • Scale neutral versus lumpy • Initial cost • Continuing cost • Rate of recovery of cost • Time savings • Start-up investment	• Expertise in monitoring deployment • Public relations

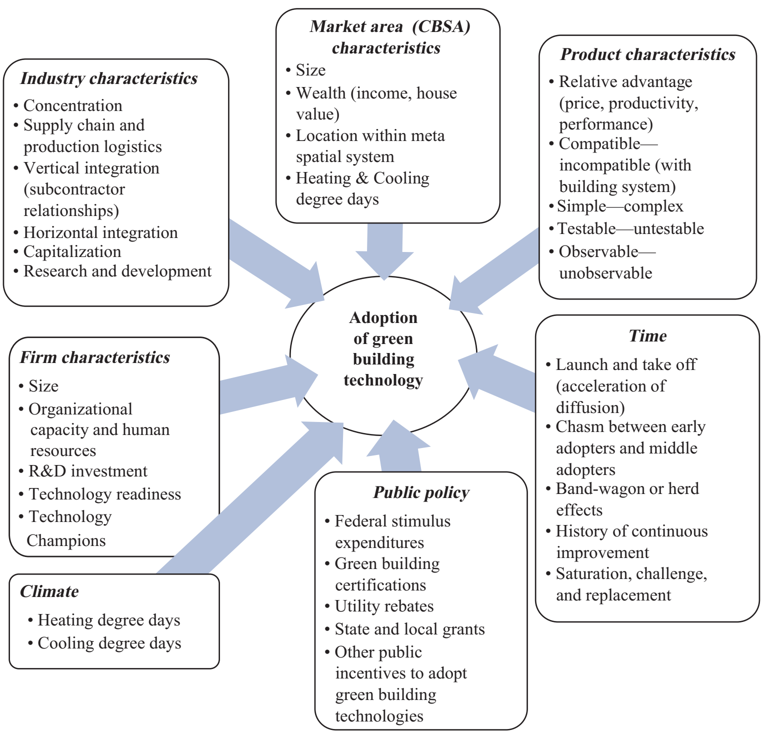

Figure 2.4. Green building technology adoption model.

and the adopter's trust in technology. The health belief model (HBM) is used in studying decisions related to prevention of injury or illness (Rosenstock 1960) and is widely used in studying health behaviors (Young-Corbett 2007) and stresses the importance of perceived susceptibility and perceived severity in the adoption decision. Young-Corbett (2007) used the HBM in studying construction safety and Weidman, Young-Corbett, and Koebel (2014) integrated the diffusion, technology acceptance, and HBMs into a comprehensive model of construction safety and health technology.

2.4 THE RETROSPECTIVE BIAS

We typically study innovation and innovation diffusion by looking backward at innovations that have succeeded. Retrospection has an inherent selection bias toward modeling success and against studying failure even when more can be learned from failure than success. Innovation diffusion can be comprehensible in retrospect, but remains very difficult to predict. For researchers, understanding the past is much easier than predicting the future. But it is essential to develop and test predictive models in order to identify interventions that can positively influence the pace and success of innovation in housing.

2.5 HOUSING AND PATH DEPENDENCY

The housing industry is often criticized for being *path dependent* and resistant to new product innovations. (Chapter 5 addresses in detail the nature of path dependency in the housing industry and the path-dependent characteristics of the stakeholders along the supply chain.) Path dependency is widespread in all human endeavors and is a valuable guard against hyperactively shifting to the new. The classic example of path dependency is QWERTY, the arrangement of the characters on a keyboard (Figure 2.5). The QWERTY keyboard was designed to slow keystrokes on a mechanical typewriter to avoid jamming the keys. The Dvorak keyboard was first patented by August Dvorak in 1936 and optimizes keystrokes on the *home row*, for fingers, and on the upper row, while minimizing strokes on the bottom row. This layout increases speed and accuracy, but has yet to make much of an inroad against the less efficient and accurate QWERTY layout. But the benefits of learning a new board have not been sufficient to overcome the power of path dependency related to habit and network effects

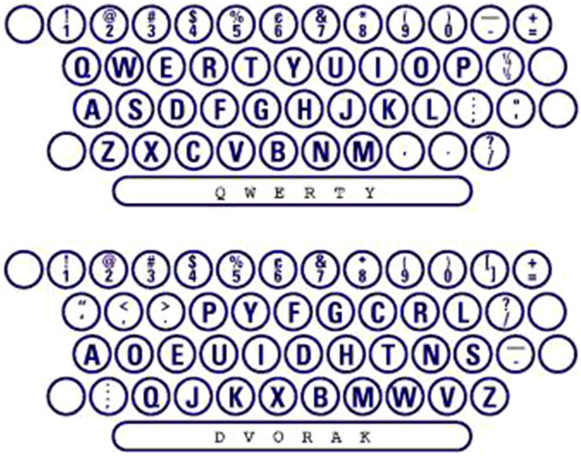

Figure 2.5. The QWERTY and Dvorak keyboards.

(including manufacturing and instruction) that reinforce the continuation of the old layout.

For housing, path dependency can provide beneficial protection against changes that might have unwanted consequences for builders and consumers. One of the benefits of building codes is to serve as a guard against products or practices that could present undue risks to workers or consumers. At the same time, codes can become rigid and can be used as a protection against innovations that could disrupt markets. The role of regulations and codes in promoting or hindering innovation in construction is only meagerly understood, and over time codes promoting innovation could degrade to an inhibiting effect, protecting a once innovative product or practice that has become the market standard.

2.6 WHAT ARE THE ATTRIBUTES OF HOUSING THAT ACT AS BARRIERS TO INNOVATION?

Housing is a complex, multidimensional, sited, and durable consumer good affected by boom–bust market cycles. As a multidimensional, volumetric product, it shares some characteristics with cars, buses, trains, and planes. While there are clear differences in these industrial sectors, the construction industry has much to learn from innovation in the production of other volumetric products built for human occupancy, particularly related to safety, whole-systems modeling, simulation, and prototype testing.

Innovations are most likely to occur for products and processes that can be shaped by science and engineering. The science and engineering affecting housing are primarily generated by product manufacturers and not by the home builder. Housing science is underdeveloped and lacks the engineering and modeling tools required to support innovation in home building beyond the innovation that occurs in product manufacturing.

The variation among housing sites (and other structures) presents distinct and possibly unique challenges to innovation. Site characteristics vary substantially and require adaptability and flexibility in housing construction. Site requirements, along with building codes, contribute to the prevalence of constructing the house on the site rather than through factory production of panels and modules that get shipped to the site. The position of construction as an on-site *assembly* industry in the supply chain of housing presents additional challenges. Manufacturers of housing products capture the rewards of their innovation. Builders who use innovative products have little leverage to gain a share in those benefits, yet they have substantial exposure to their risks through legal liabilities and possibly more importantly from damage to reputation if innovative products fail to perform to expectation. As the assembler, the builder has to balance supply-driven innovation and consumer-driven innovation without much opportunity to gain significant returns over the market (and code) standards.

The durability and cost of housing require careful attention to quality and safety through various codes and regulations. As the single most expensive durable good required by all households, housing cannot present undue risks to consumers and economies. Housing has an enormous span of impact and innovations are rarely risk-free. Poorly regulated and tested innovations in housing have produced notorious failures. The fire-safety, insulating, and material performance benefits of asbestos led to its widespread use in a variety of housing products until the 1970s. The cost, efficiency, and aesthetic appeal of synthetic stucco (EIFS) and its success in commercial and colder–drier climate locations led to its adoption for residential use in climatic conditions that resulted in product failures and substantial remediation and replacement costs. The importance of housing to individuals and societies requires minimum standards for health and safety, which necessarily impede innovation. All too often, the minimum standard required in public regulations becomes the mode for a skewed and steeply declining distribution.

While regulations help protect the consumer from the risks of innovation, the consumer can also be an impediment to innovation in housing. Innovations in many aspects of housing are invisible or difficult to assess by its occupant. Important components of the house are hidden or difficult to observe. Most components are either too imbedded or expensive to replace on a trial basis. Decisions on innovations have to be made early in the process. Even if the end-user is involved in the design of the house, the selection of innovative materials and systems exceeds the evaluative capabilities or desires of most consumers.

The highly cyclical nature of housing (Wachter and Orlando 2011) presents additional obstacles to innovation. The boom–bust character of the housing market results in a highly distributed housing industry with little rewards for horizontal and vertical integration, and the industry is numerically dominated by small firms. Even the larger housing producers rely heavily on subcontractors to limit their own exposure to market downturns. Subcontractors in turn rely heavily on routinized production that minimizes costs, variability, and call-backs. Few subcontractors would pursue innovations that do not have easy adaptation to the required routine, minimum training requirements, and very low risks of call-backs. An innovation in exterior cladding could require a different kind of knowledge and skill for the subcontractor installing the siding and for but also the framing, window, and painting subcontractors. Each of these companies is rewarded for being highly efficient at a standardized process. The success of an innovation introduced by one contractor can be thwarted by the standard practices of another.

The decentralized and fragmented structure of the industry that minimizes market cycle risks contributes to the industry's path dependency and low reward for innovation. Fragmentation increases network effects that impede innovation, as changes anywhere in the system are likely to have implications across multiple subsystems. Decentralization and fragmentation also increase risks when innovations fail. The lack of communication (structured feedback loops) from builder adopters to suppliers and manufacturers reduces the potential for field testing and for quickly correcting deficiencies in an innovation. This, in turn, increases the risk of more significant product failures and promotes defensive postures across the supply chain based on liability rather than on product improvement. In this structure, incremental, short-term improvements from small innovations are favored, while longer-term improvements are driven primarily by consumer income trends and shocks from outside the housing sector, particularly in the energy, transportation, communications, and finance sectors, or by occasional regulatory shocks. But waiting for external shocks to force innovation does not solve the challenges of innovation in the housing industry, as the responses to external shocks are also impeded by the current prevailing structure and culture of the industry. In order to become better innovators, the housing industry has to evolve toward a culture of learning and improvement rooted in building and management science across the supply chain.

2.7 IS THE GREEN CHALLENGE LEADING TO MORE INNOVATION IN HOUSING?

Global warming and environmental constraints are pushing us toward greater innovation in housing. Carbon fuels will become increasingly scarce and global warming is forcing governments and economies to change to renewable energy sources. Housing accounts for a significant amount of energy demand, including the embodied energy of residential structures and site-location energy with operating energy. There is a dwindling supply of easily developable land and greater demand for moderate density communities. Redevelopment toward the urban core is substantially more complex than development of greenfields land at the urban periphery and is forging new approaches and learning across traditional professional silos. Historically, energy has been the primary external shock prompting innovation in housing and the transition away from fossil fuels is likely to bring a long-wave cycle of innovation in housing that spans several decades.

Accompanying the energy shock, several changes in the structure of the housing industry could also foster greater innovation. There is increasing concentration of housing production among larger, production building companies that can potentially convert innovations in home building to increased market share. The top 10 builders in the United States account for over one-fifth of all housing units produced annually and the top 10 percent produce approximately three-fourths of all units. Although Pulte Homes failed with its experimentation with a systems produced, industrialized house, large production builders face ongoing challenges to improve efficiency and quality, while controlling costs. These pressures will foster ongoing and expanded efforts for bringing useful innovations to commercial benefit. Being innovation adverse is the wrong lesson to draw from the Pulte Homes venture, which provided that a company's significant knowledge of working across the supply chain and tracking and monitoring technologies goes into the homes. Pulte took this knowledge forward and into its other production processes. Improved tracking and monitoring sets the basis for diagnostics that will drive future innovation to create high performance for our homes.

The impact of firm size on innovation is complex. Large builders have greater capacity to bring innovations to the market but remain risk adverse and are punished severely by the stock market for failures. In large companies, technology champions do not control the decisions about innovation and have to convince others in the company that innovations are worth the risks. Purchasing departments are central to the decision making and wield substantial influence, as do field personnel responsible for understanding regional and local market variations (Koebel 2008; Koebel and Cavell 2006). Small companies, particularly where the owner is a technology champion, are more nimble innovators but have much less impact on the market (Koebel et al. 2003). Subcontractors march to the drums of large builders and are not likely to join the innovation bandwagon until the innovation chasm has been safely traversed. Large production builders will need to create space for innovation within their market footprints and monitor the innovations tested by smaller firms. Large firms in other industries are increasingly using randomized field trials to establish the knowledge needed to invest in larger scale innovations (Manzi 2012). This practice should be pursued in housing construction, probably with the assistance of university-based researchers. University labs focusing on housing present significant opportunities to drive the collaboration and integration of disciplines and industry stakeholders needed to move the industry forward.

Fortunately, the culture of the home building industry is shifting away from its tradition of tacit, experience-based learning to knowledge rooted in engineering and management disciplines. Innovation relies on science, and *building science* has to be the fundamental driver of innovation in housing. Improvements in information technology and whole-house tools such as building information modeling (BIM) are expanding the potential contributions of engineered system approaches to evaluating the benefits of innovation in housing. Process and whole-house innovations require substantial skill and data for accurate modeling to evaluate risks and avoid potential failures. As these skills become more prevalent in the industry, improved knowledge management systems and modeling capability will enable greater innovation in housing.

Government intervention is also needed but it too has to be smart and nimble. Tax credits, deductions, and regulations can provide important incentives for experimenters and early adopters during the launch phase of new products. Although government incentives and regulations could be very important in promoting the diffusion of green building innovations, very little is known about the impact of government interventions on the acceleration of diffusion trajectories or maximum potential market shares. The timing and duration of government interventions need to be studied more carefully, but should clearly be focused on the early phases of innovation diffusion and crossing the chasm to reach greater market shares. Beyond that point, bandwagon effects should replace government incentives to avoid wasting scarce public resources.

Public and private rating systems can also facilitate innovation in housing, but they need to be based soundly in building science in order to earn the trust of consumers. Consumers are also becoming more informed and there are owners who know and value the structural, mechanical, and environmental performance characteristics of dwellings. But ratings have to be accurate predictors of building performance to be broadly useful, and building performance, in turn, must be objectively measurable and observable by designers, builders, auditors, occupants building owners, and operators.

Past is not prologue. Housing is on the cusp of a long cycle of innovation responding to the energy shock and driven by increased industry capacity, changes in industry culture, improvements in building science, public policy, and a more informed consumer. Necessary improvements in performance require tracking after installation, where diagnostic innovation will increase durability and warranty of the home. The housing industry faces enormous challenges and the pace of experimentation, innovation, and diffusion should and must increase. The foremost challenge is to understand the very process of innovation and then for the industry to foster innovation smartly and strategically.

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CHAPTER 3

The Literature of Innovation in Housing

Andrew Sanderford

The study of innovation has, since the publication of Schumpeter's *Business Cycles*, largely focused on the concept of substitution or the supplanting of the old by the new to generate new opportunities for economic profit. For many years, researchers across an array of fields have examined and been curious about how *new men* and new ideas are capable of producing creative destruction and the space for new products, processes, and services. This curiosity has guided the innovation literature to topics ranging from the mundane to the extraordinary and from the macroeconomic to the nano-technological (and beyond).

Everett Rogers' omnibus *Diffusion of Innovations* (2003) illustrated the complexity of the decision to adopt an innovation and guided generations of scholars in the formulation of research agendas and helped to parse their results. Rogers' book helped condense the research conversation on innovation into a single volume that has remained in print from 1965 until today. Taking a cue from the great researcher, our focus here is to link together several diverse strands of research on innovation so that they can be mined by housing researchers and practitioners.

Recently, researchers have begun to explore the housing and construction industry using diffusion of innovation models rooted in the work of both Frank Bass and Everett Rogers. Relatedly, the goal of this chapter is to summarize the more recent diffusion of innovation research in housing and construction and then to touch on the diverse research being conducted outside of housing. In exploring beyond the boundaries of our domain, the goal is to provide examples of data types, methodologies, and modeling techniques from which housing research could borrow. Very simply, what can we learn from allied disciplines so that the literature can carefully consider how it establishes research benchmarks.

3.1 BACKGROUND

No matter the media—academic literature included—the chances of reading or hearing the word innovation are quite good on any given day. Use of the term has crept into the modern lexicon and become synonymous with anything new or novel. To some extent, this association with new and novel goods, ideas, and services captures the spirit of the concept though not entirely. Rogers initially defined an innovation as "practices or objects that are perceived as new by an individual or other unit of adoption" (2003). However, in spite of over 60 definitions of innovation advanced in the academic literature in recent years, intellectual property scholars point out that to qualify something as an innovation it must be both new to the adopter and new to its relevant market. They must also be introduced so that consumers or other firms can benefit from their adoption.

Extending the discussion of the definition of innovation, the related and substantial body of literature generated by scholars of health care, technology, management, operations, and computer science suggest that under the umbrella of the definition of innovation are a number of innovation typologies that clarify and illustrate how firms can distinguish different types of innovation to capture and create value. Distinctions include: (1) incremental versus radical innovations, (2) sustaining versus disruptive innovations, (3) continuous versus discontinuous innovations, and (4) open versus closed innovation.

