Building Even *Better* Homes:

Strategies for Promoting Innovation in Home Building

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Strategies for Promoting Innovation in Home Building

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Foreword

Technological innovation in homebuilding has been a research topic at HUD since the 1970s. The Department's statutory authority for building technology research is specified in Title V of the U.S. Department of Housing and Urban Development Act of 1970 which states, "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…."

HUD's most recent building technology program, the Partnership for Advancing Technology in Housing (PATH), was in operation from 1998 to 2008. PATH's mission was to collaborate with public and private housing industry experts to expand the development and utilization of new technologies that make American homes safer, more durable, and energy-efficient without sacrificing affordability. The 2003 PATH-funded report, *Building Better Homes: Government Strategies for Promoting Innovation in Housing*, examined the structure, characteristics, and motivations of major contributors and attempted to understand the institutional barriers in research and development (R&D), diffusion, and adoption of housing innovations. The report noted several critical activities that should be publicly directed and supported, such as sustained research support and identifying market trends and opportunities.

Building Even Better Homes: Strategies for Promoting Innovation in Home Building reevaluates the significant findings of *Building Better Homes*. The report uses history and experience as a guide for what role HUD might play in fostering building technology innovation in the future. The report documents prior efforts and what we learned regarding successes and failures.

Insights offered by this report can help HUD reenter the marketplace of housing technology innovation with a reasonable set of expectations for what we can and cannot do.

It arrives at a critical time. The past decade has brought forward three housing challenges in need of innovative building technology solutions:

- First, there is a critical shortage of both affordable rental and first-time homeowner housing in the metropolitan areas that are at the heart of economic growth; housing shortages risk stifling that economic growth.

- Second, we need more resilient housing that can withstand wind, fire, earthquakes, and floods. As insurance, state, and local funds are spent to rebuild communities, we must build so we won't have to rebuild again.

- Third, the United States has a growing wave of elderly households who need housing that is friendlier to the inevitable challenges of aging bodies.

We need a superhero, and that superhero is innovation. With innovation, we can build housing faster, at less cost, and of higher strength and quality. *Building Even Better Homes* offers ideas on how HUD can work with industry to foster this critically needed innovation.

Todd Richardson

General Deputy Assistant Secretary

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Contents

Executive summary

HUD requested an update to the 2003 RAND report, *Building Better Homes: Government Strategies for Promoting Innovation in Housing* (Hassel et al., 2003), from a team of researchers at the Urban Institute and Virginia Tech to better "reflect the current understanding and practice of innovation in housing while shifting the focus from Federal strategies to strategies across the board for promoting innovation in home building." The original report examined the structure, characteristics, and motivations of major contributors and barriers within the processes of the industry's research and development (R&D), diffusion, and adoption of housing innovations. In their analysis, the authors proposed a more realistic, non-linear innovation model that is appropriate to housing. The original report, however, refrained from extending such social science analysis into the domain of strategy and policy analysis, such as into the following areas.

- Mapping that model onto the menu of possible public-sector interventions—that is, ***what*** a housing innovation program could do.
- Identifying the context in which interventions exist—***why*** a program can succeed.
- Defining operational criteria for intervening—or, ***how*** a program should do it.

HUD commissioned that seminal monograph under its 1998–2009 Partnership for Advancing Technology in Housing (PATH). PATH was one of the research programs created during the boom years for the homebuilding industry at the turn of the 21st century, a unique time for how homes were built and maintained in the U.S. (Martín and Whitlow, 2012). The housing world has certainly changed since then, and federal policy interventions into the industry's means, materials, and methods must adapt as well.

Consequently, the Urban-VATech team produced the current report with 1) an exhaustive review of scholarly productions and media coverage regarding the housing innovation process and innovation rates that have been published since 2003; 2) an analysis of the industrial and policy contexts for past interventions; 3) the identification of core administrative and operational decisions that must be considered for public-sector investments in housing innovation or for promoting innovation within the private sector; and 4) outreach and feedback from housing innovation specialists and a wider stakeholder pool from industry and academia, leading particularly through a workshop held on March 29, 2018 at the Virginia Tech Research Center in Arlington, Virginia.

The resulting report follows the structure of the original RAND 2003 report while exploring the new areas of inquiry and integrating stakeholder feedback for HUD's consideration. A summary of the key findings from each of the report's chapters along with their implications for R&D investments follows.

Findings and recommendations

The discussion of possible strategies for public intervention in housing innovation is purposefully left to the end. As this report argues, the selection of detailed activities should be a natural output of the following.

- Documentation of the current state of the housing industry and its key stakeholders.
- Analysis of the barriers to and enablers of innovation in the industry, to serve as either the focal subject of an intervention or a guidepost for an intervention for a certain innovation type.
- An attempt at modeling the current innovation process for the technology in question, to help create a theory of change for the public intervention into that process.
- A review of political, policy, and industrial contexts to ensure the appropriate landscape of support for a proposed intervention.
- An objective assessment of operational capacity to implement the intervention.

The rush to select innovation projects or activities leads to failure.

Recommendation 1: A stakeholder interested in quantitatively or qualitatively improving housing innovation rates—or in assisting a specific innovation through commercialization—must take past lessons into account and accurately review current conditions across political, policy, industrial, technological, and operational factors for any future intervention's success.

The industry's significance

The industry's overall economic size and relevance to the broader national economy and employment—combined with the social importance and the financial value of homes for individual households—provided ample reason in the past to spur better housing (that is, housing performance and quality) and produce it in better ways (or, more efficiently and at scale). These same conditions exist today despite the precipitous drop in residential construction's share of the economy and overall production after 2008. Each of the industry's component sectors, however, has played a different role in these conditions. The post-2008 housing market has been marked by the proportional expansion of both single-family remodeling and the multifamily housing sectors, particularly in markets where additional single-family housing is untenable and those facing housing affordability crises. Neither sector has received as much attention in past housing R&D as new single-family construction.

Improvements in the means and methods of home construction continue to have many spillover benefits to the industry, home occupants, and to the nation. As such, the case for policy intervention is still strong. However, different industrial sectors and housing types have benefitted more to date.

Recommendation 2: Public R&D investments should reflect all housing sectors—including multifamily and remodeling of existing homes, as well as other industry players like insurers, energy auditors, and so forth—to maximize and distribute those benefits.

Barriers to innovation

RAND notes several reasons for policy intervention into the housing innovation process that reflect the broader policy scholarship's findings; in addition to the overall economic and social importance of housing to the country, redressing information asymmetries between manufacturers and builders and builders and owners remains a compelling justification for R&D intervention. The question of *how* to intervene remains. Addressing barriers along the path to innovation has been the intervention of choice in the past.

The status of traditional barriers to housing innovation varies. A few barriers persist and remain largely unchanged; for example, the way the boom-and-bust cycle of the housing industry affects private-sector capacity to invest in R&D and the stability of returns to investment, as witnessed in the recent housing recovery. Securing intellectual property also remains a challenge, as do the consistently diminishing resources for invention and innovation from all funding sources during the last 15 years.

Other barriers may be worsening, although the evidence is primarily anecdotal. First, the documented skill level of workers is substantially lower in residential construction than in other construction fields, and gaps in the supply of skilled workers are worsening. Product liability for manufacturers and builders also continues to plague the industry's openness to innovation, especially as many products are purchased from a global marketplace.

The substance of another group of barriers has qualitatively changed, although their effect on innovation remains unclear. Low barriers to entry into the industry traditionally led to questions about housing quality, but the costs of doing business have since increased and, in theory, so has the level of professionalization and organizational performance overall. The localized nature of housing construction throughout the homebuilding supply chain, between equivalent players in the same markets, and across geographic housing markets has produced a trifecta of structural fragmentation.

The recent housing recovery points to some consolidation in industry composition that alters the perceived barrier of fragmentation, as fluid transitions between small new single-family builders and other sectors are noted, and the market share for the large, corporate homebuilders has remained high even during the recession. Poor communication and information asymmetries are also a perceived hallmark of the industry; however, the internet has altered information access. Whether some builders continue as laggards, and whether information access increases in unbiased sources for content, remain to be seen.

In contrast, preliminary evidence indicates that a handful of other barriers may be diminishing or at least transforming. Building code approval for innovative technology is still costly, and the codes continue to be prescriptive about materials, means, and methods, but the near universality of code adoption has diminished the strength of building regulations as a deterrent to innovation. In fact, the increased stringency of some regulations, such as energy-efficiency, has even catalyzed some innovations. Low consumer demand for home innovations is another truism, although a few studies point to consumers' changing valuation of some housing performance improvements (especially energy-efficiency) and subsequent changes in stakeholder motivations in promoting them (such as in realty listings and appraisals).

Many traditional barriers to housing innovation persist, whereas others have waned over the last two decades. Still others have strengthened in their negative impact on the industry, including concerns regarding low labor skill, high product liability, and diminishing public-sector R&D commitments.

Recommendation 3: Stakeholders invested in minimizing barriers and improving innovation rates might focus on those that are already diminishing. Alternately, if a project's or program's goal is to grease the skids for a specific technology, then information gathering helps stakeholders efficiently navigate the barriers. In all cases, a periodic review of the state of the housing industry—supplemented by systematic data collection on impeding and enabling behaviors—helps to target resources effectively.

Evolution in the housing innovation process and rates

The research quantifying the state of innovation in the residential construction industry is still scant, although a few studies have focused on measuring rates across various innovation stages, including the diffusion of innovations (Koebel et al., 2015). However, recent studies suggest a more nuanced model of the "pipeline" is in order, compared with past generalized models, which do not account for the idiosyncrasies of a specific innovation's relevant technological performance area, supply-chain, market, costs (relative to both the technology it replaces, other technologies, and other functional performance areas), and consumers. These market characteristics affect the points where the innovation adoption decision occurs and, depending on their condition, could become either enablers or barriers to innovation.

Many brokers exist along the pathway of development for an innovation, and these vary by technology, geography, and the nature of local stakeholders.

Recommendation 4: Understanding the complex system into which any one housing innovation is introduced is critical for its development. When the interest is on a specific home performance topic, a more granular look at the relevant innovation process reveals a wealth of market information. Along with the periodic review of the housing industry, studies on the pathways to market of both successful and failed past technologies within the specific performance area could result in better evidence for future technology roadmaps.

A non-linear innovation model notes the peculiarities of each innovation's context and market, as explored in the few early studies that have been conducted in three residential performance areas: energy-efficiency, green building, and building information and manufacturing. Innovations in other performance areas such as disaster mitigation, moisture management, and accessibility appear in recent literature, but not in the context of the industry's innovation pipeline.

Contexts for intervention

Along with the scholarly literature, the researchers reviewed historical archives over the last half-century to better understand patterns across the political, policy, and industrial contexts in which the public sector has chosen to intervene in housing R&D and innovation adoption, and the success of those interventions. Three core patterns were identified.

1. Although political philosophies have differed around the level of public intervention for applied research, the record suggests that the philosophical argument in favor of intervention has dominated. In other words, public-sector housing innovation programs has been consistently supported since the 1960s, albeit with fluctuating attention and resources.
2. The policy contexts for past interventions are marked by a pressing national emergency or perceived societal urgency. A housing crisis (poor quality or affordability) or external danger (energy costs) are common rallying calls.
3. The industrial conditions in which stakeholders tended to call for R&D have typically been during periods of industrial growth—that is, when the housing industry has the financial and knowledge resources to innovate.

Political, policy, and industrial contexts shape housing innovation programs, and their conditions at a given time determine programs' existence. Political support of R&D for the sake of housing innovation alone—that is, without an explicit societal purpose—has led to short-lived innovation programs.

Recommendation 5: Focusing on a performance area that is economically or socially topical can help foment support across public and private actors and crystallize an intervention's goal and strategies.

Operational decisions

Before selecting any strategy for intervention into the housing industry's innovation process, making decisions based around core operational criteria is a fundamental step that is often overlooked in public-sector investments. The researchers reviewed the organization makeup of past programs and interviewed a purposive sample of past and current federal program officials to identify core operational criteria, which range from 1) executive support at the highest levels of public and private organizations, including appropriate and sustained financial resources matched to the strategies at hand; 2) institutional support for an investment's purpose within the public and private entities in which the strategies will be executed, particularly in relation to the competition for institutional resources and attention devoted to other goals and activities, such as program management in the public sector or profit in the private sector; and 3) functional operations such as skilled managers, knowledgeable staff, processes for ensuring R&D product quality, and a robust monitoring and evaluation capacity.

Operational constraints are as critical to an innovation program's design as the context in which the program is created and the selection of activities.

Recommendation 6: The mix of strategies should also be realistic. Setting visionary goals inspires public and private support, but not having the capacity to execute inevitably leads to failure. The failure comes both in terms of the specific innovation's progress, but also in the diminishing expectations for future innovation investments.

Policy strategies

After careful review of the above recommendations, public entities can select specific activities that best match the political, policy, industrial, technological, and operational conditions at hand. Numerous vehicles for public policymakers' intervention into industrial research have been documented.

1. Direct funding of basic research through established vehicles (like the National Science Foundation) or funding for applied research (such as that supported by the Department of Energy).
2. Technology transfer and demonstration programs in detailed cooperation with industry.

3. Supportive activities that strengthen the knowledge base, such as network building (convening, technology roadmaps, surveys, and market analyses, and so on).
4. Enhancing education, training, and information channels for professionals around innovation.
5. Using other public-sector programs or activities as leverage to spur innovation (such as requiring health and safety standards in assisted housing).
6. Creating end-purchaser financial incentives for innovative products, often tied to other housing determinants like mortgage credit markets, energy utilities, or tax policies.

The costs and complexity of strategies vary widely, and their ultimate impacts on innovation rates range from immediate catalyzing to longer-term institutional transformation.

Recommendation 7: A purposeful mix of strategies should be designed to match the innovation challenge. For example, if a policymaker wants to focus on a home performance topic that has received scant attention, activities that strengthen awareness of the topic and the knowledge development-dissemination network could be prioritized before undertaking direct funding, demonstration, skill-building, or incentive efforts.

Currently recommended strategies

The core objective of this report is to provide insight about what intentional housing innovation efforts have been, and how and why they have succeeded. Its desired output is to inform and guide the decision-making of housing technology stakeholders—but not to make those decisions for them. Ultimately, innovation is as much about the capacity to innovate as about a specific technology's wiring.

A cursory review of the current policy, industrial, and operational context suggests possible selections from among the strategy options presented in this report.

Recommendation 8: The review of current conditions corroborated by stakeholder input reveals a potential focus on disaster mitigation technology and improvements to indoor environmental quality (for example, "healthy housing") as current priorities. Stakeholders *recommend promoting existing technologies and using the opportunity to study their diffusion as a cost-effective approach. Five strategies HUD could employ now include.*

1) Convening key stakeholders and developing contemporary roadmaps for these two performance areas.

2) Promoting existing technologies in these areas at HUD events and through public information channels.

3) Integrating disaster mitigation and health performance standards into existing HUD programs.

4) Supporting data collection on innovative practices and behaviors to support other federal R&D programs.

5) Funding rigorous outcomes analyses of technologies' effects—such as mitigation techniques on disaster recovery costs or health home improvements on asthma rates—to monetize the value of innovation.

Conclusion

Residential builders and tradespeople are regularly but unfairly accused of being averse to any change from the status quo. Indeed, the industry boasts of its time-honored practices and intergenerational knowledge. In turn, its buyers hold long-standing cultural beliefs about the resulting "American Dream" of housing and the physical manifestation of what that dream represents. The historical record over the past century, however, refutes this theory. Innovation happens in the housing industry—just possibly not at an ideal rate or for an urgent purpose at a given time.

Overcoming perceived barriers to housing innovation and fostering conditions that enable it have posed challenges to policymakers and industry leaders for decades. The challenge for the private sector is to accelerate its innovation rate where the market demands, while keeping an eye on the future housing industry. For the public-sector agents that consider intervening in that process, the challenge lies in not rushing to fund projects when better results will come from undergoing a thorough review of the current housing context and its innovation challenges and an honest self-assessment of organizational and operational capacity.

Ultimately, technology champions who are capable of this reflection are within product manufacturers' laboratories, at homebuilding and remodeling sites, in universities, and, indeed, in governmental offices. This report hopefully has given them reason to persist.

Introduction

C. Martín

Innovation matters. Despite the persistence of the American home's appearance and craftsmanship as symbols of tradition and stability, what lies behind its walls—and how it got there—has undergone a quiet revolution over the last two centuries. From the light wood framing structures of the late 1800s, through the industrialization of post-war construction assemblies, to the turn-of-the-21st century's energy-efficiency movement, air and moisture dynamics, and advanced building information modeling and fabrication, U.S. residential design, construction, and operations have been anything but static.

Despite noticeable qualitative and quantitative improvements in the housing industry's products and the operational and technological processes for fabricating them, the housing industry is "often described as having many characteristics that challenge the development and deployment of innovations" (Hassel et al., 2003: 1, referred to as RAND, 2003 here on).

Consequently, scholars have argued for decades about the meager private investment in building technology research and the fragmented nature of its incremental innovation necessitating public intervention (Tatum, 1986; Slaughter, 1998; Toole, 1998). The innovation chasm is especially true for residential design, construction, and operations (Koebel et al., 2004; McCoy, Sanderford, Koebel, and Martín, 2015). Housing makes up most of America's capital stock and built environment, yet receives scant private or public research and development (R&D) attention. The bottleneck has repercussions down the innovation process; it can purportedly take 10 to 25 years for a new technology to achieve full market penetration (Goldberg and Shepherd, 1989). Often, it takes that much time to simply introduce an innovation and develop credible information around its benefits (NRC, 2001).

Several attempts have been made to rectify this situation, including those put in place 15 years ago, during the height of federal housing technology investments. Most federal efforts pursued interventions around specific performance areas; residential energy conservation and efficiency, for example, has received the bulk of federal investment in housing innovation through such research and dissemination programs as the Department of Energy's (DOE) Building America, Better Buildings Challenge; Zero Energy Ready Home program; and, with the Environmental Protection Agency (EPA), ENERGY STAR program (Hassell, Florence, and Ettedgui, 2001; NRC, 2001).

However, these programs have grappled with understanding where the seed of an innovative idea sprouts, how it grows, and when it bears fruit in the form of the industry's mass adoption and diffusion across American homes. Attempts to articulate the housing innovation process borrow from the general technological literature (Rosenberg, 1994; Rogers, 1995) while tailoring these models of the process to the housing industry. RAND, among other scholars, blew the previous traditional model of the innovation pipeline up by arguing that more iterative feedback loops and wider, more varied sources of innovation exist. Further research is beginning to understand how to apply the model for a specific technological type and context.

With the 1998 Partnership for Advancing Technology in Housing (PATH) housed in HUD, the U.S. government chose to explore the *process* of residential technology innovation and not just its products' performance. PATH promoted the industry's various innovation processes, provided seed federal investments with industry partnerships, and supported information exchange between the housing supply chain and consumers (NRC, 2003b).

Federal programs like PATH attempted to transform the operations and motivations of builders and material suppliers toward innovation, especially single-family housing. The idea was an industry stereotyped as fragmented, parochial, and technologically stagnant could, arguably, transform into a more agile, innovative, and competitive force across firm types, sectors, and regions (Koebel et al., 2004). Coincidentally, these programs were created during the boom years at the turn of the 21st century, a unique time for how homes are were built and maintained in the U.S. (Memari et al., 2014). Consumers' intensifying reliance on homes as financial assets spurred an ever-expanding demand for new housing. Home builders, the building trades, and product manufacturers were eager to satisfy this demand. However, the housing world has changed since then, and federal policy interventions must adapt.

The PATH-supported report—*Building Better Homes: Government Strategies for Promoting Innovation in Housing* (RAND, 2003)—confirmed this approach. The seminal monograph examined the organization, characteristics, and motivations of major contributors (and barriers) to housing innovation. By proposing a realistic, non-linear innovation model more appropriate to housing, the report also influenced other efforts; DOE and EPA leadership immediately referenced the report, and it was cited in 33 books, journals, international reports, and dissertations. The RAND report noted several benefits—and beneficiaries—from housing innovation. From safer, potentially more affordable, and higher quality living environments for occupants to increased professionalization among builders and tradespeople, innovating in housing involves many stakeholders. Changes in the literal bricks and mortar of residential properties have multiple outcomes, as is seen in the past record of public efforts to catalyze the industry's means and methods.

Past is prologue. Almost 15 years after the report was published and nearly 10 years since PATH ended, questions about the housing innovation process have resurfaced, more specifically, about public intervention in that process, as budgetary cuts and mission revisions are proposed to all remaining housing technology programs. In this context, HUD partnered with the Urban Institute and the Virginia Tech Housing Research Center to reevaluate the major findings of the [RAND] work, the federal strategies it suggested, and develop a broader set of strategies for promoting innovation in home building.

Study Overview and Objectives

If the housing industry today differs from the industry at the time of the RAND publication, then we must further revise the model of the housing innovation process to account for those changes. The primary objective of this report is to reassess the RAND work considering these remarkable changes in the housing industry, particularly since the effect of the 2008 recession on the market and subsequent industrial and policy transformations, to set forth decision-making tools and strategies for the contemporary age. The researchers affirm the broader definitions of housing technological innovation and the proposed model of the innovation process the RAND report put forth as a foundation for this work. However, the project contributes to RAND's findings in the following ways.

- Describing the current state of innovation characteristics (enablers and barriers) from which RAND devised its model.
- Reviewing the state of literature and professional practice since 2003 on housing innovation to identify variations on the RAND innovation model, especially in relation to different housing performance areas, technological disciplines, and market requirements.
- Tracing the industrial and policy contexts from past governmental interventions in the housing R&D stages and documenting their institutional and operational components to note when and where innovation program strategies have been most effective.
- Proposing additional needs assessment guidance and criteria for making decisions about the public sector's current and future investments in housing innovation.

Methodology and Report Organization

The research team performed four core activities to meet these objectives.

- The team analyzed secondary national data regarding the housing industry's organizational composition and characteristics regarding innovative capacity to update RAND's analysis with post 2003 trends and with additional evidence to assess the traditional theories about housing's innovation rates. Information about the industry's general economic importance and significance in other areas for the country are presented in Chapter 1, while detailed descriptions of the industry's composition follow in Chapter 2.
- The researchers conducted an exhaustive literature review of monographs in both peer-reviewed publications and professional journals to determine variations to the RAND-proposed innovation model. The review followed intensive steps: from broad searches of bibliographic archives based on documented tags; to an annotated bibliography noting a monograph's primary findings and underlying rigor; to the final, synthesis literature review narrating the key findings across themes and bibliographic categories. The resulting exploration of the RAND model's generalizability is presented in Chapter 3.
- Like RAND's review of past federal efforts to promote housing innovation, the authors reviewed key moments over time in which various agencies embarked on R&D or commercialization programs explicitly aimed at housing applications. In contrast to the RAND report's description of these programs' general activities, however, this report's Chapter 4 focuses on the industrial and policy contexts in which past programs were launched to identify the policy and program decisions. Defined as either being highly-funded and long-running or as having significant outputs (such as number of housing units affected), successful housing R&D programs are noted by general contextual patterns, although any program's existence with executive or legislative acknowledgment could also be described as a success in housing innovation policy.
- Chapter 5 operationalized all the above lessons for current public and private researchers. First, the authors reviewed the components or "ingredients" that marked past efforts to provide a programmatic menu for implementing any future strategy. Second, the policy and program strategies RAND proposed were revisited, with additional lessons from other applied research programs as well as a review of the current feasibility for those strategies. The researchers also solicited external input from a core group of scholarly advisors and practitioners, as well as a wider open stakeholder pool, to identify current research priorities

and preferred strategies. Finally, the researchers drew a basic decision tree for interventions in future scenarios for which housing R&D interventions may be called.

- The conclusion briefly summarizes the core argument that RAND's innovation model, though fundamentally accurate, varies based on the technology performance subject (as noted in Chapter 3) and the underlying policy and industrial context (Chapter 4). Future decisions to invest in housing R&D must adopt this new model to specific contexts and assess the feasibility of core operational components and decisions before selecting the strategies.

Report crosswalk

In updating the original RAND report, the team has purposely reformatted the content to distinguish background information from new findings. The following table summarizes the format and information presented in both the original report and this revision (table 1).