Incremental innovations are improvements to products, processes, and services that iterate the existing functional capability of that product, process, or service by improving it modestly for performance, safety, quality, and lower costs (Christensen, Anthony, and Roth 2004). *Radical innovations* cause significant changes in an industry. They create a new to market functional competency that did not exist prior to the launch of the innovation and which creates a gap in present capabilities (Fagerberg, Mowery, and Nelson 2006). *Sustaining innovations* are innovations that advance a product, process, or service along a reasonably predictable trajectory (Christensen, Anthony, and Roth 2004). *Continuous innovations* do not require any behavioral changes on the part of the adopter while *discontinuous innovations* demand some behavioral change (Christensen, Anthony, and Roth 2004). *Disruptive innovations* shock existing products, processes, and services by creating new markets that eventually disrupt existing markets so much that they supplant previous products, processes, and services against which they initially competed (Christensen, Anthony, and Roth 2004; Greenhalgh and Rogers 2009; Manseau and Shields 2005). *Open and closed innovations* describe two management and intellectual property right protection strategies used by entrepreneurs and firms to facilitate all types of innovation (Chesbrough, Vanhaverbeke, and West 2006).

The open and closed innovation typology is a framework in which those two typologies can be pursued and executed (Chesbrough 2004; Dahlander and Gann 2010). *Open innovation* describes a management style and intellectual property rights (IPR) framework in which a firm blends ideas generated externally from the firm with those ideas generated within the firm to advance an innovative product, service, or process (Chesbrough, Vanhaverbeke, and West 2008). *Closed innovation* is distinguished from open innovation in that it follows a more traditional pattern of hiring staff, investing in research and development, commercializing the most promising products, processes, or services from R&D, and then fiercely protecting these commercialized technologies with patents and other restrictive IPRs and law suits (Chesbrough 2004).Within the discussion of the best management style and IPR framework to facilitate innovation, Von Hippel identified user-driven innovations as a critical component of success across several industries (2005). Labeled as *democratized innovation*, this process suggests that users of products and services are increasingly able to innovate for themselves (Von Hippel 2005).

In addition to distinguishing between innovation typologies, the literature distinguishes between innovation-adopting organizations (IAOs) and innovation-generating organizations (IGOs). This distinction is important to raise in the discussion of housing and construction research as both groups have unique commercialization pathways and array of obstacles that inhibit potential adoption. Moreover, the lines between IGO and IAO can be fungible. For example, a homebuilding firm could be considered an IAO as it selects existing building strategies and products that create operational efficiency and satisfy consumer demand. Homebuilders could also be considered IGOs as they incrementally innovate within their housing unit design schemes—sending ripples up the product supply chain. One thing is clear about the distinction between IGOs and IAOs for housing and homebuilders. No matter which role a firm plays, innovation in housing is a complex process complicated by both exogenous and endogenous factors.

An additional distinction in the literature comes from economics research suggesting that despite the focus on substitution in innovation research, combinations of innovations can work together as economic complements to create value for the IAO or IGO. Economic complements are two or more items that have negative cross elasticity of demand. In other words, when demand for one goes up demand for others does too—think spaghetti and marinara sauce. The innovation chain across several industries harnesses this concept by creating new products that build layer upon layer of complementary products into an innovative whole.

Beyond examining the typologies and distinctions within innovation, innovation research tends to investigate two unique but related phenomena—the adoption and diffusion of innovations. Adoption occurs when some stakeholder such as an individual, group, firm, or government begins to use an innovation. The literature often models this as a single-step binary decision. One either chooses to adopt or not adopt an innovation. However, there are also those that consider the decision to adopt to be multistage and composed of choices among a cluster of alternatives. The literature indicates that dichotomous choice is one of the more common ways of modeling the adoption decision (Feder, Just, and Zilberman 1985) as it captures the adopt versus not-adopt framework (Mercer 2004). Both logit and probit models can be applied to a binary choice and tobit and multinomial logit (Mercer 2004) can be applied to reflect choice complexity. While the binary nature of the traditional framework reflects a good deal about the adoption choice, research indicates that multiple stage adoption-dependent variables can also be used for analysis (Dimara and Skuras 2003).

Regardless of how the adoption decision is modeled, the evidence is clear. The attributes of the innovation, attributes of the adopter, and the external or contextual factors each influence the adopter's decision. With respect to the innovation, Rogers (2003) has distilled five dominant traits associated with adoption: relative advantage, compatibility, complexity, observability, and trialability. Attributes of the adopter include the adopter's disposition toward innovation including the presence of an innovation champion, the adopter's investment in research and development, firm size, firm structure, the firm's placement within a network of peers, communication strategies, and other related indicators. Based on the timing of their adoption decision relative to the introduction of the innovation onto the relevant market, adopters can be segmented and plotted on a normal distribution curve. Those most keen on newness are known as innovators. They form a small minority at the leading edge of the distribution. They are followed by the early adopters, the early majority, the later majority, and finally by laggards. The external factors commonly associated with the adoption decision can be clustered into bundles such as regulation, socioeconomic attributes of the relevant market places, industry and supply chain characteristics, communication network structures and densities, and climate.

The diffusion of innovation is an empirical measurement of the cumulative rate at which market actors adopt one or more innovations. Often, diffusion is measured using Bass models developed as part of the science of marketing and advertising. Bass's S-curve models search for two inflection points when a product accelerates its take off into the market place and when that phase of exponential growth begins to taper. Additionally, Bass models offer insight into the nature of the factors that influence the adoption decision—primarily categorizing those factors into internal and external groups. Internal factors relate to the adopter while external factors reflect the context of the adoption decision. Models based on the work of Rogers seek to expand the analytical process to find the factors, beyond time, associated with the innovation adoption decision (Bass 1969; Burt 1980; Easingwood, Mahajan, and Muller 1983; Kok, McGraw, and Quigley 2011; Mahajan, Muller, and Bass 1990; Moore 2002.).

3.2 BUILDER AS INNOVATION LAGGARD

The construction industry is often considered to be resistant to innovation. There is merit to the "builder as an innovation laggard" argument as construction firms are relatively decentralized (use of subcontractors and disconnects between product manufacturers and installers). Additionally, property and construction markets are cyclical, driven by volumetric production, and are bound by building code requirements. Further, the fact that many building construction innovations are installed behind walls or exist under floors (Blackley and Shepard 1996; Koebel 1999) complicates the adoption decision. Finally, the residential construction industry is also often noted for having low levels of innovation and being constrained by path dependency (Lovell and Smith 2010; Lutzenhiser 1994; Xue et al. 2014). In other words, the residential construction industry faces very real industrial constraints that could significantly attenuate their appetite for innovation.

Emphasis on the laggard status of the industry has, until recently, been compounded by the limited empirical investigation of the diffusion of specific construction innovations (Rose and Manley 2014; Taylor and Levitt 2007). The construction literature has tended to investigate innovation by exploring the obstacles or barriers to the diffusion of innovation across different types of firms, building types, and products (Slaughter

1993). Interviews, surveys, and other types of mixed-method approaches have been used to illustrate the depth of nuance related to many of these obstacles (van Egmond-de Wilde and Mohammadi 2011). For example, research indicates that the pace of regulatory change, risk of resale, liability and warranty issues, fear of being a first user, cost, municipal policy, and lack of consumer awareness also play roles in limiting the spread of innovation in building construction (Choi 2010; Galuppo and Tu 2010; Koebel and McCoy 2006; Manseau and Shields 2005; Toole 1998).

Perhaps the most important obstacle to innovation in the construction industry is the natural path dependency and risk aversion of the builder or building firm (Manseau and Shields 2005; McCoy, Thabet, and Badinelli 2009; Toole 1998). This aversion to risk is a survival mechanism developed to reflect builders' place in the housing development chain. As the assembler of a kit of parts over which they have little control, the design and manufacturing of builders bear a heavy burden of liability once the kit is assembled. However, just like other industries including aerospace and automobiles, construction is a cluster of related subindustries including the commodities and manufacturing component pieces, facility design, engineering, finance, and facility assembly (McCoy, Thabet, and Badinelli 2009). It follows then that as various industry actors seek new competitive advantages over peer firms, they turn to innovation (Abbot, Jeong, and Allen 2006; Manseau and Shields 2005; Tatum 1987). Despite identifying the challenges for innovation within the residential construction space, there has been limited research applying diffusion of innovation models to homebuilding and the analysis of homebuilders' adoption choices.

3.3 INNOVATION IN CONSTRUCTION

Despite the historical perception of the builder as the innovation laggard, there is strong evidence that builders are responsive to market stimuli (Holmen Enterprises 2001) and can capture new economic value from investment in innovation (Hardie and Newell 2011). Construction innovation research has often noted the importance of diffusion of innovation frameworks and models (e.g., Koebel 2008; Larsen 2005; Pries and Doree 2005; Sargent, Hyland, and Sawang 2012) though few have embraced the various mathematical models to analyze the factors associated with the diffusion of specific construction innovation (Gambatese 2011a, 2011b; Hartmann 2006; Kale and Arditi 2010).

Of those that have advanced empirical diffusion of innovation models relative to IAOs in construction have done so with models rooted in the work of Bass or Rogers—though with limited direct investigations of homebuilding or housing. This small but insightful thread of research has analyzed the adoption of innovative software (Kale and Arditi 2005), concrete technology (Kale and Arditi 2006), and road construction products (Rose and Manley 2014). Confirming results from outside construction-specific research, these papers illustrate how internal and external factors play strong roles in the adoption. Kale and Arditi observe stronger influence from internal adopter attributes while Rose and Manley, like recent nonconstruction diffusion models (e.g., Kok, McGraw, and Quigley 2011), focus on external factors.

Relative to internal characteristics, firm organization is a natural topic for housing innovation research (Abbot, Jeong, and Allen 2006; Sexton, And, and Aouad 2006). The industry is dominated by large publicly traded firms and also by a preponderance of small firms. Questions about the attributes and structure of these firms have helped to illustrate that the adoption of innovation is influenced by an array of complex factors but that those factors do not influence all innovation equally (Sexton and Barrett 2004). For example, larger builders tended to be earlier adopters of innovations only when new materials provide potential cost savings, improvements in production processes, reductions in call-backs, and exposure to liability. Smaller builders tended to adopt new materials where consumer awareness of the product was high, the price of the new material was superior to its replacement, and where the home production process must be substantially altered (Koebel and McCoy 2006).

Additionally, builders in geographic areas where increased awareness of innovative materials was high were more likely to adopt while areas where path dependency and resistance to new technology limited the potential for adoption (Koebel and McCoy 2006). Not surprisingly, increased profitability was also associated with the adoption of innovation among smaller to medium-sized building firms (Hardie and Newell 2011). Relatedly, green innovation adopters tend to own longer-term financial interests in their projects and assert more substantial control over the construction process (Bradshaw 2011).

Organizational culture is also a critical internal factor that influences the choice to adopt an innovation. Firms with internal innovation champions, or those willing to advocate and advance an innovation agenda, have been observed to more readily adopt new products and processes. These champions have focused on the productivity gains over profits and emphasized the importance of forging their own corporate path rather than marching to the drum of the majority of their competitors. Additionally, information availability and symmetry also interact with organizational culture and structure in the decision to adopt housing innovations. This interaction varies based on the processes by which firms gather and process information (Toole 1998). Based on Rogers' discussion of adoption and diffusion as information and communication processes, these findings follow logically with the broader innovation literature.

Beyond the internal attributes of the adopting organization, contextual attributes have been observed to play a role in the adoption of innovation in construction. For example, adapting and refining their previously developed Rogers-based diffusion of innovation conceptual model, Australian researchers found that industry relationships, procurement systems, regulatory conditions, and organizational resources were the most influential external determinants associated with innovation among road contracting firms (Rose and Manley 2014).

3.4 INNOVATION IN RESIDENTIAL CONSTRUCTION AND HOUSING

There has been extensive research conducted about the factors associated with the adoption of innovation among building construction firms including homebuilders. However, until recently, there had been only a few analyses conducted using classic diffusion of innovation models. Notably, these models looked at commercial construction practice though they provide guidance for the application of diffusion modeling to homebuilders and residential product adoption decisions.

Examining a large data set composed of National Association of Homebuilders and secondary data, researchers created diffusion of innovation models that sought to identify the factors associated with the adoption and diffusion of green building innovations. Drawing from the adoption and diffusion literature, these models tested the extent to which various internal, external, and innovation-specific attributes influenced U.S. homebuilders' adoption decisions relative to high-performance building technologies. This series of papers found that each of the factor types—internal, external, and innovation-specific—were associated with builders' choices to adopt the high-performance product alternative over its traditional economic substitutes, despite limited information about the internal attributes of the firm. These results confirm findings of commercial construction research indicating that each type of factor to be significant but with a heavier weight to the internal factors. Further, just as the papers from commercial construction illustrate, there appears to be significant utility created by adapting diffusion of innovation models to the study of residential construction.

Research focused on residential real estate has contributed to the conversation on innovation in housing and homebuilding. Much like the commercial real estate literature, the recent housing finance literature has focused on the value proposition of innovation and several of the high-performance housing products including both windows and energy certifications. The literature has also examined innovations including credit scoring and automated underwriting. In the case of windows and energy certifications, homes in the markets where these technologies have been more widely adopted have been observed to command price premiums over those that do not contain them. Similarly, buyers of homes with energy certifications and those in more walkable areas are less likely to default on their mortgages; they also tend to earn higher incomes and can afford to take the risk of purchasing a home inclusive of innovation.

These findings reinforce the value proposition of sustainability and high-performance technologies as innovations and illustrate that although both windows and energy certifications are not new with respect to time on the market, they remain novel to their respective adopters, markets, provide adopters with an empirical benefit. Outside of the characteristics of homes and homeowners, it is clear that both credit scoring and automated underwriting are innovations that promoted more efficient mortgage markets prior to the Great Recession. However, these innovations were not without side effects. While they provided speed to the underwriting process, the automated underwriting process took away some of the humanity and reflective capacity required to understand an individual, their housing needs, and its relationship to their financial situation. In many cases, the automated underwriting process aided mortgage bankers. In others, it created poor outcomes and showed that not all innovations are positive or create optimal results for adopters.

3.5 NONHOUSING INNOVATION RESEARCH

That innovation research occurs across many disciplines is little surprise. However, where housing innovation research builds from the perspective of the builder as an innovation laggard, it has done so, with some exceptions, at a considerable expense. The cost takes form in the two significant risks of silo-based research and the potential for asking of the wrong questions of the wrong data. Research in energy, aerospace, information technology, automobiles, medicine, and corporate finance tends to acknowledge industry structure as a guidepost for research allowing outside scholars to draw new ideas based on observation of coarse similarities. Housing innovation researchers have not forsaken the tools and data from all other disciplines; there are notable exceptions where the literature draws deeply from the leading edge of other fields. However, the relatively strong focus on housing as a path-dependent industry with unique obstacles weighs heavily upon the literature. Perhaps then, this is an opportunity to shift gears and expand the foci of housing research—especially in the context of micro- and macro-economic changes following the Great Recession.

Future research might begin by acknowledging the unique aspects of the structure of the housing industry (e.g., the builder as an assembler) and might use, like in other disciplines, coarse similarities in structure to analyze the extent to which the innovation is present and creates new value for stakeholders. For example, Moore's chasm was originally identified as a phenomenon in information technology industry. The chasm is the critical gap between the different early and mainstream markets an IT innovation must jump to be commercially successful. Where early market adopters are concerned with newness they tend to be less concerned with the utility of performance benefits than are mainstream market adopters. Since its introduction, scholars outside of IT have identified markets where this bimodal distribution of consumers could exist and modified the concept to help analyze the diffusion of new products in areas including energy and medicine.

As the housing literature considers firms or builders as assemblers of a kit of parts, it is not illogical to use coarse similarities between industries as an initial benchmark and find that the aerospace and automotive industries could be useful guides. In each, a firm has attributes of both IGOs and IAOs. Further, each industry aggregates individual components of intellectual property (innovative and otherwise) from upstream firms and assembles them into a single product. Aspects of IT and biomedical innovation research could also take on a loose version of the firm as assembler. Though the majority of medical innovations are prosecuted through internal research and development and heavily protected by intellectual property right structures, it is clear that prior innovations are layered or interacted as part of new products or processes. Similarly, the software industry has a history of accreting innovation both internally and externally, most recently through external acquisition of intellectual property and human capital. With industry structures that rely heavily on the development and assembly of IPR into new products, it seems that housing researchers could find much to relate and modify.

Using the coarse similarity between industries, housing innovation research could begin to form smaller questions designed to exploit data used by related industries such as patent, public filings, news, and public capital markets data. For example, one line of questioning could come from decomposing the housing industry into a series of innovation generating firms that create intellectual property registered with the Federal government. Such a tactic could create more symmetry with nonhousing research and promote the use of patent and licensing data mining to measure the rates and types of innovations introduced into the residential building market place. An additional research line could draw from the public filings data of housing-related firms and the associations in time with various events. Known as the event study, the process allows researchers to measure the relationships between events such as the announcement of an innovation (in the media or as a patent filing) and the prices of equity shares of housing-related firms.

Both patent data mining and event study could help to address the common criticism that housing industry does not invest in research and development and that there are not accepted definitions for the adoption and diffusion of innovation. The use of public data could facilitate definition of innovation (and its trajectory) in the housing industry. It is plausible that the industry innovates rather slowly and continuously at the individual technology component layer. Without more discrete steps in the innovation process, it is possible that models emphasizing the builder are too coarse to pick up the accretion of innovation. Recent papers from environmental economics provide helpful insight on the way future research could interact or cluster innovation concepts together to measure change within the industry.

3.6 COMMERCIAL REAL ESTATE

Innovation was once described as the life-blood of the financial industry—drawing on Schumpeter's notions of creative destruction of old models to create new space for economic profit. However, only a handful of papers have analyzed the adoption and diffusion of innovation. Each of these papers has recognized that accelerated adoption of an innovation such as an automatic teller machine (ATM) or credit scoring is associated with a higher return on invested capital. This cluster of papers pointed out a critical lesson for scholars of innovation. These papers showed that creating models that explain diffusion as a function of time *and* other attributes, research could provide insight into the choices of adopters. This is an important lesson highlighted by Rogers' work as well (2003). Just like the corporate finance research, the study of commercial real estate has tended to use econometric and financial theory to guide the exploration of innovation and produced a slightly greater number of papers on the topic.

Given the strong connection between finance and commercial real estate, there is little surprise that real estate scholars have followed a similar trajectory to investigate a group of innovations that fall under the headings of sustainable real estate and responsible property investing. With the rise of corporate social responsibility, property firms began making investments in groups of technologies that increased the environmental performance of new and existing buildings. Just as Rogers described in *Diffusion of Innovation* (2003), the investors and researchers alike were curious about the association between the adoption of these innovations and their short- and long-term value proposition. In other words, was the adoption of sustainability practice in one's building portfolio linked to building and firm rent and price premiums?

Though the early research sought to define sustainability relative to the property business the group of scholars did not acknowledge it as traditional diffusion of innovation research. However, looking at these papers quasichronologically, it is clear that this process followed the path of theory development and value proposition definition (Miller et al. 2009; Pivo and McNamara 2005; Simons, Choi, and Simons 2009); data development and empirical measurement (Dermisi 2009; Eichholtz, Kok, and Quigley 2013; Fuerst et al. 2011; Harrison and Seiler 2011; Pivo and Fisher 2009; Pivo and Fisher 2010; Wiley, Benefield, and Johnson 2010), and then deeper examination of adoption and diffusion questions to more nuanced and detailed research (Choi 2010; Eichholtz, Kok, and Quigley 2009; Eichholtz, Kok, and Yonder 2012; Simcoe and Toffel 2011). Two papers have focused exclusively on the diffusion of innovation in commercial real estate and work to summarize the literature and provide insight specifically into the factors that influence adoption of sustainability as an innovation (Kok, McGraw, and Quigley 2011).

The primary benefits of using the commercial real estate industry as one significant research benchmark are in the similarity of the subject matter, the training received by scholars in both fields, and the similarity of the role of policy and building codes. However, there are significant differences that should be noted. Commercial real estate is focused on the investor or manager and not on the builder or assembler of a kit of parts. Additionally, the owner–tenant relationship in commercial property is complicated by different principal–agent dynamics than the supplier–builder–buyer relationship. Given these differences, one could argue that when conducting housing technology innovation research that focus on the builder or the kit of innovative parts, benchmarking to appropriate but different industries could expand the potential to generate insights.

3.7 CONCLUSIONS

There is extensive literature describing innovation in construction and the obstacles that preclude the industry from breaking out of its innovation-resistant mold. With a small number of analyses beginning to apply diffusion of innovation models specifically to construction and most recently to homebuilders' innovation choices, there is a significant opportunity to learn from industries where diffusion of innovation research is more mature.

When looking at the coarse similarities between other kit of parts industries or industries, it is rather plausible that housing innovation research can borrow liberally from the research question types and methodologies more typically deployed in health care, automotive, aerospace, and information technology research. Though not perfect analogs where researchers can apply methods and concepts seamlessly, there seem to be increasingly interesting opportunities for adaptation.

For example, where many housing technology innovations were not protected with IPRs, the increase in use of digital sensors, solar panels, energy monitoring software, and other technologies where IPRs are common, mining patent databases and examining time series data could generate exciting new insight. In other words, perhaps new benchmarks for innovation in homebuilding should be considered to help link housing innovation research into the broader conversation about the role of innovation in creating better built and economic environments.

The opportunity to learn from other disciplines is important for housing researchers so that we continue to use a broad spectrum of methods to gain insight about the factors associated with the diffusion of innovation. It is also important that research questions are developed relative to the broad array of data sets that apply to housing and innovation in homebuilding. Where the trajectory of research can learn from and adapt the lessons from the variety of disciplines, useful and appropriate benchmarks could be developed. Just as there are risks to path dependency in the housing business, there are risks to path dependency in housing innovation research—primarily in muting effectiveness of the research agenda.

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CHAPTER 4

The Policy Context for Adopting and Diffusing U.S. Homebuilding Technology

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Homebuilding technologies are a public event. We drive by construction sites in our neighborhoods to see the size and style of new homes, and guess at what those homes might be adding to the look and the value of the community. A walk through any local home retail behemoth provides aisles of visual evidence that our homes are composed of thousands of parts, and that these parts must in some way be physically joined by someone to make a house that this is bigger than the sum of its parts. If we are even more intrepid or are part of the homebuilding business itself, we read trade magazines and attend builders' shows that present a dizzying array of gadgets and materials to serve the construction workers who build the homes and the occupants who use them. The means and methods of U.S. homebuilding, including all of the practices, technologies, innovations (and lack thereof), are visible for the general public to literally see.

Yet, is technological innovation in homebuilding also a matter for public policy? The U.S. government has actively supported the study and advancement of defense and civilian science and technology of all kinds for at least a century. This support intersected with housing policy in the 1949 American Housing Act, which codified the "goal of a decent home and suitable living environment for every American family." In so doing, the Act linked the physical quality of homes with the social and economic outcomes of families and the national good. The 1970 Housing and Urban

Development Act gave the federal government additional authority to actively pursue technological change in its effort to improve the physical quality of housing:

> The Secretary shall require, to the greatest extent feasible, the employment of new and improved technologies, methods, and materials in housing construction, rehabilitation, and maintenance… and shall encourage and promote the acceptance and application of such advanced technology… by all segments of the housing industry.[1]

By mandate, then, housing technology—and its innovation—became public policy.

Since that time, improvement of our housing's physical quality has regularly surfaced as an explicit imperative for public funding and programs. Support for technological innovations in home construction and operation has been a vehicle for housing improvement, along with increased regulations and technical specifications for publically-owned or assisted housing. In turn, programs in support of innovation have ranged from basic research funding, industry demonstrations, consumer awareness campaigns, and adoption and diffusion (A&D) studies and information resources. In short, there have been public policies and programs that have altered the course of the industry's technological trajectory. So, the question of whether homebuilding innovation should be a public policy topic is more nuanced: *How has public policy addressed homebuilding innovation to date, and to what end?*

This chapter addresses this question through three lines of inquiry. First, we review the polemics of technological change in the industry that have led to calls for governmental intervention across the innovation trajectory—including the research and development (R&D) and A&D of housing technologies. This review also describes whether and where purported problems with homebuilding innovation exist to assess the social returns from public investments.

Then, we review past instances of growth and federal interventions in homebuilding innovation to uncover patterns in the public role for supporting the technological change. This survey of technological change in the U.S. housing industry includes both private initiatives that may have had some policy-based catalyst or enabling, as well as explicit public policy efforts such as federal R&D and A&D programs.

Finally, we look at the policy options that have been used and are currently available in support of innovation and compare their possible effectiveness. This final review of options is not meant to definitively identify the most successful public policy and programs for homebuilding technology. Rather, it examines the outcomes and impacts from these past efforts to provide a policy backdrop for the other chapters in this book.

4.1 WHAT IS THE POLICY INNOVATION PROBLEM?

Numerous scholars have discussed the broader societal and industrial benefits to be gained from technological innovation in general. In fact, many argue that innovation is one of, if not, the most sustained source of economic growth in any industry.[2] Given the importance of the housing industry to the U.S. economy as felt most recently during the housing crisis and recovery, it would seem that housing innovations would have proportionally large and dramatic consequences for the economy and social wellbeing. The problem, of course, is that many in the homebuilding industry feel that there is little to no innovation happening.

4.2 NAMING THE POLICY PROBLEM

Most of the literature in construction management has focused first and almost exclusively on the evolving nature of the industrial problems with homebuilding innovation. What is good for the industry and its products, then, is viewed as being good for the nation. A review of the industrial problem in this light is in order, taking some of the points described in chapters 2 and 3 forward.

While no thorough or comprehensive studies have measured the total expenditures for housing technology research, construction industry scholars and analysts commonly feel that the level of investment is suboptimal.[3] Producers of housing have regularly lamented the lack of technological innovation in our nation's homes over the last half-century. They argue that this innovation gap is especially true for detached, single-family housing—a market that makes up most of the housing stock. In fact, it can purportedly take anywhere from 10 to 25 years for a new housing technology to achieve market penetration.[4] As a consequence, it is argued, the construction industry in general (let alone the residential construction industry) invests little in technological R&D in comparison to other industries.

The conflict between the claims of technological stagnation on the one hand and the apparent innovation in the industry requires some explanation. The claims about stagnant innovation rates are based on two somewhat divergent reasons. First, it is argued that all traditional measures of innovation demonstrate that the industry is lagging. Traditional measures of *innovativeness* such as numbers of patents are particularly difficult to apply to construction because of both the number of products and industries that could be classified as building-related and because of the inability to enforce patents in this environment (and therefore, the lack of interest in filing patents to begin with). So, alternative measures such as productivity increases (holding for nontechnological changes to labor and material costs) have been put forth, also with less than optimistic findings (for example, NRC 1986a; Allmon et al. 2000; Goodrum and Haas 2001; Rojas and Aramvareekul 2003; Prieto 2003). The total investment by construction firms into R&D is particularly used as a general and comparable metric.[5] In all cases, however, homebuilding is described as underperforming industry with regard to technological innovation (NRC 1986b).

Second, this school of thought also puts forth the various structural barriers to innovation that are unique to U.S. homebuilding as symptoms of the industry's poor capacity for innovation—a condition that requires public cure.[6] These industry analysts have paid particular attention to the gaps and barriers to innovation over the last 40 years (Business Roundtable 1982; Nam and Tatum 1992, 1988; NRC 1986a). The following is a list of some examples of the many suggested barriers that are described in other chapters of this book:

- Cyclical nature of construction;
- Fragmentation and the dominance of small firms;
- Lack of vertical integration of the industry, particularly the reliance on subcontractors;
- Diverse building codes with local peculiarities in detail and administration;
- Lack of product approval systems that establish and certify based on performance criteria;
- Lack of access to information, education, and training about new products;
- Exposure to legal liability for experimental technologies;
- Limited R&D funding;
- Limited A&D vehicles, especially for federal or university-based R&D products;
- Homeowner behaviors, including resistance to change and unwillingness to invest for long-term returns;
- Builder and trades behavior regarding a reliance on traditional practices and profit drivers; and
- Lack of traditional financial incentives to innovate that are clear and large, such as patents.

Though few of these perceived barriers have been studied sufficiently to produce empirical evidence of their impacts, several have become industry canon. Usually, there is some truth to this folklore. For example, homebuilding is a localized phenomenon, with local trades dictating schedules, local suppliers dictating materials, and local code officials dictating regulations and, in turn, construction practices. The industry is further complicated by the number of parties involved through the supply chain, which includes dozens of intermediaries between the product manufacturers and the builder and the builder and the homeowner. There has been some consolidation along all of these fronts, including the rise of the production builders over the last two decades and the centralization of material suppliers for both construction and retail clients (Abernathy et al. 2011; Martín 2012). However, there is still significant fragmentation throughout the industry that prohibits both knowledge of existing innovations and the potential scale of sales that is necessary for justifying R&D in the first place.

A further complication arises in trying to define housing innovation itself; a typical, American stick-built house is composed of thousands of materials assembled into dozens of structural or system units. A change in one of these certainly has a technical effect on the whole system (though the science is still fuzzy on this), and yet it has an almost negligible change on the total cost of production and perhaps an imperceptible effect on the price and the economic value of the home. So, this challenge, in turn, perpetuates a barrier in assessing the added value from one technological change from which an innovator can reap the benefits. There is also no financial impetus for one firm to develop this public good on its own. With no perceived reward for improving the product or process, there is also little incentive for a firm to invest in R&D. Externalities such as this run throughout industrial innovation, but are particularly egregious in residential construction due to all of the previous reasons.

In reality, there is truth to the claims that homebuilding innovation is underfunded proportionally to the industry's economic size and importance according to current measures.[7] Other industrial barriers described also exist with some level of evidence with regard to the total costs and returns of R&D and A&D at the industrial or firm level. Yet, the barriers listed earlier and repeated in the literature are explicitly *industrial* problems.

But, where are the returns at the *societal* level? The benefits to a broader society—and therefore, reason for public involvement—are assumed to flow naturally after remedying the industrial problems (Jaffe 1996). In addition to the private rate of return for the innovating actors, R&D scholars note that positive externalities, or spillovers, occur because the innovation creates benefits for consumers (market spillovers), and also because the knowledge created by one firm creates value for other firms and other firms' customers (knowledge spillovers). Because the profitability of a set of interrelated and interdependent technologies may depend on achieving a critical mass of success, each firm pursuing one or more of these related technologies creates economic benefits for other firms and their customers (network spillovers). The combination of these spillovers is the total social return from an individual firm's innovation. The policy problem, then, is that the nation is not reaping the social returns when the industry is not innovating as much as possible.

The counterfactual concern regarding this argument is that there have, in fact, been technological innovations in the industry both with and without public investment. We have witnessed that both product changes (from indoor plumbing to air conditioning to energy-efficient features) and process innovations (from standardized material sizes to preassembled roof trusses to modular and panelized systems) have dramatically changed American homes and their delivery. These technological innovations have provided homeowners with more functional options in their homes, often at reduced prices. They have enabled homebuilders to construct more quickly, safely, and cost-effectively. They have also provided some level of national benefits in reduced energy-consumption, increased resistance to natural disasters, and improved affordability.

If you can imagine the difference in energy consumption in homes built today from those built 30 years ago, or the rigidity of homes in Florida now versus before Hurricane Andrew, we know that there is something there. Innovation is happening, and it is happening with and without governmental support. The simplistic argument that industrial barriers are preventing or limiting technological innovation and its consequent public benefits, then, does not quite hold.

4.3 REFRAMING THE PROBLEM

This contradiction speaks to the fact that barriers and problems are still viewed through the framework of a traditional model of innovation in which industry structure, market context, and builder and consumer behaviors are merely backdrop to the driving force of technological change rather than primary factors. The most commonly used model to describe this traditional perception of innovation is linear (Figure 4.1) (Hassell et al. 2003). In the model, several stages occur in sequence beginning with research, through development, to demonstration (or early adoption), and

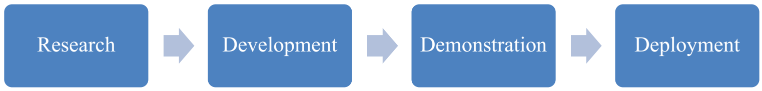

Figure 4.1. The linear model of innovation.
Source: Hassell et al. (2003).

deployment (that is, wide-scale diffusion). From this model, the catalysts for innovation are either supply-push (with research findings leading to industrial change) or demand-pull (with markets extracting innovation from the pipeline).

Recent work in the economics and sociology of technology, however, has demonstrated that this sequence is both inaccurate and could lead to flawed conceptions of the catalysts, complex processes, and outcomes of innovation (Bijker and Law 1992; Bijker, Pinch, and Hughes 1987). The traditional model is also particularly unhelpful for understanding the policy context of the homebuilding industry given the nature of the multiple, interrelated barriers to innovation described earlier.

More robust conceptualizations of the homebuilding innovation effort are conscious of the fact that knowledge and its development advances throughout the process from conception to wide-scale diffusion, and that it builds off of other pre-existing and coincidental knowledge through numerous and irregular interactions and feedback loops with other stakeholders. One major stakeholder that more complex models consider and foreground is the variety of market actors at play in homebuilding. Rather than a single consumer (for example, a homebuyer), the forces at play in homebuilding are vastly more numerous and interconnected including the product manufacturer, materials retailer, home builders, subcontractors, tradespeople, realtors, lenders, insurers, regulators, to name only the more obvious players.

When considering both the justification for policy interventions in R&D or A&D in the industry, as well as the policy levers in this sphere, all of these interconnections and actors must be considered. The argument for focusing on R&D funding as a critical public policy tool only follows the traditional model of innovation. Additional analyses of market forces and stakeholder behaviors have been sorely missing. The more subtle ways in which government induces innovation in the U.S. homebuilding industry—such as funding the gathering of business and industry statistical information, exploring stakeholder behavior and motivation, and understanding the innovation effects of increased regulations—have been overlooked. Though R&D and A&D are clearly activities that must occur for widespread innovation to occur in the industry, they are pieces in a greater puzzle that can be put together, partially, with public hands.