TABLE 1

Crosswalk of RAND 2003 and Current Report

URBAN-VA TECH 2018		**RAND 2003**
Chapter Title	*Shared Questions and Content*	*Chapter Title*
Introduction	*Why this report now?* Introduction to Housing Innovation Study Overview & Objectives	1. Innovation in Housing
I. The Home Design, Building and Remodeling Industry: 15 Years Later	*Why does housing innovation matter?* Introduction to the Industry U.S. Housing Industry's Importance	3. The U.S. Housing Industry as the Context for Innovation
II. The Industry's Innovative Characteristics and Motives	*Is housing innovative?* Characteristics and perceived barriers and enablers to innovation in the housing industry	4. Industry Characteristics and Motives and Their Effect on Innovation
III. The Evolving Housing Innovation Model	*How does housing innovate?* Literature review on housing innovations, the innovation process and rates, and the innovation model	2. The Concept of Innovation in the U.S. Housing Industry
IV. The Contexts of Past Federal Efforts for Technological Innovation in Housing	*How has the federal government intervened in the past?* Historical review of past federal interventions into the housing innovation process	5. Federal Efforts to Promote Innovation in Housing

V. Operations and Strategies for Promoting Technological Innovation in Housing	*How can the federal government intervene in the future?* Primary components and available strategies for future interventions	6. Federal Strategies for Promoting Innovation in Housing

I. The Home Design, Building and Remodeling Industry: 15 Years Later

C. Martín

Today's housing industry is qualitatively different than when HUD last explored housing innovation strategies15 years ago. The researchers reviewed secondary economic and production data for the housing industry to explore whether its national importance continues to justify pursuing improvements in its technology, and to answer questions about why housing innovation challenges matter in general and now in particular.

Key Observations

The Industry's Significance

A central premise of all investments in housing technology innovation is that the industry's overall economic size and relevance to the broader national economy and employment—combined with the social importance of the industry's products, or homes—provide ample reason to spur better housing (that is, housing performance and quality) and produce it in better ways (or, more efficiently or at scale).

The premise continues to hold true despite economic contractions during the last decade. Housing continues to be a significant economic output for the country and a financial and social input for individual households. The sector is critical in many physical ways, as well—for example, as a primary contributor to energy use and environmental impacts and as a first line of defense against natural hazards. Housing quality and health are increasingly known to be linked. However, the costs of producing and buying homes, especially in regions with high growth, have skyrocketed.

Despite the precipitous drop after 2008 in residential construction's share of the economy, the housing industry continues to remain a significant economic contributor and a determining factor in the U.S. economy and in the financial well-being and other *outcomes of American households. Returns from investment in housing innovation remain high.*

Sectoral Differences

Much of the pre-2008 growth and expansion in the U.S. housing industry came from the single-family sector. Consequently, much of the investment in technology R&D had primarily, if not exclusively, focused on this sector. The post-2008 housing market has been marked by the proportional expansion of both single-family remodeling and the multifamily housing sectors, particularly in markets where the expansion of additional single-family housing is untenable and those that face housing affordability crises.

Many small builders in remodeling and large builders moved into multifamily development during the bust, constituting sectors that may be ripe for innovation and have some record of adopting radical product innovation (remodeling) or transferring technology from the more historical innovative commercial building sector (multifamily). Neither of these sectors received as much attention in past R&D as new single-family construction.

The U.S. Housing Industry Today

Although prescient, the RAND report's authors produced analysis reflecting their specific moment in history. The exuberance of the housing market in 2003 and the preponderance of public and private investments in technologies suggested a limitless appetite for change and growth. The authors' focus consequently fell on identifying and selecting the most efficient and effective mechanisms to harness that change, and not on the economic, political, and cultural conditions that enabled those mechanisms.

By all counts, the current residential construction industry is dramatically different than it was during those "boom" years. The post-2007 recession and market crisis—the "bust" year—slowed the industry's evolution in ways that had both positive and negative consequences on technological innovation (Acharya and Richardson, 2009; Mayer, 2011). Private R&D investment plummeted as an obvious consequence of reduced sales, with public symbols like the closing of the Pulte prefabrication plants in 2007 marking the end of an innovative era (Mullens, 2008). Just *how* has the industry changed?

The homebuilding and remodeling industry at the time of the RAND report was qualitatively and quantitatively different than the industry of just a decade before, and it differs from the industry today. For example, across housing sectors and types—particularly between new and existing homes, and single-family and multifamily housing—things have shifted overall. However, the housing industry is still important to the overall U.S. economy and to specific states and cities with growing populations in numerous ways.

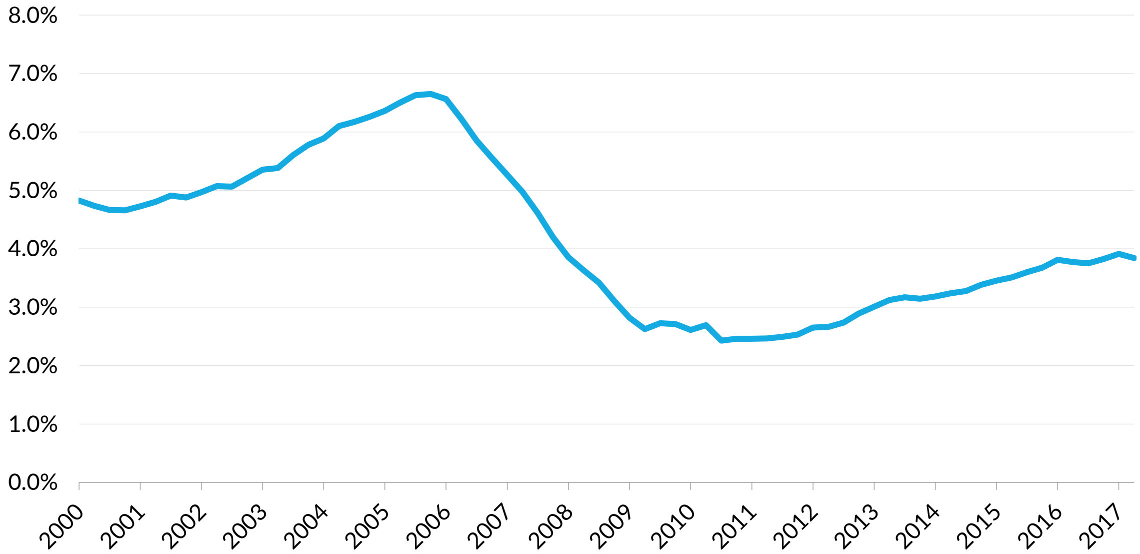
Economic Importance

The residential construction industry has historically played a significant role as a share of the U.S. economy. Since the Great Depression, residential construction (including all fixed investment but excluding residential services and finance) averaged almost 5 percent of national gross domestic product (GDP). Residential fixed investment as a percent of GDP exceeded 6 percent for the first time since the immediate post-war years in early 2004, just 1 year after the RAND publication.

However, after reaching a period high in late 2005, residential fixed investment's share of U.S. GDP dropped precipitously because of the recession, falling below 3 percent in late 2008 for the first time in the last half-century (Figure I-1). The steep drop during the recession was notable not just because of the highs that immediately preceded it, but also because of the extent of the lows reached. Since the recession, residential fixed investment has been recovering slowly, flattening around 4 percent since early 2016 but still significantly below rates during the boom years.

FIGURE I-1

Residential Fixed Investment as Percent of GDP



Source: Bureau of Economic Analysis

This sum accounts only for direct investments in new residential construction, remodeling, and equipment installation, and not the many economic spillovers that this activity has for housing finance and mortgage transactions, rents, utilities, appliances, and furniture purchases. These activities combined historically averaged 15 to 20 percent of U.S. GDP in the post-war era compared to the 5 percent which is only direct construction activity. The contraction then had many negative compounding effects beyond construction into other industries.

The residential construction industry's importance is also remarkable geographically, with housing playing a larger local economic role in certain states and metropolitan regions marked by high population growth and household formation, such as in the high-growth states of Nevada, Arizona and Florida that experienced the highest number of housing starts during the housing boom. These states relied heavily on the housing industry to bolster their regional economies. Local population growth shapes the housing market as much as local design and material traditions and building regulations shape technologies.

Changes in the number of individuals working in the residential construction industry tell a similar story about the industry's evolving importance and impact on the overall economy. Employment follows a pattern like that of the changes in residential fixed investment since 2000. During the boom, employment in residential construction steadily increased until hitting a peak in 2006, at which point more than 1 million individuals were employed by the industry and 2.5 percent of all non-farm employment was in the residential construction industry, per U.S. Bureau of Labor Statistics records. With the bust, however, employment dropped among residential building establishments below 600,000 in late 2009. Since 2012, employment has been steadily rising, and has almost reached early-boom levels.

As the industry regains some of its pre-recession momentum, headwinds associated with key industry inputs—particularly material and labor availability and costs—have held back the growth rate. Increasing costs for these inputs exacerbate the effect of the longer-standing issues with availability and cost of developable land and its associated regulatory compliance (Terner Center, 2018). Framed by fundamental changes in international trade policies, national immigration rates, and workforce training programs, some believe these concerns likely constrain housing production across all sectors for years to come (NAHB, 2018). These specific inputs—materials and labor—implicate the potential for technological innovations that can serve as substitutes.

In short, the housing industry still plays a critical role in U.S. economic production and the nation's overall employment despite the housing crisis and ensuing recession. Residential construction plays a stabilizing role in the U.S. economy as it does in most other high- and middle-income nations, especially those with expanding populations (Bon, 1989). The size and importance of the housing industry, then, makes it too big to fail for the U.S. economy in so many ways. Although not as vigorous as at the height of the boom yet, the housing industry's importance suggests investment in its innovation processes is economically justified. Given recent trends in other construction inputs, that investment may also be necessary.

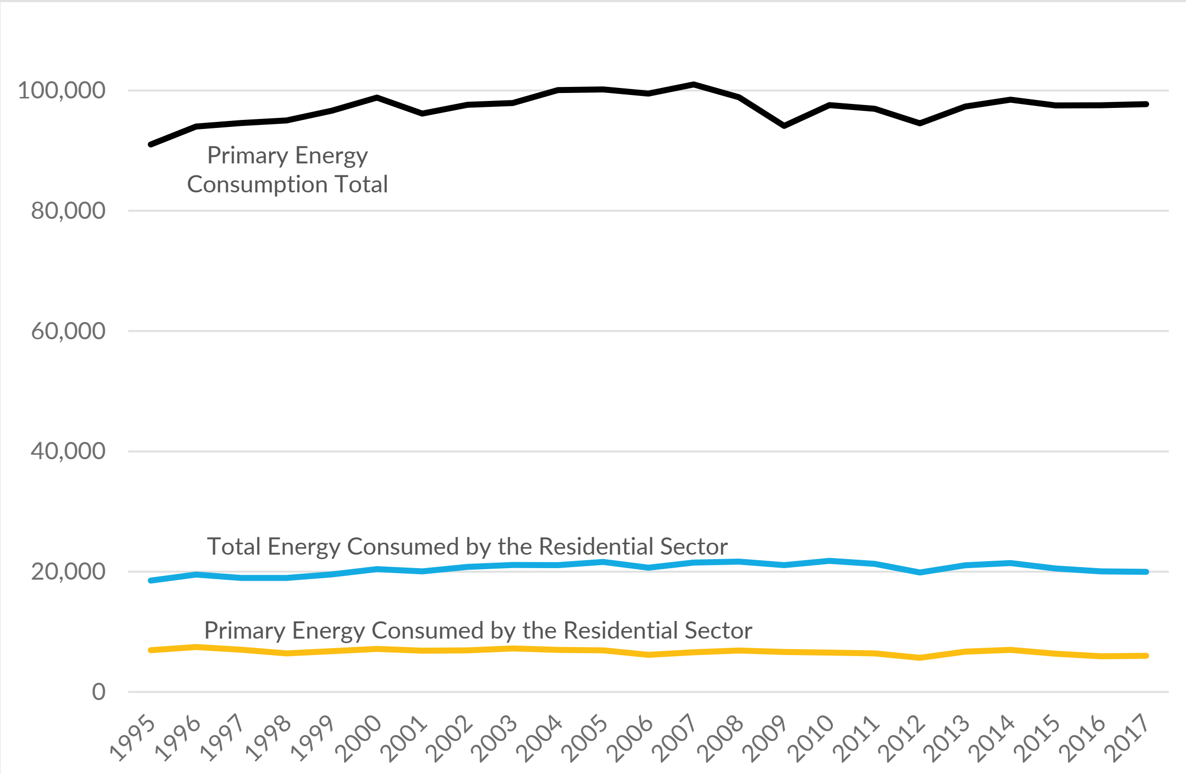
Other Significance

Housing encompasses a large share of many other nationally important activities that have undergone some change in the last few decades beyond its economic worth. Housing's role in financial asset-building for individual households has been a core justification for ongoing homebuilding and remodeling for decades, for example (Oliver and Shapiro, 1995, Herbert and Belsky, 2008). Overall, the physical quality of the housing unit contributes to that asset's value.

Other ways in which housing and its physical quality shape larger outcomes center on the industry's environmental impacts. For example, the residential sector accounts for almost 28 percent of energy consumption in the country, with older, less energy-efficient homes consuming a higher proportional share (Figure I-2). The aggregate energy impact of the housing sector has been relatively steady for the past few decades as efficiency improvements through both environmental regulations and voluntary programs (for example, more stringent energy-efficiency codes) offset housing growth.

FIGURE I-2

U.S. Energy Consumption (Trillion BTU) Overall and by Residential Sector, 1995–2017



Source: Energy Information Administration

In turn, the residential end-uses account for about 19 percent of the country's greenhouse gas emissions that contribute to global warming, per the U.S. Environmental Protection Agency (EPA, 2018). Housing and other construction sectors also consume a massive share of natural resources, estimated at 40 percent of all industrial uses of raw materials (EPA, 2016). New building and remodeling or demolition of existing buildings contribute the most solid waste in the country—almost twice the amount of other municipal solid waste sources combined. Indoor environmental qualities like air pollutants, toxic materials, and the presence of pests are also known to significantly contribute to human health (Sandel, 2000, Jacobs et al., 2009).

The mental and cultural importance of housing qualities to households are also important. From the stabilizing effects of permanent housing to housing's cultural repercussions for community and familial relations, gender roles, and life outcomes (Wright, 1983), the multiple ways in which housing is significant extend beyond, but include, its contribution to GDP.

Some recent studies question the asset value of homeownership in the post-recession era (Herbert, McCue, and Sanchez-Moyano, 2013) in particular. However, the preponderance of evidence suggests that housing remains a critical contributor to household financial, health, and social outcomes and, collectively, to environmental impacts as well as to national economic output. The housing crisis and recession shifted this standing but did not diminished it.

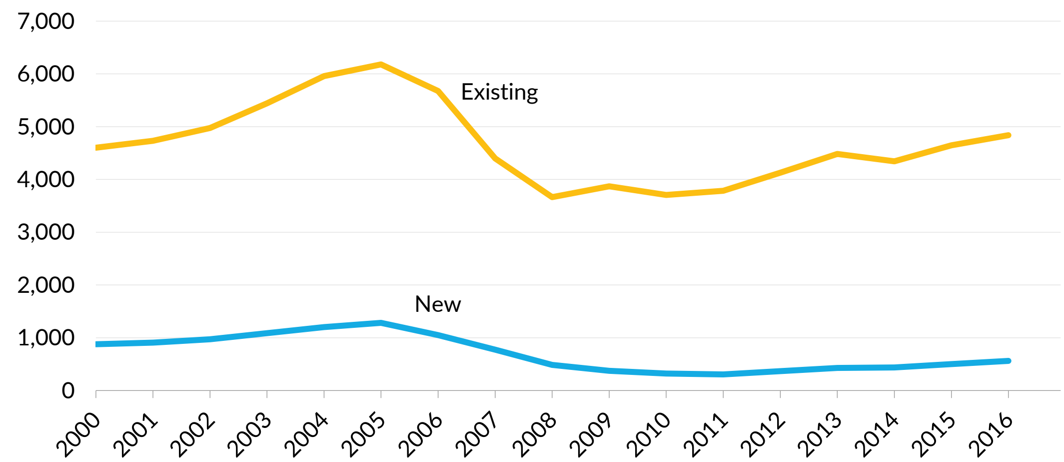
Housing sectors

The geographic, market sector, and supply chains of housing also matter when defining the industry's importance. Where housing design and construction activity occurs; who purchases those services and products; and what skills and techniques are needed by the builders all partially determine and are determined by the density and height of construction and its geographic placement. For example, major U.S. cities are facing housing affordability crises because of their inability to produce more housing and, consequently, to use more advanced technologies to produce the housing quickly and efficiently. Indeed, what is not clear is how the housing stock's various products (single-family versus multifamily) and activities (new construction versus remodeling) will evolve and redistribute proportionally.

Since 2003, the current need for housing production across all sectors is evident as rents rise and sales of both new and existing units increase during the ongoing housing recovery (Figure I-3). The recession had an impact on single-family sales of both new and existing housing units. From 2005 to 2008, sales of existing single-family housing units dropped by about 41 percent, and sales of new single-family housing units dropped by about 62 percent in the same period. Both have been steadily recovering since 2010.

FIGURE I-3

Single-Family Sales, New vs. Existing Housing Units (thousands)

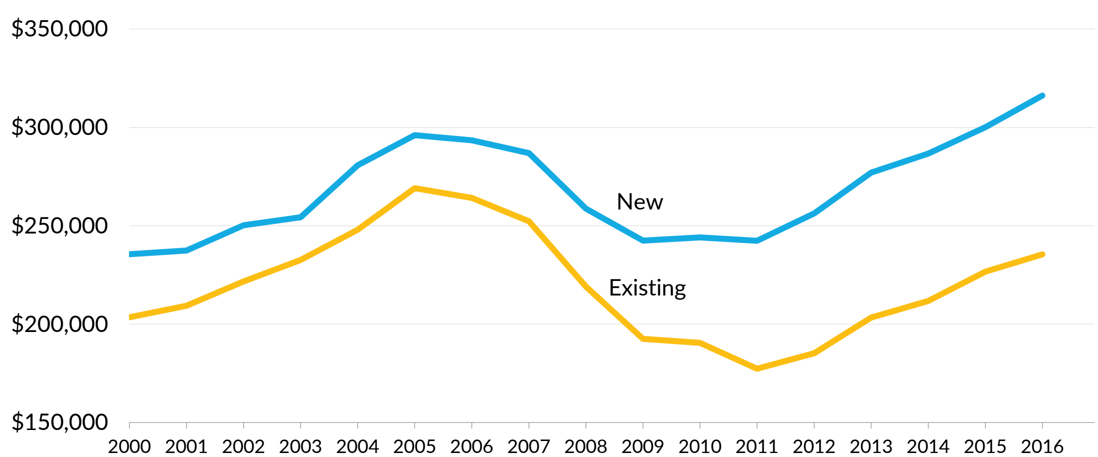


Sources: New sales obtained from U.S. Census Bureau New Residential Sales data. Existing sales obtained from the Joint Center for Housing Studies of Harvard University's State of the Nation's Housing 2017 report.

The recession also impacted the median sales price of single-family homes, for both new and existing housing units (Figure I-4). The median sales price for new single-family homes decreased by about 18 percent from 2005 to 2009, and for existing single-family homes, the median sales price dropped by about 28 percent during the same period. The recovery in housing costs has been robust for both housing tenured types, however, surpassing their "boom" sales prices in many sectors.

FIGURE I-4

Median Sales Price of Single-Family Homes, New vs. Existing (2016 dollars)



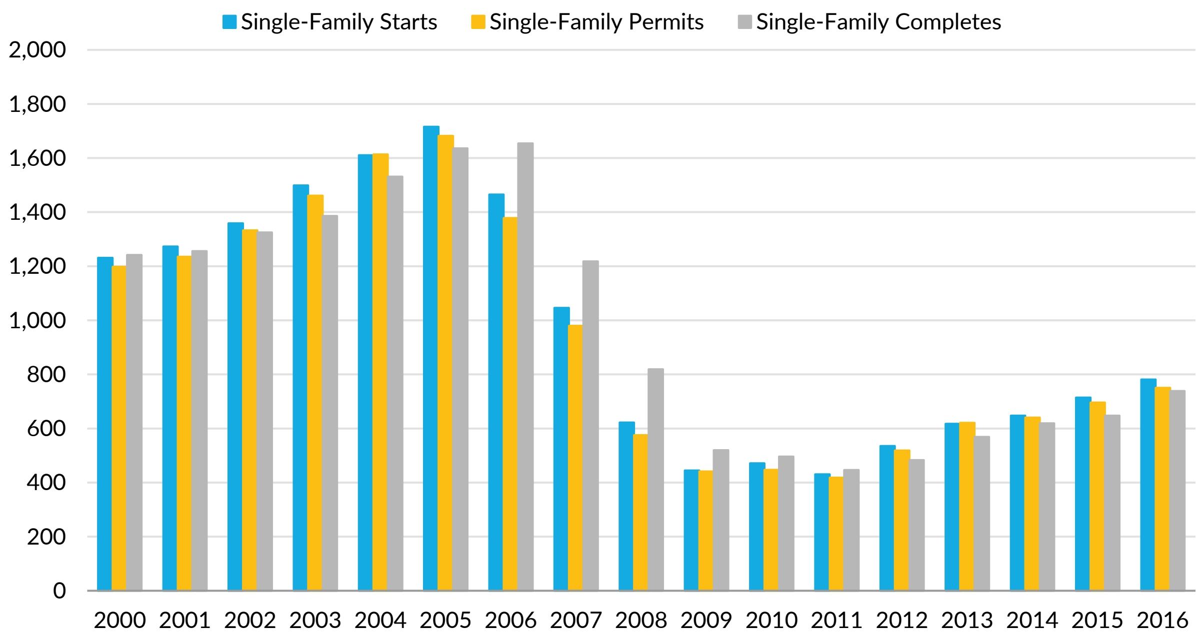
Sources: New sales obtained from U.S. Census Bureau New Residential Sales data. Existing sales obtained from Harvard University's Joint Center for Housing Studies' State of the Nation's Housing 2017 report.

The construction of new single-family homes, the touchstone of the U.S. housing industry, was hampered by the recession but has steadily been recovering since 2011. In absolute terms, however, this recovery is still far below the production levels of the pre-boom years (Figure I-5).

FIGURE I-5

Number of Single-Family Starts, Permits, and Completes

Number of housing units in thousands.



Source: U.S. Census Bureau, New Residential Construction

Remodeling is a sector with significant economic importance but also many technological challenges, for both professional and do-it-yourself home improvements. Because of the unique state of each home, it is typically difficult to leverage new technologies and reach the economies of scale needed to reap returns on the investment in remodeling innovation.

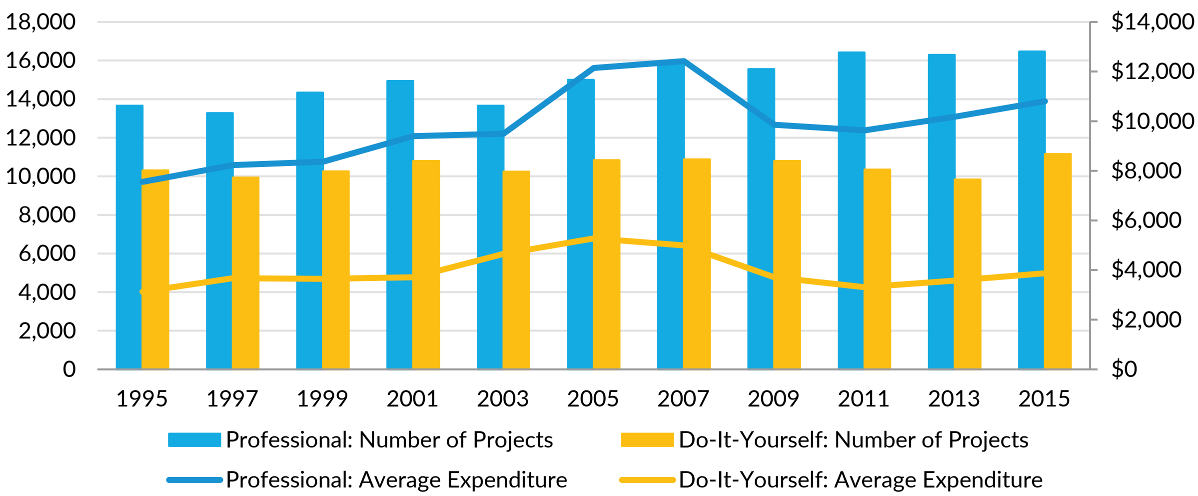
Despite this challenge, the remodeling sector was also the one many scholars projected to grow during the recession as households' motivations to purchase and move diminished during the recession. From 2007 to 2009, total expenditures across all remodeling projects for professional improvements decreased by about 22 percent but have increased since then (JCHS, 2017. The recession seems to have had a longer and more significant effect on do-it-yourself home improvements, as total expenditures in this sector across all remodeling projects decreased by about 37 percent from 2007 to 2011.

The number of projects across both professional and do-it-yourself home improvements, though, has been relatively consistent from 1995 to 2015 (Figure I-6). However, the average expenditures for professional and do-it-yourself home improvements were both affected by the recession; from 2007 to 2011, the average expenditure decreased by 22 percent for professional improvements and by 34 percent for do-it-yourself home improvements. The varying scale of projects from 1995 to 2015 show that remodeling continues to be a very project-driven industry, posing challenges to innovations that can be standardized for an industry with so many small projects.