4.4 EXAMPLES OF PUBLIC POLICY AND HOMEBUILDING INNOVATION

There are numerous examples of homebuilding innovation, but surprisingly few examples of explicit public programs devoted to housing innovation at the national level. Three of the most extensive moments to promote innovation in homebuilding technology in the last century occurred at times of clear social and economic need in the nation's housing stock—because of the desire to either improve the existing housing stock or expand it. These include:

- The U.S. Department of Commerce's 1962 Civilian Industrial Technology Program (CITP) during the Kennedy Administration;
- The U.S. Department of Housing and Urban Development's (HUD) Operation Breakthrough in the late 1960s under Nixon; and
- The collection of federal programs starting in the late 1990s to support various construction industry goals under the Clinton Administration including the Department of Energy's (DOE) Building America program, Environmental Protection Agency's (EPA) ENERGY STAR for Homes, and HUD's Partnership for Advancing Technology in Housing (PATH).

These programs have been the only ones to receive federal appropriations for the sole purposes of producing and promulgating innovation in the housing industry.[8] Each program harnessed different policy strategies and focused on different segments of the innovation chain, thereby setting different precedents for public policy intervention in housing R&D and A&D.

4.5 1960s TO 1970s: CITP AND OPERATION BREAKTHROUGH

The first federal attempt to intervene directly into the practices and products of the homebuilding industry's technology came in 1962, when the Kennedy administration requested congressional funding to be administered through the DOC to create the CITP. The request was the first of its kind in its goal to extend the funding of basic scientific and engineering research in the civilian sector during the1950s and 1960s to the development, adoption, and diffusion stages of innovation.

President Kennedy's economic and science advisors John Kenneth Galbraith and Jerome Wiesner sent a memorandum to him in February of 1961 "recommending the establishment of a civilian development commission to stimulate the growth of those civilian industries 'without any organized stimulus to change'" (Nelkin 1971). One month later, Kennedy presented the White House Special Message on Housing and Community Development by which he sought to "encourage a prosperous and efficient construction industry as an essential component of general economic prosperity and growth" (quoted in Nelkin 1971, 18).[9] Subsequently, numerous federal and nongovernmental agencies generated reports emphasizing the need to both improve the building industry's technological base and introduce building into the national political arena.[10]

The newly appointed Assistant Secretary for Science and Technology in the Department of Commerce, J. Herbert Hollomon, then proposed the CITP to the House Appropriations Committee's Subcommittee on Deficiencies in the summer of 1962. CITP's mission included studying the state of technology and the information needs in these industries, and creating an industry-university service for information diffusion and technical aid similar to the land-grant universities and Cooperative Extension systems (now part of the National Institute of Food and Agriculture) in the U.S. Department of Agriculture. Some of the wording of the budget proposal focused on the problems of the building industry, including its apparent R&D capacity combined with a lack of A&D:

> The industry's problems are becoming more acute. Technology affecting it is increasing in both quantity and degree of sophistication, and the gap between technological potential and actual building practice is widening…. The approach will be a system, one with the structure considered as a whole rather than by segment. Moreover, the study will be unfettered by existing practices, codes and regulations; it will seek to determine the ideal shelter for man's needs…. It will assess the capability of present technology to provide that ideal shelter and indicate what technical developments in the future are needed and possible to achieve that goal. (quoted in Nelkin 1971)[11]

This request for funding was particularly controversial for numerous reasons, including the general concern of funding the later stages of civilian technology innovation where industry should arguably fill this role regardless of the specific industry in question. Ultimately, funds were appropriated only to the proposed program's services to the textile industry for a small period after.[12] Though the policy intervention never occurred, the more telling lesson from CITP is the role of industry in defining what public policy can and should be.

In fact, opposition from the building industry itself secured CITP's early demise. Some of the opposing arguments were based on more philosophical grounds regarding the potential infringement on industrial affairs and free markets. Other sectors of the industry resisted CITP based on concerns for other purportedly more critical issues that needed policymakers' attention, such as increasing regulations, which were inhibiting growth after the housing industry's recent all-time high production.[13] Yet, a final more insidious source of opposition came from building product manufacturers fearful that a federally funded research center would produce innovations in direct competition with their products.

Though not mutually exclusive, the reasons provided by different groups including a majority coming from within the building industry itself demonstrate both the difficult interplay between the public and private sectors with regard to industrial innovation and that these perspectives are nuanced and complex. Since CITP was never created, there are no lessons about its implementation or its outcomes. The primary lesson, then, is obvious: housing innovation policy is politically contentious not just for policymakers but for the housing industry.

With the changing focus on urban social conditions later that same decade, national policymakers once again focused on the physical qualities of housing, the industries that produce it, and their modernization. In 1968, HUD was authorized to begin Operation Breakthrough to pursue its prime directive of establishing the mechanisms for mass-production and consequently producing them at scale. Secondarily, the program was charged with eliminating or reducing the institutional and structural barriers to modernization generally, including regulatory ones in the form of building codes that prohibited the installation—and therefore, creation—of new technologies. Newly appointed HUD Secretary George Romney, with his extensive background in the automotive industry, took the charges and the program was launched in mid-1969.

HUD saw Operation Breakthrough as both a means and an end. Generally, the program sought to encourage "new technology, improving architectural design, using the full range of labor skills, [and] overcoming building code, zoning and labor constraints" (HUD 1970, 2). In so doing, the federal government hoped to fill the "… more than 10 million units short of our housing needs" and "have as great an impact as the development of the railroads in the last century or the growth of the electronics industry in this century" (1970, 7).

Two strategic flaws were inscribed into Operation Breakthrough early on. First, the program created an artificial demand for the innovations to be produced by relying on HUD funds for assisted housing. The program accepted proposals from various contractors, architects, engineers, and building component manufacturers for manufactured, large-scale housing systems. These systems would incorporate all aspects of the design and construction process, including zoning assessments, multiple-use designs, streamlined mass-produced building materials, and expedited construction methods. A key policy intervention, then, was to create demand separate from the existing market and its production.

Second, HUD also developed a top-down strategy for addressing innovation barriers despite the fact that many of these barriers played out differently across housing markets, stakeholders, and housing types. For example, while HUD evaluated the various construction system proposals, it also attempted to hasten the process by which building codes across the nation would accept these systems. In its attempt to "eliminate or alleviate important constraints like building codes, zoning, and financing that historically have stood in the way of volume production," HUD developed a set of internal performance-based code criteria in conjunction with the National Bureau of Standards for all proposed systems. After choosing and contracting with specific firms, HUD would issue waivers which the firms, in turn, could present to local code officials as adequate assurance that the federal government approved of the system's soundness and safety (Field and Rivkin 1975, 30; HUD 1969, 17). HUD also made attempts to educate local building officials with regard to the proposed housing technologies and in the hopes that code officials would more readily accept the regulatory waivers (HUD 1970, 7). In essence, these waivers created loopholes within the traditional regulatory process.

HUD found other ways of leapfrogging the existing industry's practices. In contrast to CITP's advocates, HUD delineated a clear role for the building industry—and clear motives for each building group's participation—at its onset. First, professional groups were integrated into OB's schemes rhetorically: "We seek the utmost cooperation from builders, developers and private industry" (HUD 1969, 1).[14] By having professional groups generate the designs and construction techniques for the systems as well, HUD further garnered designers' and contractors' support: "Private enterprise can best provide the muscle, the talent and the major effort. Private enterprise has demonstrated it can build subsidized housing with speed, efficiency, and economies" (1969, 1).[15] HUD made appeals to labor unions in equally dramatic fashion (1969, 1). In the end, HUD successfully designed a program to contravene extant building identities, roles, practices, and—ultimately—products. This collective policy strategy, in effect, crafted an innovation process parallel to that of the actual industry.

Operation Breakthrough, with its top-down federal approach to housing innovation, could not overcome the locally regulated and market-specific nature of the industry. In the end and $72 million later, Operation Breakthrough was deemed a failure on multiple counts (Comptroller General of the United States 1976). While the program brought attention to barriers in information sharing, regulations, and collective bargaining, the barriers persisted well beyond the program. Moreover, the A&D of the demonstration technologies in question were also inhibited, with little attention.

The success of this subversion was limited to the few large-scale housing projects of 2,794 prototype housing units constructed in nine test cities by the program's termination in 1973. In its 1976 audit of Operation Breakthrough, the U.S. Comptroller General reported that as much as 28 percent of contractors felt that the program had actually hurt the industry more than it helped (17). Despite the extensive efforts to combat the traditional regulatory process, the program also did little to change these procedures (Baer et al. 1976).[16] By 1972, a U.S. Senate Committee hearing on public housing continued listing out the same barriers to technological advance as before (U.S. Senate Committee on Banking, Housing, and Urban Affairs 1972).

In both the CITP and OB cases, similar issues regarding the role of government in homebuilding innovation surfaced. CITP failed because it did not fully incorporate the motives and understandings of any building group. In its attempts to assist all building groups, Operation Breakthrough failed to sustain any significant change in building technology, regulation, or practices. Operation Breakthrough created an artificial process and market for its technologies that denied the realities and conflicts of housing. In short, Operation Breakthrough teaches that you can take the housing innovation out of the housing industry, but you cannot take the housing industry out of the housing innovation.

4.6 1990s to 2000s: Energy Star, Building America, and the PATH

A more recent set of national public programs devoted to housing innovation processes began within years of each other in different federal agencies, with different catalytic histories, and different goals—but with overlapping charges to address homebuilding innovation and diffusion rates.[17] Each program's origins heavily influenced its policy intervention among the R&D and A&D stages and its strategy for intervening. In all three of these cases, policymakers and program staff actively solicited guidance from external stakeholders—especially from industry, though this involvement was not necessarily a conscious act based on evidence from the CITP and Operation Breakthrough experiences. Rather, this collaboration often had as much to do with the explicit need to have industry partners (for marketing or field testing of new technologies), and industry's growing influence on general policy decisions in general.

The program with the earliest start, ENERGY STAR, began in the EPA in 1992 as a voluntary labeling program for energy-efficient products and appliances in coordination with manufacturers. Though the overall program has undergone numerous administrative transformations as well as expansion into other industries, it is rooted in the central concept of public branding and marketing for the purposes of increasing energy efficiency. In 1995, EPA partnered with the U.S. Department of Energy to expand ENERGY STAR labeling into new homes.[18]

To date, ENERGY STAR has certified over 1.5 million new homes (EPA 2013). Home performance with ENERGY STAR, the certification for retrofitted existing housing, was launched in the 2001 program.[19] Its certification has been given to almost 350,000 homes. With its focus on voluntary standards, shared marketing campaign with industry, and recognizable branding, ENERGY STAR has been able to harness the builder and the consumer demand for housing performance, which, in turn, has led to wide-scale A&D of housing and housing product innovations. Viewed widely as one of the most successful of the three public interventions related to housing innovation that were launched in the 1990s, the program's policy strategy uses policy incentives (such as consumer branding, financial benefits, and performance competition) to induce market-pull changes in housing technologies related to energy performance.

In contrast to the focus on market stimulus, DOE's Building America program has primarily funded basic and applied research for new technologies, thereby potentially improving the energy-efficiency and quality of housing. The program originated from a 1993 research pilot between the DOE and the manufacturer, General Electric, focused on systems engineering in housing—or, optimizing the performance interactions between the various structural, mechanical, electrical, and plumbing systems (Norberg-Bohm and White 2004b). The program quickly grew into an ongoing research collaborative using DOE contract research funding and teams of industrial consortia working on applied housing innovations and industrial improvements.

ENERGY STAR and Building America shared common goals particularly with regard to energy-efficiency, as well as a common strategy of working with key stakeholders in the industry to advance technological change.

In Building America's case, industrial partnerships were critical for identifying research questions and advancing research products—that is, the early stages of the traditional innovation process with adoption occurring primarily among the homebuilders involved in the consortia (Norberg-Bohm and White 2004a). ENERGY STAR focused on market triggers in the form of certification, branding, and consumer awareness, or the demand-side pull that would lead to widespread diffusion of technologies.

The third of the *boom* programs, PATH, focused on the murky activities between the development and adoption stages of the traditional innovation sequence. PATH was launched in 1998 following the drafting of the National Construction Goals in 1994.[20] The goals for the housing sector involved both improvements in the quality and performance of units as well as streamlining production processes and labor practices. With such roots in federal policymaking and grounding in the scholarship from the fields of construction and technology management, PATH focused on the stakeholder behaviors, institutional contexts, and industrial practices with regard to innovation in the homebuilding supply chain.

The justification for PATH as a public program was fourfold (NRC 2000). First, it was argued that standards for housing innovation is a public good because individual housing product manufacturers, builders, and other stakeholders would be unable to recoup the costs of creating the standards. Second, for similar reasons, adoption rates were low because early adopters would be forced to take on all the risks of new technologies or practices, but all eventual adopters could reap the benefit. This disincentive ultimately reduces adoption—a market externality that could only be overcome through public programs for educating builders and consumers and minimizing all other barriers to innovation. Third, the housing market is one wrought with information asymmetries, with buyers and sellers having different access to different types of information about housing technologies and performance and few or no neutral sources to ensure an equitable decision-making playing field. A program such as PATH could, then, assist in reducing information gaps between parties and increasing public and builder awareness in general.

Finally, and most pragmatically, the lack of federal funding for R&D in the residential sector's technology in both magnitude (given the size of the industry) and in content (beyond DOE's energy-related investments) compared to other research portfolios in different industries suggested the need for a clear public intervention (Hassell, Florence, and Ettedgui 2001; Martin 2005).

The intervention took the form of PATH, whose original goals focused on housing performance improvements as outlined in the National

Construction Goals. These objectives were replaced with more realistic and practical goals focusing on the overall expansion of R&D funding, the supply of neutral information on housing technology performance, and the monitoring of the innovation process in the industry including development, adoption, and diffusion rates (NRC 2001, 2002). PATH, then, was charged with the transitions between R&D, and development and adoption in the traditional innovation process along with reconsidering the overall innovation challenges in the industry.

Like its ENERGY STAR and Building America, PATH integrated industry views and actors directly in its activities. Where CITP and Operation Breakthrough were top-down and R&D heavy, these programs were voluntary, market-based, and more A&D focused. Unlike its two siblings, PATH's federal funding decreased without compensating increases in industry investment through the 2000s. The program's administration in HUD—an agency typically uninvolved in technology research—further complicated its execution. By 2010, PATH was the first program to be terminated.

These five historical and contemporary public programs focused on housing innovation at the national level that provided numerous lessons—including the pragmatic fact that the public intervention in housing technology needs to be justified. Indeed, this idea of justification has been repeated in the most recent incarnation of national building policies, such as the group of *Better Buildings* initiative programs in DOE that are attempting to focus 2009 American Recovery and Reinvestment Act (ARRA) funds and program guidance.

A few of the ARRA grants were used to create residential energy retrofit programs or were used directly on residential retrofits themselves. The housing-related components of the initiative, the Better Buildings Residential Network and Better Buildings Neighborhood Program, are less robust with regard to impacts on housing innovation and much shorter lived than the commercial and industrial components.[21] However, they were created to stimulate the diffusion of already-adopted housing technologies within the existing building stock with a justification that this investment would spur employment in the sector following the Great Recession, in addition to increasing energy efficiency (Research into Action 2012).

4.7 POLICY VEHICLES

While the justifications for policy that promotes housing innovation have varied widely depending on the historical political, economic, and social context, the types of interventions have been restricted to a limited menu of options. This is particularly true at the national level, where significant resources can be put toward addressing national problems but where solutions are also limited by mandate and partisan politics.

The pool of policies and public programs that are available to government to innovation in any sector is limited, and even more so for housing innovation in particular. In the general field of innovation policy, the primary activity at the federal level in the post-War era has been the financial *support of basic research*, particularly that focused on defense-related needs or in major new areas of inquiry in the physical sciences, health and medical sciences, and in nascent areas of engineering (Committee on Science, Engineering, and Public Policy 1992). Much of the funding for civilian technology innovation goes to university research centers from the executive agencies traditionally charged with R&D funding, such as the National Science Foundation and National Institutes of Health, and to a lesser extent, from subject–matter focused agencies such as DOE. As is noted in other chapters, the funding for basic research in the housing sector in particular—and the building construction industry in general—has at best been inconsistent, meager, and spread out thinly across a variety of federal entities.

Aside from the volume of funds, the primary critique of focusing policy solely on basic research funding has been that innovation is more complex than the traditional model perceived during the Cold War, as described earlier in this chapter. Numerous challenges for the products of any one basic research project to reach development and adoption persist and could impede any returns on the investment to the original work. As a consequence, policy interventions are needed to more appropriately respond to this complexity in ways that support development, adoption, and diffusion of civilian research products more robustly, including industry participation in basic research and collaborative research topic identification. For the former, a variety of *incentives for industry-based research* have been utilized, ranging from securing patent licenses for for-profit enterprises using federal research dollars, to extending tax credits for firms that engage in research activities.[22] As described in this book, however, these incentives rarely apply to housing innovators. Other *nonfinancial supports for industrial research* have been slightly more common, though still rare, like allowing cost-sharing of research at universities and for-profit research facilities, or developing forums for identifying key research topics or agendas between federal, university, and industry researchers. The 1994 National Construction Goals were an example of this kind of collaboration. The primary concern regarding this kind of collaboration and investment in industry research has been the possible collusion implied by *selecting winners* by industry and political leaders.

Financial *support for development* or commercialization of technologies has been one of the key policy responses in light of the critiques of the traditional innovation model in the 1980s and 1990s. Development is often very costly, however, and limited federal funding is appropriated to support it directly. Instead, this work is often performed directly by university and laboratory commercialization centers, which, in turn, often received public funding indirectly as a cost component of basic research funding.[23] In the housing industry, large product manufacturers often incur the costs of testing and refining innovation.

Smaller manufacturers, however, have generally been disadvantaged in this arena—a dominant source of innovation in the sector. Like basic research activities, a variety of financial and nonfinancial *incentives for industry-based technology development* also exist in parallel to the direct support. The primary vehicles for these incentives include participation in collaborative topic-setting (often called *roadmapping* in regard to technology development as opposed to agendas for basic research). Assistance with regulatory approvals is another common developmental activity for which public resources have been employed. Cost-sharing for collaborative testing and development has also become a possible public incentive since laws in the mid-1980s both limited antitrust actions against for private firms involved in public–private R&D, and allowed for the legal vehicle by which publicly funded and private research could collaborate.[24]

Collectively, the direct investment and incentivizing for development and commercialization have historically been helpful in improving the transition to early adoption. This is particularly true when the development and early adoption are linked, such as the Building America field testing and demonstrations of technologies performed in an effort to better integrate builder feedback for technology improvements. At the adoption stage in the innovation process, direct funding of builders' or homeowners' adoption is generally not a politically or economically viable policy vehicle. A notable exception to that rule is the funding of experimental technologies through procurement in federally owned buildings, such as Operation Breakthrough attempted. Because the pool of federally owned and controlled housing is so small and generally is targeted at a unique and often disadvantaged population, however, there is limited opportunity for this policy vehicle in housing.

In this case, *adoption incentives* are often the policy of choice. Much of the recent DOE adoption and *deployment* work, including that in Building America described in this chapter, has provided the case studies for this policy activity in housing. In most cases, the builders that adopt the technologies do so because they believe they will gain some additional knowledge or information that will either distinguish them from their competitors, improve their production, or simply minimize any liability issues they may face from consumers by not adopting. Occasionally, governmental awards and recognitions for early adopters can be helpful, though not comprehensive, drivers for innovation.

Federal adoption incentives primarily involve field testing opportunities and technology assessments, but several local policy incentives have also been effective. Zoning or building code incentives (such as expediting permitting, density bonuses, and so on) have been used to incentivize voluntary technology adoption. Early local green building programs and certifications in the 1990s and early 2000s used these policy incentives to increase early adoption rates in their housing markets.

Diffusion incentives and supports cover a wide range of vehicles and have been applied to the gamut of housing stakeholders. The most commonly cited support across federal agencies has been that of acting as an information clearinghouse of housing innovations and technologies, particularly to the building and consumer communities. This vehicle for reducing the information asymmetries identified in the literature has been employed by all recent housing innovation programs in different ways. Its form has ranged from promotional campaigns for the general public regarding research products to serving as a neutral arbiter of new products and practices for decision makers in the building trades. The success of providing this information is partially determined by the currency of the information, as well as the resources from either public or private sources for providing the information in a digestible way for its target audience—which can be a costly endeavor.

A related public activity for supporting diffusion is the creation of *performance standards* and similar voluntary criteria for innovations. The innovation literature suggests that a lack of performance standards for the multitude of housing innovation across an equally wide variety of performance attributes has hindered the ability to diffuse innovations and, in turn, the success of the innovations themselves. Performance standards beyond the minimum requirements set forth in building for health and safety, potentially developed with industry, could be a critical public role. DOE's lighting and appliance standards, particularly for ENERGY STAR's certifications, is the most known recent example of this activity.

Finally, a variety of financial incentives and tools among builders and consumers could serve as the market pull needed for widespread adoption of innovation. The sample of these kinds of public policy incentives such as tax credits, bulk purchase rebates, subsidies, and loan products are perhaps the easiest of diffusion policy vehicles because they generate demand and reduce the risk for adoption. In most cases, these kinds of publically generated incentives are costly since they require either significant funding of a magnitude and scale to be effective, or involve an equal reduction in public revenue.[25] The strategy works best for diffusion of well-tested innovations that meet performance standards and for which a clear good (such as improved energy-efficiency or public health) can be gained for the cost to public coffers. Almost all recent examples of this deal with energy efficiency (such as federal tax credit deductions for certain energy-efficient systems, windows, or major appliances), though there are also some preliminary insurance premium incentives being offered for disaster-resistant technologies.

Three additional activities are often overlooked as A&D policies because of their *indirect diffusion* effects, though they are public policies and programs that potentially enable broader increases in A&D rates. First, the diffusion of technologies could be supported through public procurement policies related to the federally owned housing stock. Unlike early adoption, this option is more politically tenable because it involves more tested and proven innovation. However, even if all federally assisted housing were required to adopt an innovation, the current proportion of this stock compared to the total population of housing units in the country could still be too small to produce the economies of scale needed for widespread diffusion.[26]

A second indirect policy activity involves the public funding of social science explorations of the housing market's innovation behaviors such as those funded by PATH have been an indirect policy vehicle because they assist researchers and innovation developers with targeted A&D strategies. This was particularly true of the sociological, economic, and behavioral management studies of builders and consumers with regard to A&D decision making. Findings from this work could enable housing innovators, particularly smaller enterprises without market research capacity, to plan for development and adoption.

Second, increasing the residential design and construction workforce's skill set and knowledge base has been proposed as a viable innovation policy because the resulting professionals are believed to be more adept at determining technological performance, more creative and inventive with regard to their work, and more open to adopting others' innovations. The significant support made by the U.S. Department of Labor's Employment and Training Administration for local construction training programs and apprenticeships could, then, be considered a public innovation policy and program investment, as well.

A third activity that is often looked at as an indirect driver of innovation, though in reality it may lead directly to innovations of all kinds, as well as immediate A&D, is *regulations*. In the construction management literature, regulations—typically, building codes—are described as barriers to innovation because of their restrictive specifications of materials or methods in statute, and the reluctance of local building officials to accept new technologies during enforcement (Martín 1999). Traditionally, building codes are a tool for establishing the minimum requirements for public safety and health, though in recent years its use has expanded to include economic, environmental, and other social goals as well (such as energy efficiency).[27] As a consequence, innovations are not typically addressed by building regulations until they are tested, demonstrated, proven, and cost-effective technologies—that is, when they are no longer innovative. However, the increase in nonsafety regulations such as building energy codes and green building requirements among municipal and state code adoption agencies provides an opportunity to question the relationship between regulation and innovation in housing.

There is some evidence from other industries, however, that regulation imposes a compliance burden that requires innovation (Ashford, Ayers, and Stone 1985; Jaffe and Palmer 1996; Pickman 1998). This includes studies involving residential appliance manufacturing (Newell, Jaffe, and Stavins 1999). Michael Porter, a management scholar, suggested that regulations that serve to correct a market externality such as environmental protections induce innovation both in terms of R&D (requiring new, cost-effective means for compliance) and adoption (providing early adopter advantages by signaling trends in regulation, such as energy codes) (Porter 1991; Porter and van der Linde 1995). This literature also suggests that the stringency and disruptiveness of the regulation can lead to differences in the type of innovation—that is, between radical and incremental technological changes. In the U.S. building industry, no studies have tested this hypothesis, though there is some anecdotal information that the increasing stringency of building energy codes has prompted innovation.[28]

4.8 CONCLUSIONS: POLICY CONTEXT AND STRATEGY

The strategic selection of any combination of these policy vehicles is tempered by the critical role that the political and economic context plays. For each of the instances reviewed in this chapter in which policymakers created defined programs focused on housing innovation, context determined the justification for the program's creation as well as the strategy for selecting the policy vehicles. For example, the direct investments of R&D proposed in CITP and conducted by Operation Breakthrough and Building America were predicated on the financial resources available in the government (that is, during times of general economic prosperity) or strong social need (for example, after the War on Poverty) as well as the political will for directing those resources to the housing industry. The public–private partnerships and shared marketing campaigns of ENERGY STAR and PATH could also only grow in a policy environment in which industry collaboration was desired and possible. This delicate interplay between politics and policy is often overlooked in the innovation policy, but is essential to understanding how, why, when, and even whether policy for R&D and A&D housing innovation transpires.

Aside from partisan or electoral politics, however, are the three underpinning contextual conditions that also play a role in shaping policy strategy. The first is unique to the housing design and construction sector, and that is the *roles between federal, state, and local policy* (and in some cases, regional) when it comes to housing markets as well as innovation. According to the adage, housing is local. This is true for zoning and land development policies, as well as building regulations and, to a decreasing extent due to consolidation and globalization trends, is also true for the pool of builders and trades, the architectural styles, and construction means and methods. It is definitely true of climate and other environmental factors that might shape demand for housing innovations. Typically, states and municipalities do not engage in explicit housing innovation policy largely due to resource constraints and the assumption that the national government sets R&D and A&D policies and programs.

Some large states, California or New York, with resources and an explicit interest in housing performance subjects such as energy consumption have funded engineering and market research in the residential sector. Some have provided funds for technology development through their extension systems and business incubation funds, though these are not explicitly for housing innovation and have only occasionally resulted in investments or support for the sector. Government below the national level then typically can only engage in diffusion incentives and regulations. Several states and utility regions have established financial incentives for the diffusion of technologies for similar reasons. Building code adoption and enforcement, then, are likely the primary levers for state and local policies with regard to housing innovation—leaving federal government with the policy role of supporting research, development, and adoption almost singlehandedly.

Another context has been the practical availability of public funds for any one policy or program. The political advocacy associated with funding for housing innovation in many of the past contexts described here have resulted in too inconsistent a funding stream to determine generalizable effects. Aside from the politics, however, this funding is also often predicated on a determination of the *policy's costs in relation to the social benefits*. Direct funding of R&D directly costs government by definition. Innovation activities for adoption such as information clearing houses and market-pull incentives for diffusion such as subsidies and tax credits also have a public cost either in direct appropriations or lost public revenue.

In general, any public innovation investment results in long-term benefits that are usually difficult to monetize. Policy investments that involve long-term returns are less likely to receive sustained funding and attention. The sporadic energy conservation and efficiency R&D program funding during the 1970s energy crisis is often described as an example of the lost investments resulting from intermittent funds. With the exception of enforcement costs, then, building regulations are often the only housing innovation policy that do not directly cost government. However, because of their costs to industry, they may result in reduced production that would indirectly impact public revenues negatively. The decision to use carrots or sticks to spur the housing industry to innovate must carefully weigh these costs.

For many proponents of reducing the costs to government of funding innovation, however, there is a much deeper philosophical concern regarding any public role in technology R&D and A&D. Commonly disparaged as corporate welfare, the funding of any civilian technology innovation beyond basic research (and in some cases, even that) is viewed, at best, as a substitute for what private industry can or should be investing and, at worst, government overreach that distorts the market for innovation and yields unsuccessful research products. Because housing technology has received such a small public investment compared to other industries, this criticism has rarely been directed at the national housing programs.

In fact, there is significant evidence that the housing industry can and has innovated its practices and materials without investment. In addition to the innovations produced under the public programs described in this chapter, it is important to note instances in which there were no active public policy or program interventions but still significant rates of innovation were present. This included the transitions to balloon-framing in the early 1800s and later platform-framing for single-family residences that occurred in the 1930s (Cavanaugh 1997). Major advances in plumbing, mechanical, and electrical systems starting at the turn of the 20th century also emerged without direct public innovation investments (Bigott 2001;

Cooper 1998; Ogle 1996). With broader technological changes such as energy production and social conditions such as population growth, land access, and mortgage financing, technological innovation went part and parcel with a changing U.S. economy in the post-War era (Tobey 1996; Wagner and Wagner 2010). Most of the prefabrication innovations introduced during the housing boom of the 1990s and early 2000s had no policy intervention at all. In these cases, either documented market demand or industrial benefits such as reduced cost, labor, material, or production time were key if not the only motivators beyond possible regulatory desires from insurers or public health advocates.

However, as evidence from the other chapters in this book demonstrates, the core reasons for public investments in civilian technology R&D and A&D still hold. Market failures persist in numerous ways, and the assumption that market pull or industrial will produce all necessary innovations (and diffuse them widely across the U.S. housing stock) simply is an inaccurate framework from which to analyze and respond to the industry's condition. As the revised model described earlier suggests, basic research rarely produces innovations that are commercialized immediately and demanded by homebuyers and property owners. Most users of housing innovation's products—builders, remodelers, tradespeople, and housing consumers—rarely have the information or knowledge to make informed decisions about any innovation's characteristics, costs, and benefits.

While some R&D and A&D activities are clearly within the purview of private industry, there is still a role for government at all levels and throughout various stages, contexts, and stakeholders involved in innovation. Early public programs and policy focused on R&D. More recent efforts have emphasized A&D, in some ways at the expense of R&D. Public policy can learn from the past, and better define that role.

END NOTES

1. Title V of the Housing and Urban Development Act of 1970. December 31, 1970. Public Law, pp. 91–609.
2. Fundamental work in the economics of innovation begins with Schumpeter (1934) and Schmookler (1962). Broader econo-historical reviews of these theories were then developed by Rosenberg (1972, 1982), Dosi (1984), Dosi, Giannetti, and Toninelli (1992), among others.
3. Studies that qualitatively describe the poor innovation development and diffusion rate in construction at large and housing in particular include Nam and Tatum (1989), Bernstein and Lemer (1996), Blackley and Shepard (1996),

Ball (1999), Toole (1998), Koebel (1999), Menanteau and Lefebvre (2000), and NAHB Research Center (2001). It should be noted that other scholars have disagreed with this assumption, for instance, Slaughter (1998).

4. This number was established by Goldberg and Shepard (1989), and is regularly cited, though not adequately substantiated. However, the argument that there is a significant delay in the duration of time from a housing innovation's conception, though market introduction, and to some reasonable market share is generally agreed.
5. Ventre (1980) offers one critique of this argument and the quantitative data upon which it is based.
6. Industrial analysis and advocacy presenting the argument for public policy interventions addressing the innovation barriers in housing came in the wake of the failed early R&D programs discussed later in this chapter. See NAHB Research Foundation, Inc. (1971) for an example of early studies in this vein.
7. The most commonly cited statistics come from the National Science Foundation's Division of Science Resources Statistics, including the Survey of Federal Funds for Research and Development. In the latest version of the survey from 2013, applied research in civil engineering accounted for $467 million, or about 1.6 percent of total federal R&D funding for applied research in 2011 ($28.7 billion)or less than 0.3 percent of total federal R&D funding ($135.7 billion). Presumably, housing was the research topic of only a fraction of that. http://www.nsf.gov/statistics/nsf14312/content.cfm?pub_id=4408&id=2
8. Several ongoing research and research funding programs that have had some housing innovation outputs have also existed, like the U.S. Department of Agriculture's wood research laboratories, the ongoing energy-source and efficiency research out of the U.S. Department of Energy (DOE) and national energy laboratories, DOE's Solar Decathlon and other promotional campaigns, the National Institute of Standards and Technology's engineering laboratory, and the National Science Foundation's ongoing solicitations for university research in civil, mechanical, and manufacturing engineering. These served as long-term R&D resources that were less focused on housing innovation per se, as much as the application of topic-focused research on housing (such as energy-efficiency). A possible exception to this was the set of alternative energy programs created during the 1970s energy crisis, some with research programs focused on housing like the Industrial Energy Conservation Program.
9. Kennedy's *White House Special Message on Housing and Community Development* cited in Nelkin (1971).
10. Some examples of these reports include the Building Research Advisory Board (1962) and Arthur D. Little, Inc.(1963).
11. Testimony of J. Herbert Hollomon, *Hearings on Supplemental Appropriations Bills, Subcommittee on Deficiencies of the Committee on Appropriations, 87th Congress, Second Session, August 1962* (Washington: GPO, 1962), pp. 48–49 cited in Nelkin (1971), pp. 36 and 106.
12. CITP evolved into the State Technical Services program in 1965, but was eventually terminated in 1969.