FIGURE I-6

Average Expenditure and Total Number of Remodeling Projects (Professional and Do-It-Yourself)

Number of projects in thousands. Average expenditure in 2015 dollars.



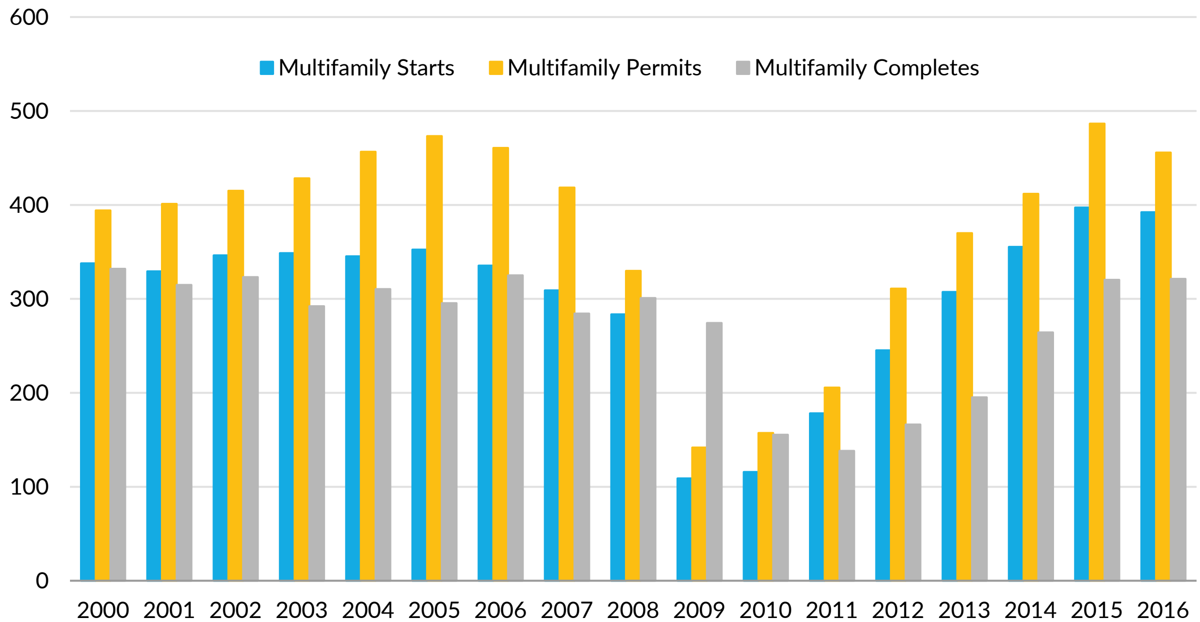
Notes: Expenditures adjusted for inflation. 2013 tabulations use JCHS-adjusted weights, 2015 tabulations use HUD weights.
Source: JCHS tabulations of the Department of Housing and Urban Development (HUD), 1995-2015 American Housing Surveys

Some remodeling project categories fared better than others during the recession (JCHS, 2017). From 2005 to 2011, the total expenditures for room additions, including both professional and do-it-yourself improvements, decreased by more than 60 percent. The exterior improvement category (including siding, roof, and painting) experienced a slight dip in total expenditures from 2007 to 2009, but then increased to finish off in 2015 with more total expenditures than any other remodeling project category. Systems and equipment projects (often for mechanical, electrical, and plumbing remodeling) also have been on the rise; by 2015, this project category ranked as the second total after exteriors. According to American Housing Survey data, the absolute number and proportion of energy efficiency and accessibility improvements have been steadily increasing over the last two decades.

Along with remodeling, the multifamily sector was one predicted to gain in importance because of the recession. As with single-family production, multifamily production diminished during the recession, but since 2010 has regained the levels of the boom years (Figure I-7). Rising rents and increased demand for more rental properties, along with enough regulatory freedom to produce multifamily units in key growth regions, contributed to this sector's growth in relation to new single-family construction.

FIGURE I-7

Number of Multifamily Starts, Permits, and Completes (thousands)



Source: U.S. Census Bureau, New Residential Construction

Overall, the distribution of market sectors has altered, establishing the need to consider alternative sectors' innovation processes. In 2003, 83 percent of completed housing units were in single-family structures. By 2015, that proportion had decreased to 67 percent. The increasing proportion of multifamily starts suggests a focused opportunity for R&D in the near term, given the historical transferability of technology from the more innovative commercial building sector into multifamily construction. Similarly, many small builders moved into remodeling during the bust (NAHB, 2015), constituting another housing sector ripe for innovation with a record of adopting radical product innovation (Koebel et al., 2004), but has received scant attention in boom-time R&D programs.

Implications for Innovation Policy

Residential builders and tradespeople are regularly but unfairly accused of being averse to any change or departure from the status quo. As an industry that boasts of its time-honored practices and intergenerational knowledge—and one that manufactures a product that buyers often associate with long-standing cultural beliefs about design and physical function—it is argued that housing is tradition-bound (Wright, 1983). The historical record over the past century, however, refutes this theory. Builder and remodeler practice surveys track the consistent adoption of new technologies and practices to both satisfy market demands (product innovations) and satisfy them efficiently (process innovations). The challenge for the industry is not why it should innovate, but how to expand and accelerate the innovation rate. For the public sector, the challenge is in directing the investments in accelerated innovation rates into areas which will reap the most societal benefits—such as in increased housing access and affordability or reduced environmental and health effects.

Understanding the industrial and policy context in which housing R&D discussions arise is a central principle and task of this update to the RAND report. Three primary themes arise from the review of the housing industry since RAND's 2003 publication that should be considered in contemporary decisions regarding investments.

First, the housing industry continues to be a sizable component of both overall economic production and employment in the United States despite the 2008 recession and its detrimental effects on the market. The industry's economic importance is particularly notable in local markets with continued population growth and new household formation. The industry's ongoing importance provides a compelling justification for investment in its materials, means, and methods as much now as it did in 2003.

Second, the post-recession recovery continues. Although overall production has not reached the peak levels of the early 2000s, a consistently upward swing is evident. As later historical reviews will suggest, periods of expansion present opportunities to the housing industry for the investment of financial and knowledge resources, and the market in which to apply innovations.

Finally, the ongoing recovery highlights the importance of various sectors in the housing construction industry—such as single-family remodeling and new multifamily construction—where production has fluctuated in relation to the new single-family sector that has historically received most of the focus of past housing R&D. The increasing size of these sectors (and occasionally proportionally larger size to the new single-family market) suggests a ripeness for expanding investments in innovation to cover a wider swath of American housing. These sectors are not new to change; for example, multifamily housing has a history of transferring structural modeling and building envelopes from commercial building. In contrast, remodeling involves site constraints that in theory promote bespoke creativity but impede the diffusion of its fruits.

In short, the significance of housing—economic and otherwise—merits a deeper look behind the walls. Investments in design and technology innovations, in turn, are likely to yield benefits from that are real and realistically achievable. As one study suggests, technological investments alone could produce double-digit improvements in construction productivity (Barbosa et al., 2017)—a pressing goal for a nation with a massive housing shortage, persistent housing unaffordability, and dire land and environmental effects that remain unaddressed.

II. The Industry's Innovative Characteristics and Motives

C. Martín

Prior literature in the sociology, economics, and management of construction technology has produced a litany of industry characteristics and structural conditions that have been deemed as barriers to the industry's capacity to innovate—that is, these factors frame *why* industry stakeholders choose to or choose not to innovate. These characteristics have become dogma among scholars, with limited review of their effects across time and geographic market. In the current age of housing, however, stakeholders and characteristics that enable or inhibit innovation should, in theory, fluctuate.

To identify the best strategies for accelerating innovation rates or qualitatively improving innovation processes, we must first explore which factors contribute to the industry's innovativeness. In this chapter, the researchers look at both scholarly literature and industry studies to assess the state of innovation overall, and to revisit the discussion of previously identified barriers to and enablers of innovation in the housing industry.

Key observations

This report categorizes the historical innovation characteristics within the housing design, construction, and remodeling sectors into three groups.

1. Barriers to innovation well-documented in the past that have continued to have the same strength and persistent, negative impacts on innovation capacity and rates since the recession.

2. Characteristics that have changed qualitatively since the recession but whose resulting impacts on home innovation remain unclear.

3. Barriers that appear to have diminished in recent years and, in some cases, appear to have become enabling characteristics for innovation.

The housing industry characteristics associated with preventing or enabling innovation have changed over time, although early studies suggest they were obdurate. Evidence of an increasing and intentional consumer demand for housing innovation, albeit limited to certain performance categories like energy efficiency, where the conventional wisdom in the past suggested otherwise, is an example.

The first group of historical industry characteristics are those that appear to remain in place today as significantly as when they were documented two decades ago, and with the same generally negative effect on innovation rates. Several past innovation barriers persist and remain largely unchanged. For instance, the extreme boom-and-bust cycle of the housing industry affects both private-sector capacity to invest in R&D and the stability of returns to investment, as witnessed in the recent housing recovery. General gaps in securing intellectual property also remain, although these may be attributable as much to the costs of securing it (such as patent filing and enforcement) as to the nature of the property being secured. Finally, reductions in the public investments in housing R&D meant to compensate for private-sector gaps have continued and are likely to further diminish given current budget projections.

Many structural barriers to housing innovation persisting today remain beyond the control of the housing industry itself, including macroeconomic, legal, and political factors for which no ready private-sector interventions or public-sector programming exist. The industry's boom-and-bust cycle is the most known; as predicted by past studies, the 2008 recession appears to have dampened internal R&D functions among homebuilders.

The second group of industry characteristics, contrary to the dominant assumption in construction literature, demonstrate change either for the better and for the worse. These conditions are recent and not sufficiently measured. Consequently, the extent of their change and the subsequent direction and magnitude of their effect on innovation remain unclear.

Within this broad second group of industry characteristics, a few barriers may have continued to grow worse, and are likely to reduce innovation capacity further. However, the available evidence is primarily anecdotal. For example, the documented skill level of residential labor is substantially lower than in other fields in construction, and the supply of skilled workers is decreasing. Lower skill level, in general, implies lower capacity to innovate and to adopt others' innovations—although it may also result in the substitution of labor with technology. Recent publicity regarding construction automation and prefabrication narrate one possible direction. In addition, product liability for manufacturers and builders continues to plague the industry's openness to innovation, especially as many products are purchased from a global marketplace. A few highly-publicized incidents (for example, 2009 Chinese drywall litigation) have heightened liability concerns.

Other barriers in this second group have qualitatively changed, perhaps with positive effects on innovation rates. The low barrier for new construction firms to enter the industry has been described as a cause for limited technological experimentation, as has the local, fragmented nature of housing construction markets. The recent housing recovery suggests some structural changes in industry composition are under way, with noted fluid transitions between small new single-family building and remodeling and the continued market share for the large, corporate homebuilders. Poor communication and information asymmetries are also a perceived hallmark of the industry. Although the internet has altered access to information, it is evident some builders are laggards in usage and few sources for technical content are unbiased.

Over the last few decades, the change in some industrial barriers to housing innovation has been notable, although the effect of these barriers on innovation capacity and productivity remains unclear. Early signs suggest some change for the worse (for example, from decreasing workforce skills, decreasing public-sector R&D investments, and increasing product liability), and some for the better (such as from the increasing consolidation in the supply chain and the rise of housing technology "start-ups" and online access to information).

The third group of industry characteristics involves innovation barriers that may be diminishing, or even transforming in ways that enable innovation. Low consumer demand for home innovations has been the norm, yet a few studies point to consumers' changing valuation of some newer housing performance improvements (especially energy-efficiency) and subsequent changes in motivations in promoting them among the various housing stakeholders (such as in realty listings and appraisals).

Some have described building regulations as a deterrent to innovation, both because the process for getting innovations accepted by code officials is onerous and because the codes continue to be prescriptive about materials, means, and methods. Although code approval is still costly, the near universality of code adoption has diminished this barrier's strength. The increased stringency for some regulations, such as increased energy-efficiency requirements, has even led to more innovation according to some exploratory studies as noted later in this chapter.

Evidence suggests other factors traditionally described as barriers to innovation—namely, consumer demand and building regulations—have become enablers.