13. William Wisely, the chair of the American Society of Civil Engineers, wrote to Hollomon stating that "the complicated building code problem… had to first be resolved" before a program such as CITP should be enacted, and that "any approach to Congress for a building research funding program should be deferred until a plan is devised that will have the solid support of all segments of the building industry." William Wisely, Letter to Hollomon (January 21, 1963) quoted in Nelkin (1971), p. 66.
14. The National Commission on Urban Problems (the Douglas Commission), March 1969, referred to in HUD (1969).
15. President's Commission on Urban Housing (the Kaiser Committee) referred to in HUD (1969).
16. Chery Cook's "Operation Breakthrough (Industrialized Housing Techniques" cited in Baer et al. (1976).
17. Other programs for research that had housing innovation implications were also active during this time, including those mentioned in Endnote 9 as well as HUD's Lead-Hazard and Healthy Homes program of grants and technical assistance, and DOE's Appliance & Equipment Standards Program (though this is often in service to ENERGY STAR), and the Building Energy Codes Program.
18. EPA also began the Water Sense program in 2006 for voluntary certifications of plumbing fixtures and appliances.
19. DOE took over major management roles over this program beginning in 2009, as several other management tasks for the overall ENERGY STAR program were redefined between EPA and DOE.
20. The original goals were drafted by the Subcommittee on Construction and Building of the Committee on Civilian Industrial Technology in the White House's National Science and Technology Council, an entity that was created one year before in 1993 by Presidential Executive Order. See Wright, Rosenfeld, and Fowell (1994). The industry's response and commitments to the goals were articulated in Civil Engineering Research Foundation (1995). Plans for the goals related to the residential sector were written by the National Association of Home Builders' Research Center. These were affirmed by the Subcommittee that same year (Wright, Rosenfeld, and Fowell 1995).
21. In this incarnation, the public role in housing innovation has been again one of unbiased information clearinghouse rather than active funder or arbiter of R&D activities or A&D research.
22. For example, the 1980 Patent and Trademark Amendments (Bayh-Dole) Act allowed federal agencies to grant licenses to small businesses and nonprofit institutions, including universities, for inventions made at government-and contractor-operated laboratories.
23. The national laboratories are required to allocate at least 0.5 percent of their budgets to development and commercialization (or, technology transfer) per the 1980 Stevenson-Wydler Act.
24. The National Cooperative Research Act of 1984 limited antitrust laws against companies working on cooperative R&D projects. The legal agreement

between federal and private entities known as the cooperative research and development agreement (CRADA) was established under the 1986 Federal Technology Transfer Act.

. CRADA allow a private company to provide personnel, equipment, and funding for federal research projects (especially in national laboratories) that allow for shared intellectual property rights.

25. Increasing energy rates for consumers could also feasibly be a financial incentive for adoption and diffusion, though that policy regulation would be debated beyond its effect on the homebuilding industry alone.
26. There is also some preliminary evidence that adoption of design and construction change in certain housing units like assisted housing has negative consequences on widespread diffusion based on implicit bias or perception of the early adopters. Modernist architectural design is one noted example: see Wright (1983).
27. DOE's Building Codes Program was created to advocate for increased energy code stringency and enforcement.
28. A study of German residential energy codes suggests that regulation had a significant, positive impact on innovation: El-Shagi, Michelsen, and Rosenschon (2014).

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CHAPTER 5

A Review of the Residential Construction Supply Chain and Its Characteristics

Andrew McCoy

Compared to other industries, residential construction does not follow a traditional model of innovation. Utterback (1994) discussed three distinct phases of traditional industry innovation models through time: (1) *early fluid*—product enhancement is critical, (2) *transitional*—dominant product designs emerge, and (3) *specific*—competition happens between a few large firms through performance improvements. However, complexity in the homebuilding industry presents challenges to traditional innovation models that resist the use of innovative products, processes, and services. Residential construction is considered a *complex product and system* (CoPS) (Gann 2000); it is not characterized by a few large firms with similar product designs. CoPS industries, such as homebuilding, rely on third-party stakeholders as innovation brokers—organizations that do not originate or implement the final form of the innovation. Further, the residential construction supply chain is decentralized, variable, and contains many stakeholders who do not originate or implement, yet strongly influence innovation adoption. Along the supply chain, the literature suggests that some stakeholders either do not fully comprehend the benefits of innovation or go so far as to resist it.

Adding to industry complexity, residential construction contains specific characteristics that contribute to uncertainty, which can inhibit the adoption of innovation: low levels of research and development (R&D)

expenditures, volume-based modular product offerings that have to be adjusted to site characteristics, a dependence on processes and values (in the supply path) that have worked historically, asynchronous liability problems among product stakeholders, highly cyclical markets, disaggregation (many small firms), and reliance on subcontractors, diverse building codes, as well as financing and insurance impediments.

This chapter presents a broad review of uncertainty specific to the homebuilding industry and its supply chain stakeholders. First, we discuss a milieu of the industry, including defining homebuilding as a CoPS industry and aspects that make residential construction unique. We then identify areas that increase uncertainty toward innovation adoption and diffusion for all residential construction stakeholders to establish recent innovation activity for homebuilding and current trends that affect innovation adoption. Uncertainty gives way to risk, which is the concluding listing of the chapter.

In the next chapter, we delve deeper into uncertainty across the residential construction innovation supply chain and provide commercialization strategies for residential construction products.

5.1 THE INNOVATIVE MILIEU OF RESIDENTIAL CONSTRUCTION

For some time, economists and scholars of innovation have engaged in the process of identifying the role of innovation in economic growth and the factors contributing to innovation and its adoption. In 1910, Schumpeter suggested that “it was the exceptional creative drive of independent entrepreneurs, undertaking risky innovative developments, that led to the launch of radical new products and new industry sectors which changed existing market structures” (Rothwell 1989). However, in capitalism, socialism, and democracy, he shifted his position to argue that it was science and technology, primarily within the R&D laboratories of firms that played the dominant role, increasingly substituting for the mechanism of the *exogenous* inventor setting up in business (Rothwell 1989; Schumpeter 1939). Today, it is accurate to argue that both perspectives are correct and that innovation is an agile process, arising from garages in Silicon Valley as well as laboratories of private and state sponsored firms in large metropolitan cities (Chesbrough, Vanhaverbeke, and West 2006; Christensen, Anthony, and Roth 2004; Hall 1998; Koebel 2008; Rutten, Doree, and Halman 2009; Schumpeter 1939; Slaughter 1993a, 1993b).

Just as scholars have debated the factors influencing innovation, so too have they puzzled over the agility of innovative people and firms, and how and why they adopt in particular places at particular times (Porter and Stern 2001; Porter and Van der Linde 1995). The theory of the city as an innovative milieu suggests that the city (or region) serves as the physical or social setting in which innovation occurs (Hall 1998). Such theory contends that significant innovation advances were made possible by unique clustering of opportunities, people, capital, infrastructure, resources, and public policy. While attempting to replicate the conditions for success in those places, Hall cautions “building innovative milieu is not something that can be done either easily or to order” (1998).

Innovation proponents often misinterpret the role and the magnitude of innovation in residential construction as reflecting a proinnovation bias in much of the research on innovation and to technology transfer programs in general (Sexton and Barrett 2003a, 2003b). This proinnovation bias is partly a reflection of a macro-Schumpeterian perspective that innovation drives economic growth. Although we do not address the macrocontribution of innovation to economic growth (or even more narrowly to efficiency in construction), we argue that this proinnovation bias interprets resistance to innovation as backward and presents a laggard and tradition-bound industry. These same assumptions promote false, or at least premature decisions, about innovation levels in the residential construction industry and lead to misguided and ineffective actions by government and industry associations.

5.2 RESIDENTIAL CONSTRUCTION AS CoPS

Housing production is a CoPS that spans multiple industries, including material (raw and finished) producers, manufacturers, suppliers, land developers, engineers, architects, builders, specialty contractors, financial institutions, insurers, marketers, and consumers. Winch (2003) defined CoPS as industrial sectors where the traditional innovation model does not fit—they are not characterized by a few large firms with similar product designs striving for the attentions of the customer. CoPS industries, such as homebuilding, rely on third-party stakeholders as innovation brokers—organizations that do not originate or implement the final form of the innovation. Further, the residential construction supply path is decentralized, variable, and contains many such brokers: material suppliers, manufacturers, distributors, retailers, developer and builder firms, installers, regulatory bodies, and end users. The decentralization of resources, knowledge, and projects often creates uncertainty and reduces risk tolerance. To be specific, 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). Risk is measureable and can be managed along the supply path, while uncertainty cannot. Organizations that fail to innovate increase the uncertainty and reduce the risk tolerance for other stakeholders across the industry central to adoption and diffusion.

Discussions of innovation in construction, as a whole, and for residential construction in particular focus on builders and contractors as key brokers who manage the assembly of product. The literature suggests that builders resist adoption without fully comprehending the benefits of innovation. To a great extent this is reasonable—the builder occupies the key point in the process where many decisions about systems and products, as well as about assembly, are located. The builder, more than any other group, decides how to balance the characteristics of supply to market demand. However, innovation investments can take place upstream from the builder with the materials producer, the manufacturer, and the supplier. From an accounting perspective, this is likely to understate innovation investments in construction as measured by national audits. The paucity of quantitative work on investments in construction innovation reflects the difficulty of measurement whether by R&D investment, patents, or efficiency, both in the United States and abroad (Winch 2003). Despite the lack of hard evidence, there is nearly a world-wide assumption that construction is resistant to change through innovation (Manseau and Shields 2005; Winch 2003).

5.3 THE RESIDENTIAL CONSTRUCTION INDUSTRY

It is important to define residential construction in terms of its scale compared to other industries. Koebel (2008) described 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, the industry contains many of the same risks due to scale that can be found across any industry and its supply chains.

In terms of employment, building-related occupations and construction trades contain a major portion of national employment and are key brokers in the larger occupational supply chain. According to the Bureau of Labor and Statistics' (http://www.bls.gov/oes/) occupation employment statistics in 2013, *installation, maintenance, and repair occupations*, *construction and extraction occupations*, *building and grounds cleaning and* *maintenance occupations*, and *architecture and engineering occupations* categories account for 16.89 million jobs or 12.74 percent of national occupational employment. These occupational categories are second only to *office and administrative support occupations* and were larger than health care occupations in the United States in 2013.

In terms of construction spending, the forecasted new construction in the United States in 2016 is $1,153.39 billion, of which the forecasted value of new residential construction in the United States is $451.91 billion, or 39 percent. The residential construction is vast and far-reaching in terms of its contribution to employment and national spending, including the number of related occupations and economic stakeholders.

As a result, many argue that residential construction is a major driver of the U.S. economy, highly connected to many other industries and therefore similar and should not be allowed *unique* characteristics that might set it apart or allow it to be treated differently in terms of the ability to innovate. For example, residential construction shares similar supply chain management and scalability barriers as the automobile industry. Yet challenging characteristics unique to its own industry often hinder the adoption of innovation in residential construction (Moavenzadeh 1991; Slaughter 1993a; Toole 1994, 1998; Toole and Tonyan 1992).

Like other industries, common factors affecting adoption are firm characteristics; tasks and activities associated with using new products and materials; a firm's perceived benefits; a firm's market and competitive strategies; size of the firm; competition; and business cycles (growth, payback, and downturns) (Hassell et al. 2003; Koebel et al. 2003).

Unlike other industries, site variability and the one-off nature of construction resist industry adoption (Koebel and McCoy 2006). 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. In terms of site variability, 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). Construction supply chains additionally complicate variability by isolating any knowledge associated with the innovation that is discovered onsite. 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 even more 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, nonproprietary 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 (large or small) 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.

5.4 INNOVATIVE TRENDS IN RESIDENTIAL CONSTRUCTION

A firm's resistance to change indicates a lack of economic benefits (rents) to be derived from innovation. Understanding the distribution of economic benefits (Von Hippel 1988) is central to understanding the advantages gained as a first, second, or later adopter (often referred to as *mover advantage*) of innovation. If benefits consistently come after the point of early adoption, then the rational firm strategy is to be a second mover after others demonstrate the relative merits of the innovation. However, if economic benefits associated with innovation are low, the industry as a whole can become highly risk adverse and reliant on established practices (known as path dependency). Von Hippel (1988) defined the first mover (or lead user) as an individual or institution that displays two characteristics: facing the needs of a market well in advance of others and being positioned to benefit significantly from facing market needs in advance. Second movers anticipate market needs but do not anticipate rewards for responding or are too risk adverse to pursue those rewards. The placement of the builder within the housing production process exposes the innovating builder to significant risks while others (manufacturers and suppliers) are better positioned to expropriate the benefits of the innovation.

Innovation research in construction in general and the residential building industry specifically has been slow to develop (Dewick and Miozzo 2004; Koebel 2008; Matar, Georgy, and Ibrahim 2008; Mitropoulos and Tatum 1999), with a shorter history than innovation research in other fields.

This has been attributed to many factors: 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 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 economic longevity and stability (1999).

In homebuilding, according to a National Association of Home Builders (NAHB; Hudson 2011) poll, almost 80 percent of respondents mentioned actions and products within the *green* portfolio. Building industry professionals provide ample testimony that green building is not a trend or a passing phase (McCoy et al. 2012). Instead, energy efficiency and related building practices are becoming the state of the art in the building industry, and the ability to deliver these services to clients is becoming increasingly important to maintain a successful business.

Much of the work on the adoption of sustainability and green practices has focused on the property and building markets, as well as consumer behavior, and this will continue to be defined as its influence grows. Recent research initially explored the following aspects of green building: costs and benefits, profiles of ecologically conscious consumers, evidence of price premiums associated with green certified residential space, and processes of creating new green construction technologies (Kok and Khan 2012). This growing body of literature used green building rating systems as its foundation; analyzing whether their presence or absence was significant and if so, to what extent. Recent green practices focus on the measurement of specific products, technologies, or processes within the facility. Further, prescriptive systems for facilities in the construction industry have grown in purview and influence within green practices (Tucker et al. 2012). At present, though, there is significant variation in emphasis across the primary national prescriptive rating systems (ENERGY STAR™ for Homes or Energy Star; LEED™ for Homes or LEED; NAHB's National Green Building Standard [NGBS]).

While many of the skills required to offer *green* homebuilding services are similar to existing skill sets in the Architecture, Engineering and Construction (AEC) industry, the additional complexity results in uncertainty among building industry professionals and educational stakeholders. Who can best provide the training for firms, individuals, or both so that they might better compete in the changing market? Equally important, how might training complement existing industry trends and provide marketable skills for the new workplace?

Amid uncertainty, residential stakeholders must determine which services to provide and credentials to require in order to satisfy key stakeholders of the industry and market while also satisfying needs of employers and employees. A sound approach for overcoming barriers to green jobs skills and training should involve multiple levels of education and strategies to address stakeholders' needs and benefits. Such strategies add to the complex nature of the industry as it attempts to move into the future.

5.5 RESIDENTIAL CONSTRUCTION UNCERTAINTY

Many publications broadly discuss uncertainty in the residential construction industry and emphasize its impact on homebuilder firms, but do not identify and analyze risk metrics (Blackley and Shepard 1996; Slaughter 2000; Toole 1998). Uncertainty is the likelihood of an undesired event's occurrence while the risk is the measure of the probability. Said differently, uncertainty cannot be objectively calculated, while risk can. Therefore, uncertainty and its lack of measurement in homebuilding increase resistance to innovation adoption. Residential construction research (as noted) identifies the following factors as causing uncertainty and influencing resistance to innovations.

Characteristics of the market:

- Product variability (Toole 1998)
- Site variability (Toole 1998)
- Demand and price volatility (Slaughter 1993a, 2000)
- Long time frame for production (Toole 1998)
- Complex product and subsystems (Toole 1998)
- Codes and regulations increase costs and uncertainty associated with innovation (Blackley and Shepard 1996; Slaughter 1993a; Toole 1998), but more builders disagreed than agreed that codes and regulations were a barrier to technology diffusion (Koebel et al. 2003)
- Changing ratio between construction costs and land costs (Slaughter 1993a)
- Land acquisition might be primary determinant of profit (Ball 1999; Koebel 1999)
- Innovation more likely in lower-price houses (Oster and Quigley 1977) reflecting possible preference of high-income consumers for craft-built houses (Koebel et al. 2003)

Characteristics of the firm and individuals within the firm:

- Tacit knowledge (Toole 1998)
- Integration of products creates opportunities for builder innovation (Slaughter 1993a)
- Larger firms have greater capacity to innovate (Blackley and Shepard 1996; Koebel et al. 2003; Oster and Quigley 1977)
- Operating in multiple markets reduces risks and increases opportunities for regulatory acceptance (Blackley and Shepard 1996)
- Small firms lack capital for innovation including costs of implementation and require returns more quickly (Slaughter 1993a)
- Owner and president most influential followed by the project manager in influencing decisions about new products and materials, and owner and president almost exclusively responsible for final decisions about new products and materials (Koebel et al. 2003)
- Purchasing, design, and marketing departments have influence on innovation in only one-in-five firms (Koebel et al. 2003)
- Owner and CEO technology champion in two-thirds of the firms (Koebel et al. 2003)

The business model:

- Small firms are risk adverse (Slaughter 1993a; Toole 1998) and most homebuilders serve only the local market area (Koebel et al. 2003)
- Inadequate knowledge management and technology scanning (Slaughter 1993a; Toole 1998)
- Barriers to innovation prevent the widespread adoption of bad ideas (BTI 2005)
- Thirty percent have no plan for growth in profits or plan to downsize (Koebel et al. 2003)
- One-third hold positive attitudes about innovation and one-sixth hold negative or conservative attitudes (Koebel et al. 2003)
- Greater emphasis on aesthetic improvements, total quality practices, subcontractor dependability, marketability, and reducing callbacks than on reducing costs and liabilities through investment in innovative products (Koebel et al. 2003)
- Proinnovation business strategy, technology champion, and emphasis on cooperation associated with higher innovation (Koebel et al. 2003)

- Emphasis on land development associated with lower innovativeness (Koebel et al. 2003)
- Wider involvement in vetting innovation makes better use of diffuse, tacit knowledge (Toole 1998)

Characteristics of the interfirm network (including client and owner):

- Large, multiparty network (Toole 1998)
- Industry fragmentation (found to have no effect on innovation by Blackley and Shepard 1996)
- Inadequate opportunity for field testing innovations (Slaughter 1993a)
- Builders have the advantage of being able to demonstrate the efficacy of an innovation (Slaughter 1993a)
- Lack of systems integrator (NAHB Research Center 2001)
- Sales and supplier representatives, subcontractors, other builders, and trade publications are the most influential sources of information on innovation, while universities and technology transfer programs least influential (Koebel et al. 2003)
- Reliance on established companies that stand behind their products (Koebel et al. 2003)
- Cooperation of suppliers rated most important in innovation followed by subcontractors, manufacturers, and project managers (Koebel et al. 2003)
- Having a greater number of information sources reduces uncertainty associated with innovation (Toole 1998)
- Builders who rate other builders, in-house testing, and subcontractors as more important sources of information were more apt to adopt high uncertainty innovations (Toole 1998)
- Builders using architects, homeowners, manufacturers, and subcontractors for important sources of information were more apt to adopt low-uncertainty innovations (Toole 1998)

Characteristics and perceptions of innovation:

- Complexity of establishing relative advantage (Hudson 2011; Koebel et al. 2003; Toole 1998)
- Uncertainty surrounding costs and benefits, assumption that innovations are too risky without ample field testing and demonstration of results (Toole 1998)
- Integrative innovations prohibitively risky (Slaughter 1993a)

- Consumer prefers visible benefits (aesthetics) and discounts invisible building improvements without short-term payoff (Koebel et al. 2003)
- Higher cost is the most significant impediment to the adoption of innovations (Koebel et al. 2003)
- Increased quality seen as the main benefit to innovation, followed by creating image as the innovative builder (Koebel et al. 2003)
- Increasing productivity was positively associated with innovation, whereas increasing profit was negatively associated (Koebel et al. 2003)

5.6 CONCLUSIONS

This chapter presented a broad review of uncertainty specific to the homebuilding industry and its supply chain stakeholders. We discussed a milieu for the industry, identified areas that increase uncertainty toward innovation adoption and diffusion, and provided a list of stakeholder risks.