U.S. Housing Innovation Today

The 2003 RAND report identified several challenges to technological innovation in the housing industry that the authors described as virtually inherent in its current practices and historical composition. Indeed, despite the generally positive market trends noted in the previous chapter, parallel improvements on the barriers and challenges to innovation are unclear. *How innovative is the industry compared with before the bust?*

Other typical indicators of innovation, such as the number of patents or R&D tax credits issued, show similarly meager trends—although these indicators were never particularly helpful reflections of the housing industry's innovative capacity given the disproportionate share of process innovations in the industry (Slaughter, 2000) and the inability to readily monetize them. Available evidence suggests the housing industry should be adopting more innovations now based on investments made during the housing boom, but the fundamental practices and characteristics that promote innovation have not substantially altered and, in some cases, they have regressed.

In the RAND report, five structural markers were noted as characteristic, if not intrinsic, to the housing industry that prevent innovating to its perceived maximum potential. Others have summarized these barriers as well (NRC, 2003b, PATH, 2005). The RAND report's authors acknowledge empirical evidence to substantiate the persistence and strength of most of these barriers at the time of the publication was scant, and the lack of data and potential analytical findings persists on most counts. Regardless, a review of the state of these barriers in the current conditions is in order.

Innovation Barriers

The first group of industry characteristics reviewed are those that appear to continue to plague housing innovation capacity in the industry, and subsequent innovation creation and adoption rates.

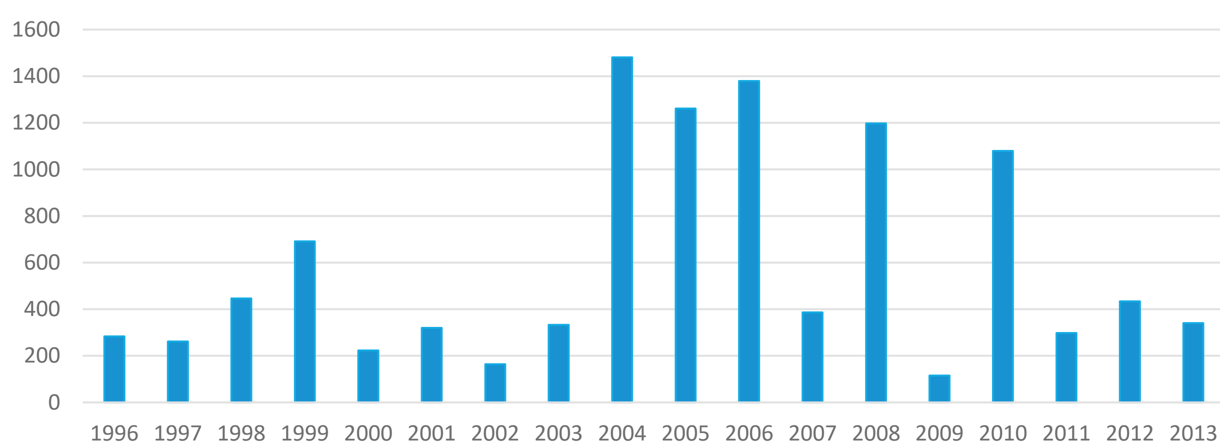
BUSINESS CYCLES

The cyclical nature of the housing industry has been well documented and is likely to have a noted effect on innovation rates, given the potential aversion to risky investments during booms and the physical inability to apply innovations during busts (Bon, 1989). The overall size of investments in innovation appears to be associated with cycles. Additional econometric analysis based on more valid indicators for innovation adoption rates is needed to confirm this hypothesis.

Evidence suggests that many of the opportunities the turn-of-the-21st-century housing boom programs posed have diminished. The research wings of major homebuilders were shuttered just as the recession began (Mullens, 2008). In some cases, the governmental innovation programs themselves were slowly wound down, as was the case for PATH in 2009. Although housing-specific data are unavailable, information on the entire construction industry's R&D expenditures suggests a mixed bag regarding ongoing investments in innovation (Figure II-1). R&D expenditures in the construction industry peaked as the housing market boomed in the early 2000s. However, these formal R&D efforts sputtered soon after the recession, with a few years of high expenditures attributable to funding from federal economic recovery programs.

FIGURE II-1

Value of Domestic R&D Expenditures in the U.S. Construction Industry, 1996–2013 (Millions of U.S. dollars)



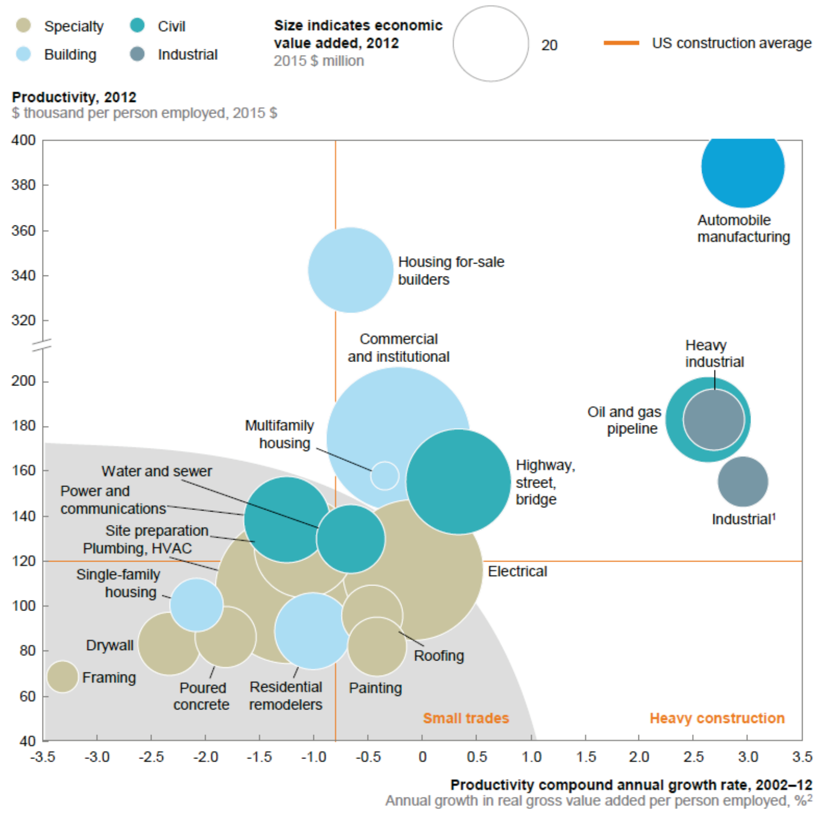
Sources: Urban Institute tabulations of OECD Research and Development Expenditure in Industry (1996–2006) and NSF Business Research and Development and Innovation (2006–2013). Values are for all R&D performed by industry regardless of funding source (for example, public, private, or philanthropic).

Gains made during high R&D investment periods could, presumably, result in innovative products and processes that persist today. In turn, however, the gaps in R&D investment since the housing crash are preventing new innovations from being developed, adopted, diffused, and integrated into the industry for years to come. This fluctuation in R&D resources should be reflected in changes in the traditional outcomes of innovation, such as overall productivity.

Whether any of the past investments have made a quantitative difference in the housing industry's underlying productivity, however, is unclear. By some estimates, the U.S. construction industry's productivity has stagnated or even declined since the late 1960s—a distinction from other countries (including Japan and several western European nations) and other U.S. industries (such as agriculture and manufacturing) (Sveikauskas et al., 2016). Delving into housing sectors, some analysis finds negative growth in housing productivity compared with other construction sectors and in relation to the sectors' overall growth and economic value (Figure II-2). Single-family home builders and remodelers are lagging multifamily builders and other construction counterparts.

FIGURE II-2

Construction Sector Productivity by Growth Rate, 2002–2012



Source: McKinsey Global Institute tabulations of U.S. Economic Census data in Barbosa et al., 2017, p. 36.

The relationship may mask the relative investments across different innovations, however. Rather than perceive the business cycle as a barrier to innovation, it is possible that the type of technology and the magnitude of a new technology's innovativeness vary along with the cycles, with riskier process innovations being employed, under more robust economic conditions. Later discussions will note how interest in specific housing performance areas (like energy efficiency) may alter the point along the business cycle at which any one innovation is potentially more feasible.

INTELLECTUAL PROPERTY

RAND 2003 and others have reported the inability of housing technology innovators to protect their wares from competitors through patents, other costly intellectual ownership channels, and even basic physical observation, as homebuilding is in several ways a public activity (Egbu, 2004; Pellicer, Yepes, and Rojas, 2010). Process changes can be visually observed on the jobsite and are often tailored to specific project sites or home designs only—although some prefabrication techniques overcome such specificity. Product improvements stand a better chance at remaining within the innovators' laboratories or manufacturing facilities, although innovations would need to be permitted by building code officials—a transparent activity that reduces the ability to maintain intellectual property rights. In the few technological areas subject to performance standards, such as energy appliances and fixtures, we might expect to see more protections.

In fact, lighting appears to be the housing-related category with the highest number of patent applications annually (Marco et al., 2015). Other categories related to housing include coatings, materials processing, furniture and housing fixtures, and heating. Recent analyses suggest, during the last three decades, the total number of applications in these categories has increased, although all categories saw a downturn in applications after the recession.

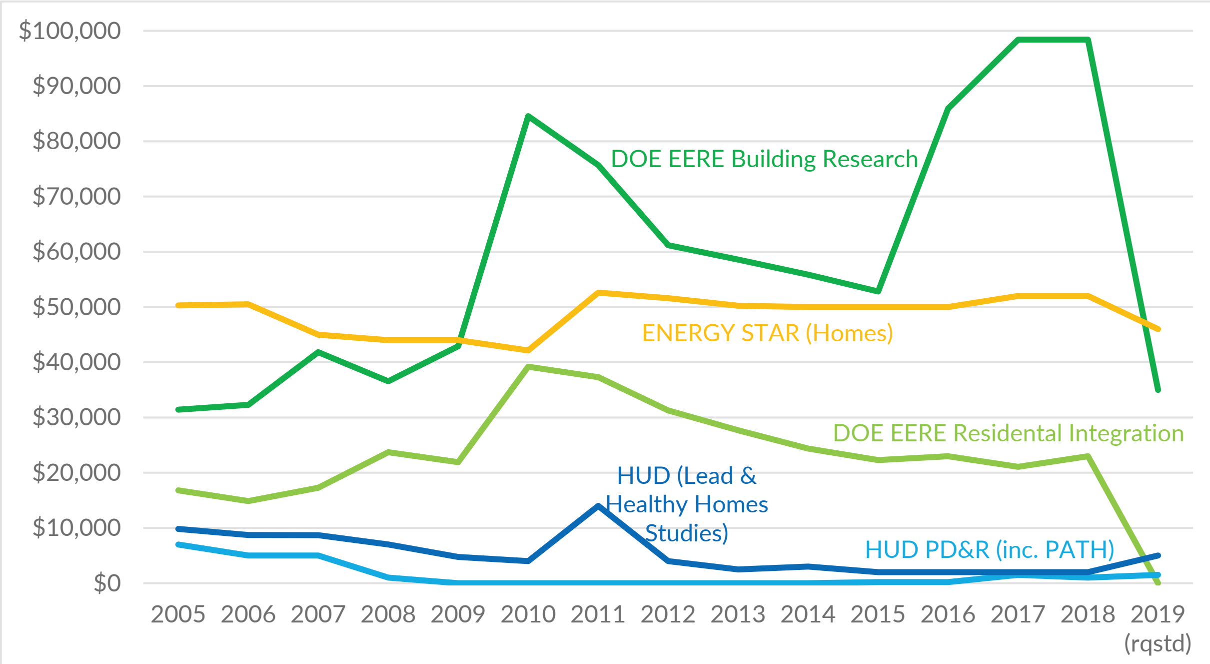
Evidence is lacking for the finding that any housing product and process innovators have proportionally increased patents when compared to categories with much higher patent applications (like computer hardware and software, communications, and drugs) (Altwies and Nemet, 2013). Consequently, the conditions for strengthening property protections for housing innovations have not substantially changed.

R&D INVESTMENT

In contrast to other industries, housing has not benefited from massive investments in public R&D expenditures. This gap prevents the provision of private-sector matching resources for housing technology in areas identified by the public sector as needing focused attention and resources. To this point, a review of the program budgets of the housing R&D programs that existed at time of the RAND report demonstrate how stable funding (such as that of ENERGY STAR) may contribute to the design of housing technology (Figure II-3). An important corollary to the contribution of public R&D funding is that it influences the private-sector cost share as well, and mechanisms for ensuring commitments for both funding partners must be established early on, in supporting innovation in those areas believed to yield greater societal benefits. The public record, and later chapters of this report, argue that this resource deficiency and its effects persist.

FIGURE II-3

U.S. Federal Budget for Select Housing-Related Technology R&D Programs, 2005–2018 (in thousands of dollars)



Notes: 2019 values based solely on budget request. No appropriations have been made at the time of this report's draft.
Sources: Annual Agency Congressional Justification Budget Requests and Past Appropriations (HUD, DOE, EPA).

Factors with Unclear Effects on Innovation

A second group of long-held beliefs about the industry's structural characteristics that purportedly inhibit innovation has undergone some drastic change during the past few decades. Although the changes themselves are measurable, their effect on innovation rates to date remains unclear.

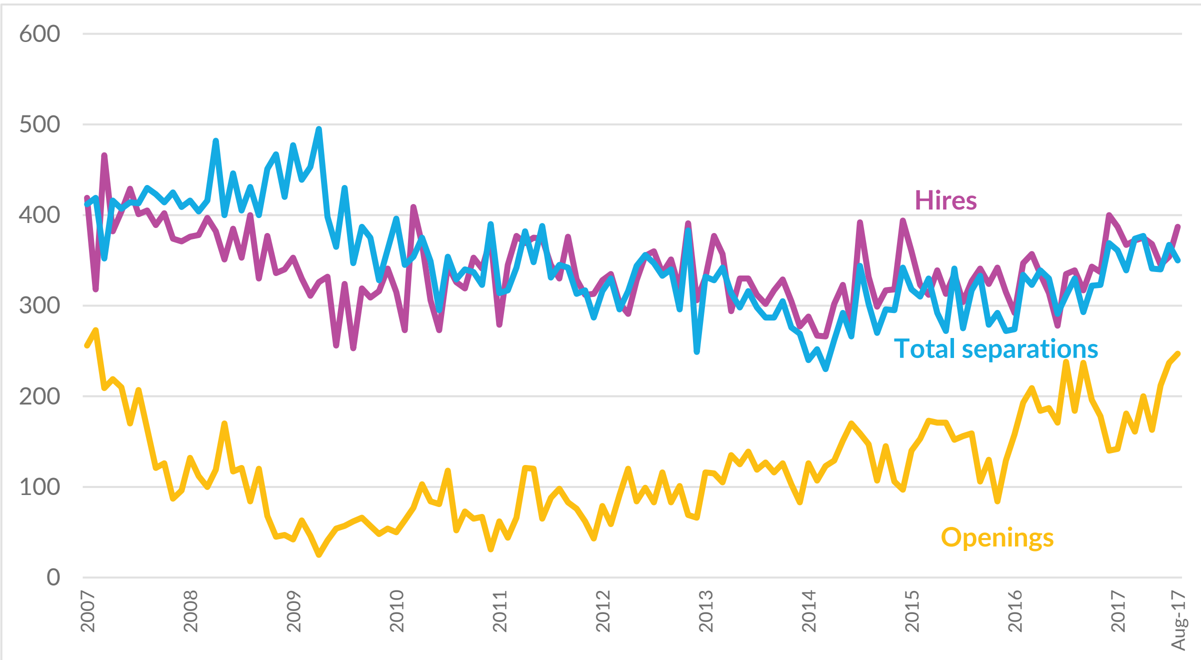
LABOR SKILL

As discussed previously in this report, the lack of a well-trained workforce with access to information, education, and training about new products and processes is regularly noted as a barrier to introducing innovation. During the boom, the residential construction industry argued the workforce was insufficient to meet housing demand. Open-shop, immigrant labor pools were increasingly employed, with increased pre-fabrication viewed as a necessary technological consequence regardless of perceived skill levels (Dai and Goodrum, 2010). Today, builders argue that skilled labor of the type that could develop and deploy technology is insufficient (NAHB, 2016).

Since the initial wave of layoffs during the recession, the residential construction industry has been hiring at a modest pace, with new hires slightly exceeding employee separations. The number of unfilled job openings, however, continues to increase (Figure II-4).

FIGURE II-4

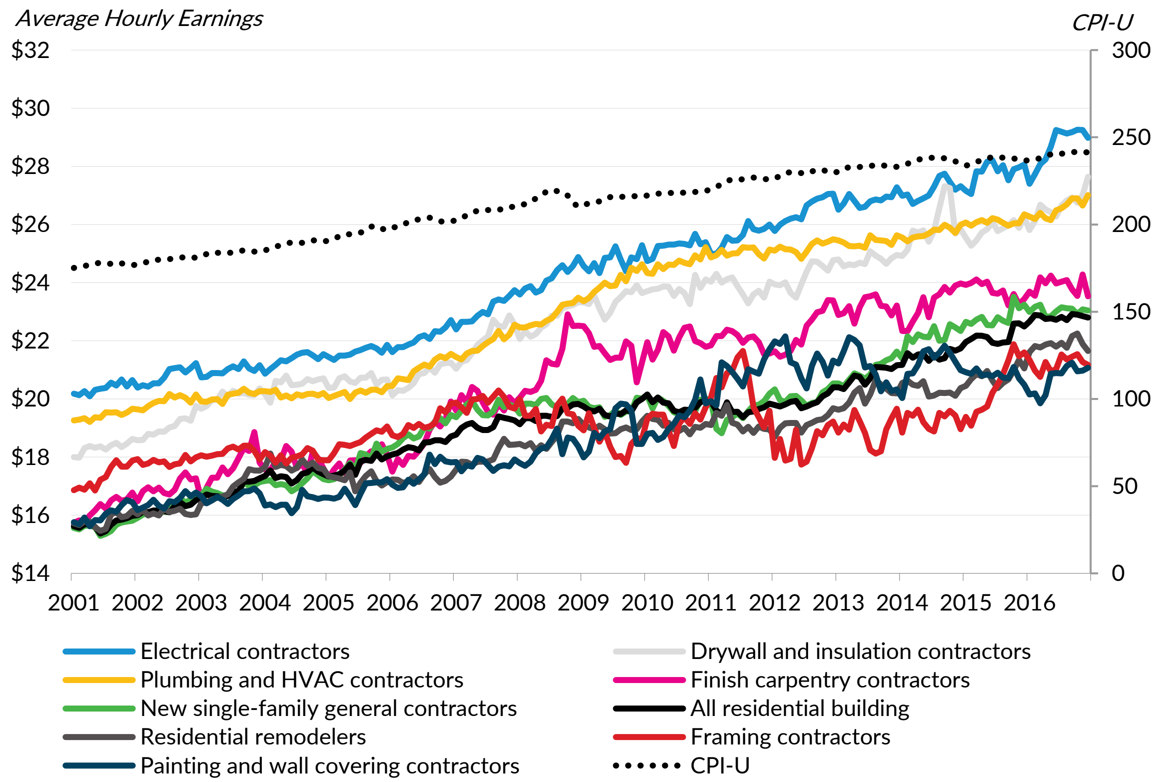
Residential Construction Monthly Total Employee Turnovers (thousands): 2007–2017



Source: Job Openings and Labor Turnover Survey, Bureau of Labor Statistics through August 2017.

FIGURE II-5

Average Hourly Earnings of Housing Production and Nonsupervisory Employees



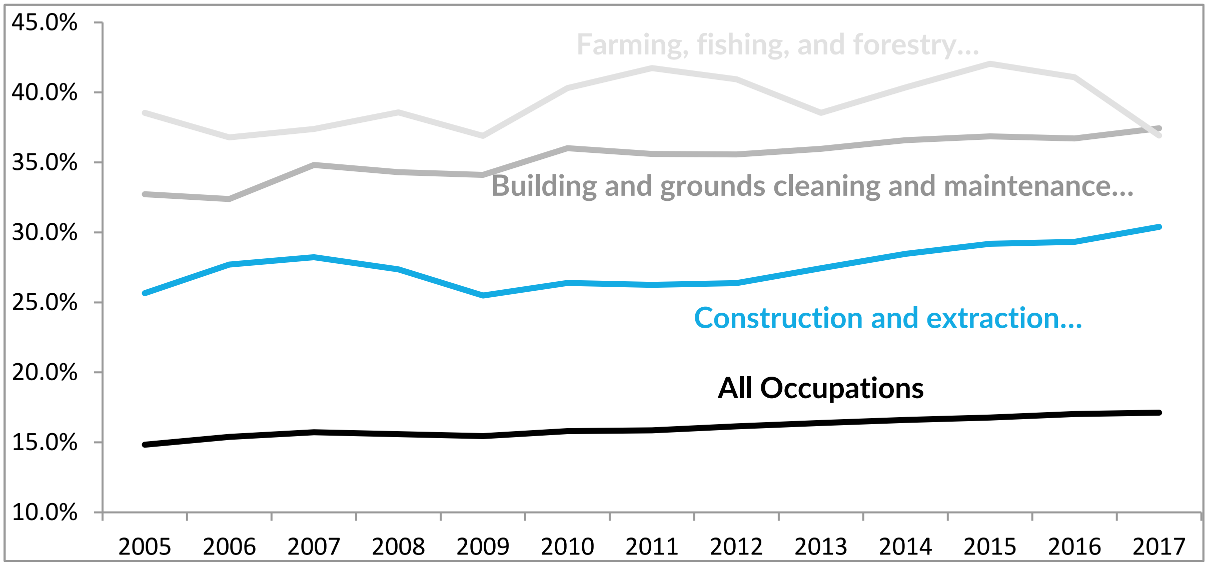
Note: Not seasonally adjusted.
Source: U.S. Bureau of Labor Statistics

Wages have also been on the rise absolutely and in relation to overall inflation (Figure II-5). The wages for finish carpentry carpenters and framing contractors were hit more significantly by the recession than other sectors. Wages for electrical contractors, drywall and insulation contractors, and plumbing and HVAC contractors increasingly trended up during the recession and afterwards.

With increased competition and wages, the assumption that workforce skill is increasing overall in the industry could be reasonable. However, other factors associated with demographic changes in the workforce during the past few decades potentially support the persistence of workforce skill as a barrier, particularly the increased share of immigrant labor (Figure II-6) and decreased share of unionized (Figure II-7) workers. Both trends in worker characteristics portend changes in a variety of productivity measures, including skill sets, wages, and occupational hazards (Goodrum, 2004; Goodrum and Dai, 2005; Belman and Voos, 2006; Theodore, 2015; Theodore et al., 2017)

FIGURE II-6

Foreign-Born Worker Share of Major Occupational Groups, Percentage: 2005–2017

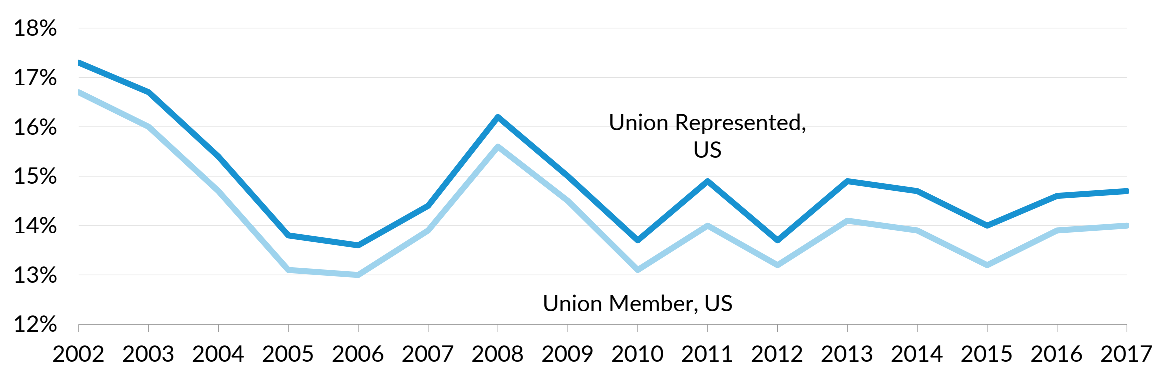


Source: Current Population Survey, Bureau of Labor Statistics

Historically, local builder associations and union apprenticeship programs have been a resource for worker skill development. However, builder associations no longer focus on skill development, and additionally, union membership and representation have been falling in the U.S. construction industry, particularly in the residential industry. The combination of knowledge gaps among workforce entrants and reductions in on-the-job training can reasonably be associated with decreases in innovative capacity. However, the potential for these gaps to then be filled by substituting new technology for labor is also possible.

FIGURE II-7

Percent Union-Member or Union-Represented of Total Construction Employees



Notes: Includes employment in all construction sectors. Not seasonally adjusted.