In the next chapter, we dive deeper into uncertainty for residential construction innovation, introducing stakeholders that influence the adoption along the residential supply chain, discussing the varying nature of the residential path to market, exploring homebuilding products and their attributes that reduce uncertainty for stakeholders, specialty product and local market characteristics that influence adoption, and a commercialization strategy for residential construction products.

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CHAPTER 6

The Residential Construction Supply Chain and Its Stakeholders

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Compared to other industries, residential construction does not follow a traditional model of innovation: Complexity in the homebuilding industry presents challenges to traditional innovation models that resist the use of innovative products, processes, and services; it is considered a *complex product and system* (CoPS) (Gann 2000) not characterized by a few large firms with similar product designs; the supply chain is decentralized, variable, and contains many stakeholders who do not originate or implement, yet strongly influence innovation adoption. Along the supply chain, the literature suggests that some stakeholders either do not fully comprehend the benefits of innovation or go so far as to resist it.

In the previous chapter, the authors reviewed uncertainty specific to the homebuilding industry and its supply chain. First, we discussed a milieu of the industry, including defining homebuilding as a CoPS industry and aspects that make this industry unique. We then identified areas that increase uncertainty toward innovation adoption and diffusion to established recent innovation activity for homebuilding and current trends that affect innovation adoption. Next, we broadly listed the uncertainties and the risks for all stakeholders along the supply chain of residential construction innovation.

In this chapter, we will dive deeper and introduce the stakeholders that influence adoption along the residential supply chain, discuss the varying nature of the residential path to market, explore homebuilding products and their attributes that reduce the uncertainty for stakeholders, examine specialty product and local market characteristics that influence adoption, and a commercialization strategy for residential construction products. Due to the changing marketplace and increasing aggregation, defining barriers along the supply chain is key to unlocking innovation resistance unique to the homebuilding industry. At the end of the chapter, we further narrow our focus to the central role of builder firms as a critical gatekeeper of innovation.

6.1 THE RESIDENTIAL SUPPLY CHAIN

Research on innovation in construction has failed to distinguish adequately between the commercial versus residential construction sectors. Gann (2000) argued that construction has evolved to a new production system made possible by the digital age, but the evidence of this new production system is based on larger, complex commercial and industrial, or heavy construction projects (offices, institutional buildings, and infrastructure) managed by large firms who have recognized the benefits of information technology. The simulation and modeling used to test *prototypes* ensure best practice in management and IT tools that facilitate knowledge transfer and coordination among stakeholders such as clients, engineers, architects, and contractors. Specialists and suppliers are not yet part of the residential firm's daily practice. Mitropoulos and Tatum (1999) and Briscoe et al. (2004) argued that clients were the driving force for innovation in commercial construction based on their needs for higher quality buildings and new performance standards.

Despite these rosier perspectives of innovation in commercial construction, clients will most likely not demand IT solutions except in the case of *smart home* technology end-use. Instead, Blayse and Manley (2004) point to fragmented supply chains as an ongoing pressure in residential construction that resists innovation. Unlike commercial construction, and except for the custom-designed house market limited to those with sufficient wealth and income, most residential construction firms build to a known set of plans and offer a limited grouping of options. Standardization of product requires that each home built is similar to others built by the company, rather than a unique product. Commercial builders entertain options from clients or designers that have a combined range in the tens or hundreds of thousands within one building program. Custom homebuilders can have up to 75,000 options, while production builders report approximately 7,500 to 10,000 options. Reducing options means reducing uncertainty, from product concerns to other stakeholders along the supply chain.

Uncertainty along the supply chain plays a major role in determining the innovation-adoption decision for builders, with individual stakeholders strongly influencing the success of adoption (McCoy, Thabet, and Badinelli 2009). Residential construction is unconventional due to decentralization, variability, and the presence of many stakeholders, including material suppliers, manufacturers, distributors, retailers, builder firms, installers, regulatory bodies, and end users. Individual stakeholders strongly influence innovation adoption through either veto or endorsement. Further, the inclusion of stakeholders such as inspectors, who may not physically possess a product, adds critical roles in deciding if an innovation proceeds to the next owner in the chain, adding additional uncertainty. In residential construction, "the builder, more than any other [stakeholder], decides how to balance the characteristics of supply against market demand" (Koebel 2008). Yet, 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). Figure 6.1 illustrates a typical supply chain for residential construction.

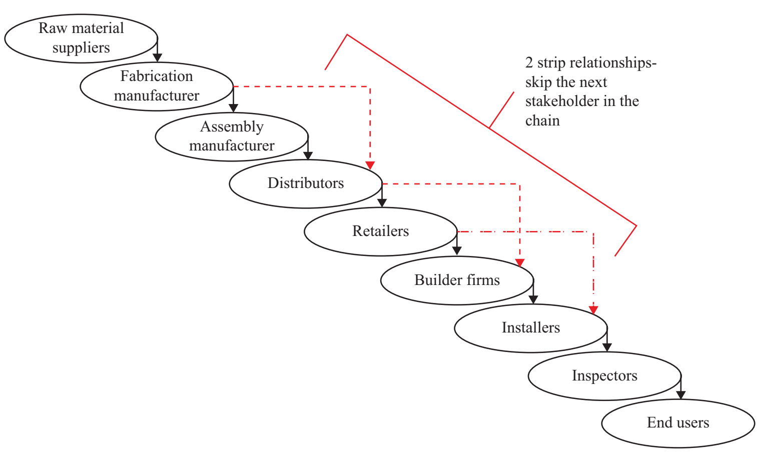

Figure 6.1. The residential construction supply chain.

6.2 THE RESIDENTIAL PATH TO MARKET

Along the path from the concept and raw material to the construction site, several factors unique to the homebuilding industry reinforce resistance to innovative construction technology. Notably, entrepreneurs characterize residential construction with informal business plans organized to minimize exposure to industry cycles, and decentralization of resources, knowledge, and projects. A high cost of failure is also an issue, thereby making warranty and durability factors especially salient (Koebel and McCoy 2006). As a result, *path dependency* is often viewed as a form of risk mitigation.

Path dependency in a firm refers to its resistance to change the processes it does (and knows) well. Some maintain that resistance protects the firm from adoption of bad innovation, further reducing risk (BTI 2005). The additional complication of the construction supply path maintains that any knowledge or innovative behavior discovered on-site remains remote due to its isolated nature. As stated before, the construction site is at the end of the supply path and new, project-specific knowledge does not flow upstream. Manufacturers and distributors complicate this process by often resisting a reverse-transfer of the knowledge. When occasionally successful, tacit knowledge transfer upstream is considered public now, not proprietary. Two-step dealers transfer knowledge for the benefit of other clients, allowing second movers to continue to wait on new knowledge, not defining it for themselves. A firm's lack of innovation definition reinforces their second mover tendencies.

Residential construction projects historically require less adaptability than commercial projects. While small firms often change in nature similar to the one-off nature of commercial work, medium-to-large and production homebuilder sites contain a similar kit of parts. A consistent home footprint recreated hundreds or thousands of times across flattened terrain does not require new processes or products (unless quality is suffering). The production homebuilder's kit of parts resists change and the risk involved, offering incentive for top-down knowledge and retaining good practices, not change. This core competency is a valued attribute, not diversity.

Perceived risks associated with the development of new technologies can also hinder adoption (McCoy, Thabet, and Badinelli 2009; McCoy et al. 2010, 2012). McCoy, Pearce, and Ahn (2012) reported on structural insulated panel (SIPs) systems and found that initial trials and continued use were affected differently by product attributes controlled in the manufacturing process and further down the supply path into the home. Such studies indicate the importance of defining product attributes for the market early in the development process; otherwise, products such as SIPs can suffer from low adoption and diffusion in the U.S. market.

6.3 RESIDENTIAL PRODUCT ATTRIBUTES

Moving an innovation along the supply chain and down the path of the market requires more than just developing an efficient product. Manufacturers must also match appropriate product attributes to a synchronized, increasingly sophisticated assessment of both the potential market and the channels through which the product travels.

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. Researchers across multiple domains of inquiry have accepted these attributes, including Atun, Gurol-Urganci, and Sheridan (2007), Black et al. (2001), Habets, Voordijk, and van der Sijde (2006), Rogers (2003), 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 in an attempt to facilitate their acceptance (Koebel and McCoy 2006; McCoy, Thabet, and Badinelli 2009) through the following terms:

- *Timing of commitment*: timing or flexibility with implementation of the product during the construction schedule (Slaughter 1993b, 1998; Toole 1998)
- *Compatibility*: congruency with the habits of users or existing products (Cagan, Oner, and Basoglu 2003; Holmen Enterprises 2001; Rogers 2003; Slaughter 1993a; Toole 1998)
- *Supporting innovation*: innovations that require other innovations to make them compatible (Flood, Issa, and O'Brien 2003; Slaughter 1998; Toole 1998)
- *Complexity and simplicity*: the products' ability to be understood by users (Cagan, Oner, and Basoglu 2003; Flood, Issa, and O'Brien 2003; Holmen Enterprises 2001; Rogers 2003; Toole 1998)

- *Trialability*: ability to be experimented without risk (Cagan, Oner, and Basoglu 2003; Flood, Issa, and O'Brien 2003; Holmen Enterprises 2001; Rogers 2003; Slaughter 1993a, 2000; Toole 1998)
- *Observability*: product visibility within the marketplace (Cagan, Oner, and Basoglu 2003; Holmen Enterprises 2001; HUD 2005; Rogers 2003; Toole 1998)
- *Cost advantage and relative advantage*: cost and relative benefit to using the product as opposed to traditional products (Cagan, Oner, and Basoglu 2003; Eaton, Akbiyikli, and Dickinson 2006; Flood, Issa, and O'Brien 2003; Holmen 2002; HUD 2005; Rogers 2003; Slaughter 1993a, 2000; Toole 1998)
- *Risks*: impact and probability of negative consequences for using the product (Eaton, Akbiyikli, and Dickinson 2006; HUD 2005; Koebel and McCoy 2006; Slaughter 1993a)
- *Supervision competency*: experience or education and training required to use or install the product (Blackley and Shepard 1996; Slaughter 1998; Toole 1998)
- *Consumer resistance* (end user): opposition originates that from the consumer (individual-based) (Flood, Issa, and O'Brien 2003; Koebel and McCoy 2006)
- *Trade resistance*: opposition that originates from trades (organization-based) (Blackley and Shepard 1996; Koebel and McCoy 2006; Slaughter 1993a, 2000;Toole 1998)
- *Regulatory resistance*: opposition that originates from government organizations (authority-based) (Blackley and Shepard 1996; Blayse and Manley 2004; HUD 2005; Koebel and McCoy 2006; Oster and Quigley 1977; Slaughter 1993b; Toole 1998)
- *Coordination within the project team*: synchronization of various stakeholders is required for implementation (Blackley and Shepard 1996; HUD 2005; Slaughter 1998; Toole 1998)

As previously discussed, recent development and diffusion of green building technologies have become central to homebuilding. 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 contributes to a safe and healthy work environment, regardless of whether these effects were the main objective of the product or not (McCoy, Pearce, and Ahn 2012).

However, scant research has empirically studied attributes of green building technologies. McCoy, Pearce, and Ahn (2012) reported on attributes that affected adoption for SIPS, a green building technology, in the Commonwealth of Virginia. They relied on a small sample of builder responses of product attributes that influenced both the first trial and continued use (2012).

6.4 FIRST TRIAL CONCLUSIONS

Regarding the attributes of innovation of SIPS upon first use, McCoy, Pearce, and Ahn (2012) reported several trends. Timing of commitment, consumer resistance, trade resistance, and regulatory resistance had the lowest rated effect on adoption.

Based on limited findings, supporting innovation, relative advantage, and risks show the highest effect on adoption of SIPs (McCoy, Pearce, and Ahn 2012). Supporting innovation was discussed by Sarah Slaughter as one of the primary sources of builder innovation on the jobsite due to the necessity to manipulate and incorporate the product into existing building systems (Slaughter 1993a). Respondents identified risks and relative advantage as barriers to adoption for general green building innovation by Koebel et al. (2003).

SIPs also contained an interesting clustering of data that emerged around trialability, observability, and coordination within the project team. The clustering indicated that a large portion of survey respondents agreed that these attributes 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 and the data indicated that builders might perceive consumer uncertainty, either through a market *pull* or market resistance, as a large barrier to the adoption of green technology. Such a distinction could also indicate a need for the attribute to be redefined for green products, or those innovations that have been on the market for some time without high saturation.

6.5 CONTINUED USE CONCLUSIONS

Regarding the attributes of innovation of SIPS among builders with continued use, McCoy, Pearce, and Ahn (2012) reported little variance from the first use among the attributes timing of commitment, compatibility, complexity, risks, supervision competency, trade resistance, regulatory resistance, and coordination within the project team. In general, the innovation attributes appear to have relatively similar effects on adoption for the first trial and continued use of applications.

Compatibility and relative advantage and cost contained a positive correlation, though, between the initial trial and the continued use. Compatibility was also addressed in the literature by Slaughter (1993b) as a barrier to adoption due to the need for congruence between manufactured products and industry habits.

Relative advantage and cost also contained increased risk through the continued use of a green technology. If such advantages are not understood fully through the initial trial, it seems evident that such issues would be more and more pressing through time.

Finally, McCoy, Pearce, and Ahn (2012) reported the correlation of risk as a negative association between the initial trial and the continued use. This finding indicates that builders can reduce general risks associated with adopting SIPs through continuous use, as expected.

6.6 SPECIALTY PRODUCTS AND LOCAL MARKET BARRIERS

Regardless of broader trends in the industry, specialized products and local market characteristics present additional risks to the industry and its fragmented supply chain. Product or local market differences, when matched with the development constraints of manufacturers and other brokers along the supply chain, might contain additional barriers for innovation adoption and diffusion.

By way of example for specialty products, windows and doors contain uncertainty early in the manufacturing process that can often transfer down the supply chain to complementary products and subsequent stakeholders. Figure 6.2 describes an example of uncertainty for the vinyl residential window market, which constitutes a majority of the residential construction industry's products. In the vinyl window market, raw material suppliers originate the extrusion of certain shapes every year. These shapes limit the assembly of window types, designs, and variations at the manufacturer level. In the case of vinyl windows, manufacturers are therefore more of assemblers of the vinyl extrusions than fabricators of the pieces that define the window attributes. Then, depending on the specifications of the windows, a series of distribution channels might or might not be appropriate for reaching end-users. Further, the characteristics of the installer firm will also drive the appropriate matching of certain vinyl window attributes to the distribution process. For example, remodeling firms

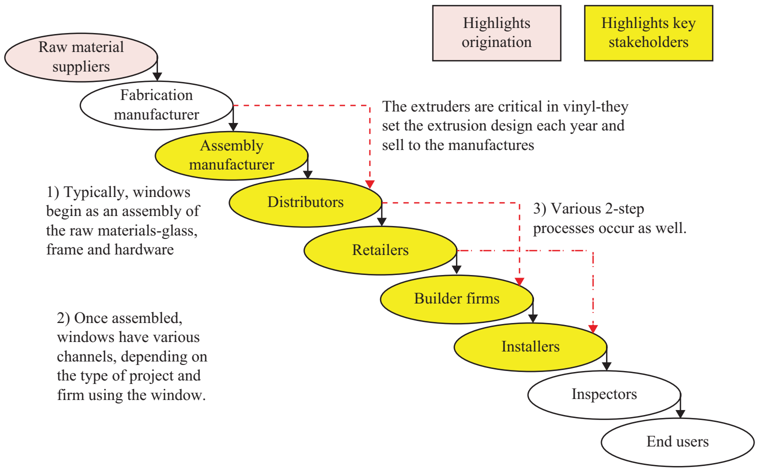

Figure 6.2. Window supply chain diagram.

require a different window installation process than new construction firms, which can all come down to the original shape of the vinyl extrusion (whether or not it has a fin for installation). Such variations require manufacturers to constantly study and respond to local market conditions that might limit adoption of their products.

Outside of specialty product attributes, local market characteristics also influence the decision to adopt products, according to the literature (McCoy, Koebel, and Sanderford 2013). Local characteristics reported to affect innovative products include (McCoy, Koebel, and Sanderford 2013):

- Cost—A product's price point remains a key variable for adoption while relative advantage refers to competing substitute products within its cluster of technologies that influence adoption. Cost factors that affect the local cost of doing business are also a possible source of uncertainty in the industry.
- Efficiency of installation—Relative advantage from local labor productivity and the cost of insurance for the labor force.
- Local firm characteristics—These include size; organizational capacity and human resources; R&D investment; and the presence of technology champions. Mixed results have reported the impact of firm size in the residential construction industry; evidence indicates that both small companies led by a technology champion and large companies with technology capacity can promote product innovations.

- Market area characteristics—Contagion effects associated with market area sizes and distances are expected, based on the opportunities for learning from builders in other nearby markets.
- Public policy—Included are federal stimulus funds (state level ARRA funds), green building certifications, utility rebates, state grants, and a variety of other state and local incentives for energy efficiency.
- Time effects—Bandwagon effects provide positive impacts on a product's use and saturation effects reflected in negative impacts of use over time. Housing's long lifecycle extends risks beyond those of many other industries, creating longevity of warranties.

6.7 RESIDENTIAL PRODUCT COMMERCIALIZATION

To overcome resistance to adoption, innovation brokers, especially manufacturers, must consider an appropriate business model to support the different technical and marketing stages of an innovation, while also protecting 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). A poor commercialization strategy can limit adoption from early mistakes in the development process.

The success of a new product requires the establishment of a complete supply chain (see Figure 6.1), which is possible only if every member of the chain foresees net benefits in joining the chain. The construction-products supply chain is marked by the endemic reluctance of builders to readily adopt innovative products. Interviews with builders have exposed the reasons, obvious in retrospect, for their inertia (McCoy, Thabet, and Badinelli 2009).

Some inertia results from the fact that the home-building industry is competitive mainly in the early procurement of land for the homebuilding process (i.e., price of land). The most significant battle is won once a builder firm acquires a prime piece of real estate. The builder's disincentive to innovate is also supported by a lack of awareness by homebuyers of the relative merits of a construction process or product. These two characteristics of the housing market conspire to create in the minds of builders sensitivity to the risks of adopting innovation. Therefore, a successful commercialization of a homebuilding product requires creative approaches to mitigating the perceived risks of stakeholders or to concurrently share these risks with other members of the supply chain.

Concurrent commercialization (CC) offers a model for sharing risk along the residential construction supply chain (McCoy et al. 2010). In common with classic concurrent engineering (CE), a CC strategy for homebuilding requires the involvement of all supply-chain parties in the design and development of a new product during the earliest stages. CC additionally broadens the scope of product–development decisions beyond the technology considerations within the commercialization framework. In effect, CC is directed at designing a commercialization venture as opposed to only designing a product. In a direct correlation to CE, CC expands the definition of the market to include all supply-chain participants, not just the end users.

Since previous research indicates that the builder is the most reluctant customer in the supply chain, CC applied to construction products emphasizes the influence of mitigating builder firm risks in the design of a commercialization project. In general, management of uncertainty and related risk is implemented through three types of interventions: buffering, contingency planning, and hedging. CC incorporates each of these approaches to adoption resistance in the design of a product and supply-chain relationships.

6.8 MOVING FORWARD: THE ROLE OF THE BUILDER IN THE DIFFUSION OF RESIDENTIAL CONSTRUCTION INNOVATION

The impact of firm size probably has been discussed more than any single organizational attribute influencing adoption and diffusion. Size does not have a uniform relationship to innovation. The capital, talent, and market advantages of large firms could enable them to be more innovative, as suggested by Hassell et al. (2003), but this is not always the case. Large builders are constrained by responsibilities to shareholders (if they are a publicly owned company) not to risk losing quality, safety, and profitability, which may be an outcome of adopting an innovative technology. Since they produce a significant number of units quickly, large builders are especially vulnerable to defective innovations.

Large and production homebuilder firms increasingly control local metropolitan market share and are also therefore key brokers to innovation adoption in residential construction. In 1992, the four largest homebuilders captured 3 percent of the new home sales market (Slaughter 1993a), and in 2005, the top 100 national homebuilders captured 37 percent of new home sales market (Koebel 2008). In 2014, post recession numbers reported annually in Hanley Wood (2014) indicate that the top 100 command between 30 and 40 percent of most major U.S. housing markets for new residential construction of single family homes, as opposed to across the country. While this consolidation is projected to continue over time, it is important to note that small homebuilding operations still capture approximately a majority of the national market. Compared to large national firms, where diffusion often hinges inside the firm with purchasing manager behavior and management buy-in, small firm diffusion often hinges outside the firm on installers, interested owners and programs designed to champion innovation (i.e., green certification). Cantrell and Hudson (2006) found larger builders are more likely to be the first to adopt innovative materials if it results in cost savings, improvement in the production process, reduction in call-backs, or exposure to liability.

Koebel and McCoy (2006) argued that larger firms might be more path-dependent (that is, reliant on familiar practices) and resistant to change than small homebuilding firms where the owner has more direct control and can champion innovation more effectively. According to several prominent analysts of innovation (Christensen 1997), disruptive innovations (those that significantly change industry practices) are most likely to come from small and new companies that compete on innovative business models for the industry.

Slaughter (1993a) demonstrated that small firms are a significant source of innovation in homebuilding. Koebel et al. (2003) found that national builders were more innovative than builders operating in a single market area but otherwise found that size was not statistically significant. The sample for that study was dominated by small firms. In their analysis of the NAHB Annual Builder Practices Survey, they also found that the impact of firm size on innovation was mediated by characteristics of the innovation. Eastin, Shook, and Fleishman (2001) argued that small builders tend to adopt modifications of materials and technologies to fit the existing housing system, while larger firms are more likely to introduce more substantial or radical innovations. Furthermore, small builders might be more sensitive to the opinions of their customers, making them more responsive to *demand-pull*. Several studies of commercial construction point to higher innovation levels for medium and large firms than for small firms (Kangari and Miyatake 1997; Nam and Tatum 1992; Seaden et al. 2003) and associate this phenomenon with their greater access to capital and talent.

Although measuring firm size would appear to be a simple task, it is complicated when data are collected at the level of operational offices (most studies have been done on an establishment, or local office, basis). Large homebuilding companies decentralize their operations to metropolitan and regional levels, in part due to the importance of site variability in construction (Koebel and McCoy 2006). Measuring the size of the *company* can thus confuse the size of the local establishment and the size of the larger corporation. Research to date has not adequately addressed this complexity.

Centralization of decision making, organizational complexity, and formalization are possible impediments to innovation. Since most studies of residential construction have involved small companies, the relationship among these organizational characteristics of larger, more complex firms has not been studied. Among smaller homebuilders, the owner is often both the technology champion and the decision maker (Koebel et al. 2003). When the owner is a technology champion, the firm is more likely to be innovative. Purchasing, design, and marketing departments had less frequent influence on innovation in these firms.

Based on the central role of builder firms within the supply chain, some risks will continue to affect the adoption decision of innovation no matter the size. The risks of Table 6.1 draw heavily on those previously reported in this chapter, while focusing the lens to the view of builders and key brokers in residential construction.

Table 6.1. Distilled sources of builder risk

Distilled sources of risk	**Literature references (For builder firm risks)**
Consistency of installation (site variability and project variability)	• Inconsistency between construction costs and land costs creates risk (Slaughter 1993a) • Complex products and subsystems are risky (Toole 1998) • Poor land acquisition might reduce profit (Ball 1999; Koebel 1999) • Integrative innovations are prohibitively risky (Slaughter 1993b) • Industry fragmentation affects profit (Blackley and Shepard 1996) • Firms view subcontractor dependability and reducing call-backs as more important than reducing costs and liabilities through investment in innovative products (Koebel et al. 2003) • Reliability of suppliers reduces risk most (Koebel et al. 2003) • Product variability creates risk in lifecycle costs (Toole 1998)

(*Continued***)**

Table 6.1. Distilled sources of builder risk (*Continued*)

Distilled sources of risk	Literature references (For builder firm risks)
Product lifecycle (includes durability, serviceability, maintainability, reliability, and disposability)	• Lack of ample field-testing and demonstration of results increases risk in adoption (Toole 1998;Slaughter 1993a) • Product variability creates risk in lifecycle function and costs (Toole 1998) • 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 et al. 2003) • Lack of established companies that stand behind their products increases risk (Koebel et al. 2003) • Many technical information sources reduces risk (Toole 1998)
Diffusion within and across builder firms (knowledge transfer between builders, i.e., small, independent builders)	• Knowledge transfer more difficult in large, multiparty networks (Toole 1998) • Other builders, sales, and supplier representatives, trade publications, in-house testing and subcontractors are less risky as sources of information (Toole 1998) • Architects, homeowners, manufacturers, universities, technology transfer programs, and subcontractors are more risky as sources of information (Toole 1998) • Reliance on tacit knowledge less risky and more resistant to innovation adoption (Toole 1998) • Larger firms have greater capacity to innovate (Blackley and Shepard 1996; Koebel et al. 2003; Oster and Quigley 1977) • Small firms lack capital for innovation including costs of implementation and require returns more quickly (Slaughter 1993a) • Owner or president most influential followed by the project manager in influencing decisions about new products and materials (Koebel et al. 2003) • Owner or president almost exclusively responsible for final decisions about new products and materials (Koebel et al. 2003) • Owner or CEO technology champion increases adoption (Koebel et al. 2003) • Proinnovation technology champion and emphasis on cooperation associated with higher innovation (Koebel et al. 2003)

(*Continued*)

Table 6.1. Distilled sources of builder risk (*Continued*)

Distilled sources of risk	**Literature references (For builder firm risks)**
Market awareness (knowledge of end-user preferences or influence within the building process)	• Innovation more necessary in lower-price houses (Oster and Quigley 1977) • High-income consumers prefer custom houses, not necessarily innovation (Koebel et al. 2003) • Firms rely on marketability more than on reducing costs and liabilities through investment in innovative (Koebel et al. 2003) • Consumer prefers visible benefits (aesthetics) to invisible building improvements, unless they provide short-term payoff (Koebel et al. 2003) • Increased quality seen as the main benefit to innovation (Koebel et al. 2003) • Creating image as innovative builder is secondary benefit (Koebel et al. 2003) • Innovative product demand seen as risky (Slaughter 1993b, 2000) • Innovative product price volatility seen as risky (Slaughter 1993b, 2000) • Inadequate knowledge management and technology scanning seen as risky (Slaughter 1993b; Toole 1998) • Increasing productivity was positively associated with innovation (Koebel et al. 2003) • Increasing profit was negatively associated with innovation (Koebel et al. 2003) • Purchasing, design, and marketing departments have limited influence on adoption (Koebel et al. 2003) • Proinnovation business strategy associated with higher innovation (Koebel et al. 2003) • Higher cost presents most risk in adoption of innovations (Koebel et al.2003) • Operating in multiple markets reduces risks (Blackley and Shepard 1996)

(*Continued*)

Table 6.1. Distilled sources of builder risk (*Continued*)

Distilled sources of risk	**Literature references (For builder firm risks)**
Customizability (complexity of product)	• Complex product and subsystems increase uncertainty of adoption (Toole 1998) • Lack of systems integrator increases risk (NAHB Research Center 2001) • Complexity of establishing relative advantage increases risk (Koebel et al. 2003; NAHB Research Center 2001; Toole 1998) • Long time frame for production contributes to innovation resistance (Toole 1998) • Integration of products creates less risk (Slaughter 1993a)
Breadth of code compliance (extent of local and regional regulation)	• Operating in multiple markets increases opportunities for regulatory acceptance (Blackley and Shepard 1996) • Codes and regulations increase costs and uncertainty associated with innovation (Blackley and Shepard 1996; Slaughter 1993a; Toole 1998) • Builders do not necessarily see codes and regulations as a barrier to technology diffusion (Koebel et al. 2003) • Code barriers to innovation reduce risk in adoption of bad ideas (BTI 2005)

By increasing research and understanding from the builder's vantage, the centralization of information (as shown in Table 6.1) presents promising ways to increase innovation adoption and diffusion processes, previously causing builders to lag behind others in the supply chain.

6.9 BUILDERS' INNOVATIVE TRENDS

In fact, based on research produced over the last 10 years, the idea that the builder is lagging behind others in the housing supply chain with regard to innovation is changing. Instead of considering builders as innovation laggards, researchers are able to (1) use increasingly more robust data to analyze decisions builders make about the choice to adopt innovative technologies, (2) deploy best data management practices and analytical methods in processing these data, and (3) see more clearly the incremental innovations that have been made through products assembled or modified on-site by the builder. So, as data continue to be developed in detail and scholars are able to ask questions with new data, it appears that builders are not necessarily innovation laggards—especially with respect to green and energy-efficient technologies.

One emergent theme is the builder as a selective risk taker, echoing second mover advantage discussions by Koebel and McCoy (2006). A selective method emerges as one is continuously improving on what works, while the other is waiting for others to be first and capitalizing on the advantage of secondary adoption. As builders are also assemblers of innovative components, they are different brokers (organizations that do not originate or implement the final form of the innovation) than typically analyzed in information technology or other areas of innovation research. The builder as the assembler is not responsible for creating the innovations but rather identifying, economically and safely combining innovations that work together in systems to meet the needs of the end user. Such adoption decisions are influenced by market conditions, the availability of credit, qualified appraisers, climate, and a number of other complicating risk factors. Where innovations such as green certifications have been shown to increase mover advantage, such as market and performance risks in housing, builders are adopting these innovations. Often, such innovations are mature and beyond advantage for those first in the market, such as energy-efficient products.

6.10 CONCLUSIONS

In the previous chapter, we presented a broad review of uncertainty specific to the homebuilding industry and its supply chain stakeholders. We discussed a milieu for the industry, identified areas that increase uncertainty toward innovation adoption and diffusion and provided a list of stakeholder risks. In this chapter, we dove deeper into the uncertainty of residential construction innovation, introduced stakeholders that influence adoption along the residential supply chain, discussed the varying nature of the residential path to market, explored homebuilding products and their attributes that reduce uncertainty for stakeholders, examined specialty product and local market characteristics that influence adoption, and a commercialization strategy for residential construction products. At the end of the chapter, we further narrowed our focus to the central role of builder firms as a critical gatekeeper of innovation.

In conclusion, the builder as an innovation laggard may, at one time, have been a useful paradigm for the construction industry. However, where this paradigm often paints all builders with a broad brush, we find evidence that in some cases, builders are using more innovative products than traditional products (Sanderford et al. 2014). In fact, as building science scholars adapt best research practices from their counterparts in information technology (e.g., patent analysis—see Altwies and Nemet 2013; Johnstone et al. 2012; Johnstone, Hascic, and Popp 2010), the prevailing notion of the builder as laggard may begin to crumble.

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Policies, Programs and People That Shape Innovation in Housing

Andrew P. McCoy • Andrew R. Sanderford • C. Theodore Koebel • Carlos Martin

Businesses, consumers, industry groups, and governments understand the importance of innovation and the innovation process for continued economic success and improvements in quality of life. However, innovation remains an opaque topic. A paradox exists in housing at-large; using innovation is vital yet accounting for the value to individual organizations remains a challenge. This paradox is supported by a landscape that includes a sizeable graveyard of failed attempts at innovation on grand and small scales.

This book seeks to decrease the opacity of innovation processes in residential construction and housing. Along with the next book in the collection, this book addresses key questions pertinent to the potential for widespread diffusion of green buildings and for improvements in community sustainability. The overarching purpose of this book is to provide context and foundation for later books in the collection and to assist readers in peeling back the complex layers of innovation in housing and residential construction.

Andrew Sanderford, PhD, is an assistant professor at the University of Arizona in the College of Architecture, Planning, and Landscape Architecture. Previously, Sanderford was post-doctoral research fellow at the Virginia Center for Housing Research (VCHR), a research center within the College of Architecture and Urban Studies at Virginia Tech.

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