Source: U.S. Bureau of Labor Statistics

RISK AND LIABILITY

The risk of failure of any of the products and practices in the homebuilding industry is a barrier to innovation (Toole, 1998), particularly since the burden of the risk is taken by the innovative manufacturer or builder (HUD, 2005). Many of the legal precedents regarding product liability for both individual technologies and whole homes date back to the 1970s and 1980s, particularly as pertains to larger homebuilders (Boyle and Hasting, 1989, Gable, 1998). Since the RAND publication, this risk became more acute because of publicized product failures in existing technologies and materials, particularly in relation to the use of imported drywall from China during the housing boom to Southeastern builders (NAHB, 2014). Despite that attention to construction defect litigation, legal decisions and legislative proposals to limit it have not substantially altered the terrain of liability for new technologies.

The increasingly globalized trade of building products and materials has also potentially increased the actual technical risk of innovations (Bardhan and Kroll, 2007). This trade is subject to extreme price fluctuation and to concerns related to product quality (NAHB, 2018). Housing innovation in the United States is increasingly a global activity—a changed R&D context in which areas of federal policy like global trade negotiations will come into play. No corresponding change in risk mitigation strategies has occurred during this same time, however, beyond increasing insurance policy requirements and coverage—a likely deterrent to developing or adopting technologies.

BARRIERS TO INDUSTRY ENTRY

RAND argued that low barriers to entry in the housing industry affect innovation rates counterintuitive to what occurs in other industries. In theory, fewer barriers to entry generate more competitors who, in turn, seek competitive advantages like technological innovations. In housing, however, low barriers to entry yield a wider pool of lesser qualified establishments with minimal technological proficiency, increased risk aversion among established and better qualified establishments, and a likelihood that technological innovation will not improve profits as much as other advantages (such as material finishes or location of land holdings).

Generally, technological innovation is not widely viewed as a notable competitive advantage in the homebuilding industry. The persistence of low barriers to entry and their impact on innovation behaviors holds true in some housing sectors, such as small-scale remodeling, but is not necessarily the case in others. Increased contractor licensure requirements in some high-growth areas; the tightness of acquisition and development loan markets; the increased cost of urban, developable land, labor and material costs; and regulatory pressures have effectively increased barriers to entry for new single-family and multifamily builders.

A trend toward publicizing the technological "disruption" from newer entrants to the industry has been on the rise very recently (Barbosa et al., 2017, McManus, 2018). The small, but documented growth in firms that are funded by venture and other equity capital suggests a potential for the industry's low entry barriers to support innovation in ways that mirror those of other industries. This has been particularly noted about firms focused on prefabrication and automation techniques (Terner Center, 2017).

However, the trends of increasing costs of doing business (and raising the barriers to entering the marketplace) have expanded since the housing bust, suggesting that establishment creation could slow and produce the opposite effect on innovation rates as originally theorized, with more technologically-proficient establishments that are more receptive to innovation investments and the risks involved. To date, however, no rigorous evidence indicates this is the case, or that this characteristic is either an enabler for or a barrier to innovation.

INDUSTRY FRAGMENTATION

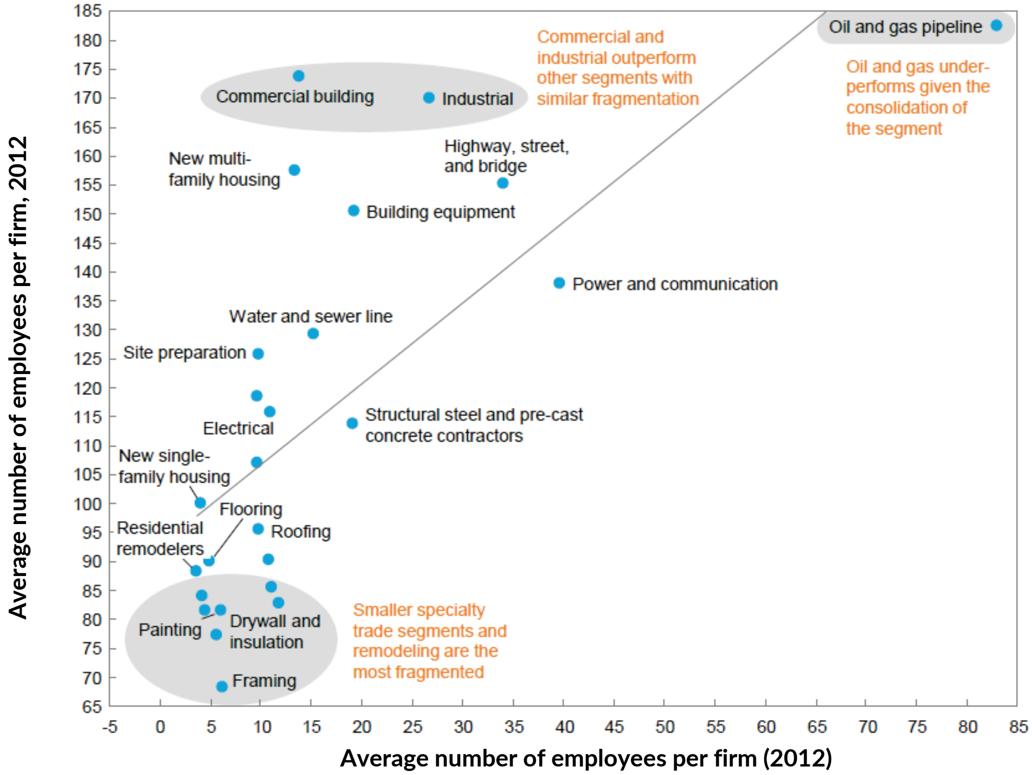
Related to barriers to entry, fragmentation in the industry has been noted in past literature as a deterrent to innovation. In fact, the vast number and geographic spread of small and medium-sized homebuilders is the final barrier category that RAND highlights, but also the one industry scholars most consistently point to as a primary—if not the most significant—barrier to the industry's innovative capacity.

Arguably, many small builders and trades have few resources to support R&D or access to innovation, nor the market scale to facilitate the commercialization of new technologies. One recent study proposes a linear relationship between firm size (as measured by number of employees) and productivity, a hypothesis that clearly disadvantages the smaller remodeling firms and trades that work on new single-family housing compared to other construction sectors and, in turn, other industries altogether (Figure II-8).

Studies like these typically define a highly-fragmented industry as one with many small players in the same market, where markets are defined geographically (for example, the Dallas, Texas metropolitan area) and by project scope (such as, a single-family HVAC replacement or a new multifamily rental building). Size is defined as either the number of employees or the value of annual sales or revenues. These studies, however, do not consider the fragmentation in one link of the homebuilding supply chain—for example, the existence a sole vendor for a product or of one trade subcontractor in a region—and its effects on the composition of establishments in functions at other points of the supply chain.

FIGURE II-8

Average Firm Productivity ($/Employee) by Average Firm Size (No. Employees) 2012



Source: Reproduced from McKinsey Global Institute tabulations of U.S. Economic Census Data (Barbosa et al., 2017, p.48)

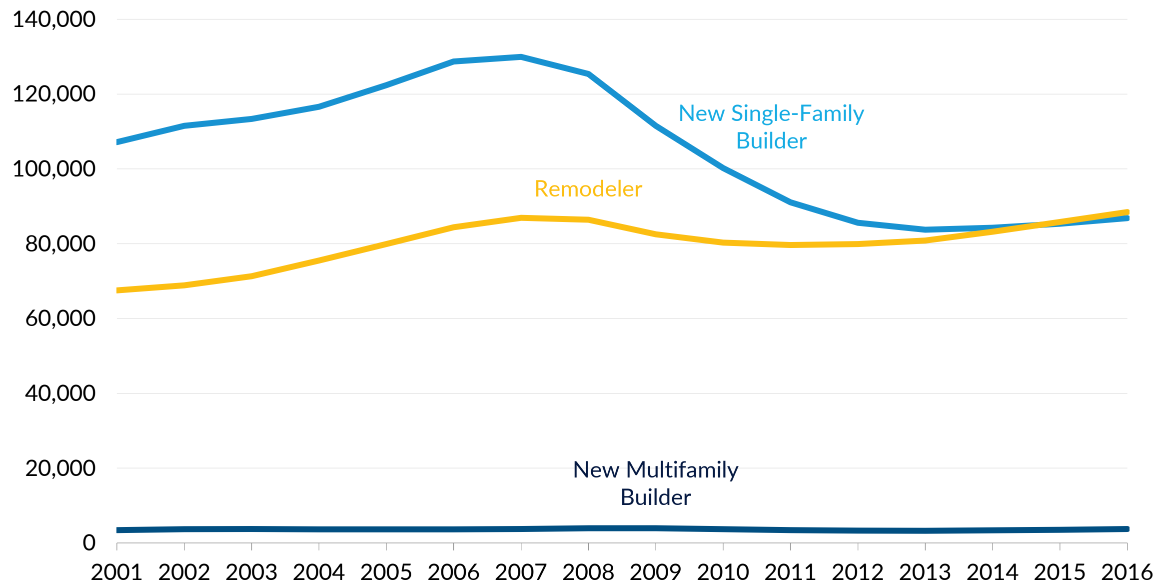
Broad analyses of the housing industry suggest that these connections are real, can have spillover effects on other points in the supply chain and, in turn, can shape innovative capacity (Martín and Whitlow, 2012). For example, material suppliers for both retail and wholesale construction markets were the source of much media attention during the boom year as the "big box" hardware vendors increasingly moved from the DIY markets into large-scale builder sales—even with a few production builders. The number of retail building material establishments declined nationally by approximately 10 percent since its 2007 high to the present and has not shown any signs of growing—reflecting an underlying growth in both the "big box" retailers with over 100 employees and the small retailers that employ less than 4 individuals and the squeezing out of the establishments in between (authors' analysis). The market share of the largest retailers has also approached nearly one-half of all retail sales in the country, as well.

In contrast, the number of wholesale material establishments—the most likely to promote new materials and products directly to building professionals—has been bouncing back since the post-recession lows, and with a decrease in the number of large establishments by both size of employees and sales. Between 2007 and 2012, sales of wholesale building material establishments with 50 to 99 employees or 100 or more employees dropped by about 50 percent, whereas sales for establishments with 0 to 4 employees or 5 to 9 employees slightly increased per the U.S. Census Bureau's Quarterly Census of Employment and Wages. The effects of these kinds of fragmentation spillovers are not fully known.

For the purposes of this paper, however, the research team focused on fragmentation within the three main home-building activities: the general contract builders of new single-family homes, the developers of new multifamily housing, and home remodelers. The numbers of establishments in all three sectors decreased after the recession (with the biggest proportional drop in builders of new single-family homes) but have steadily risen since (with the number of remodelers even surpassing its boom year highs) (Figure II-9).

FIGURE II-9

Number of Establishments: Single-Family Builders, Multifamily Builders, and Remodelers, 2001–2016



Note: Includes both new single-family general contractors and operative builders.
Source: U.S. Census Quarterly Census of Employment and Wages

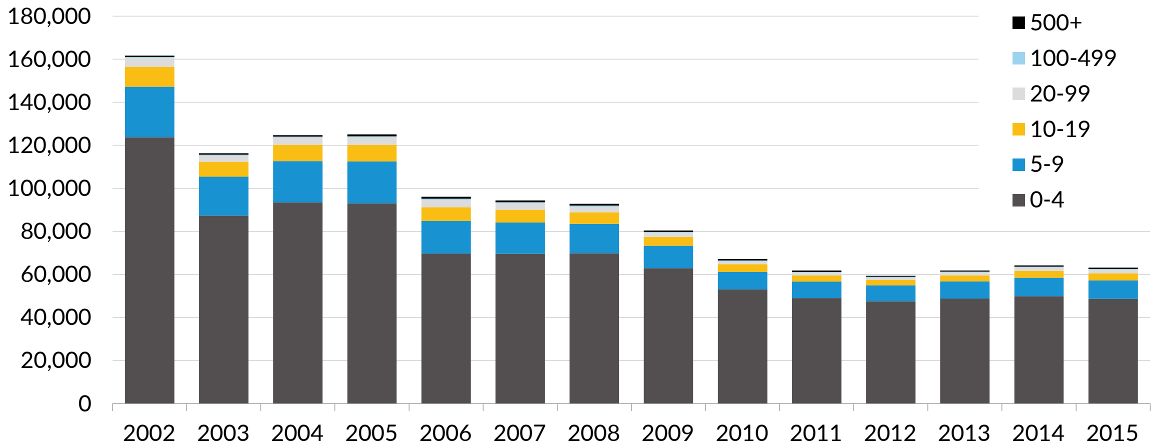
Single-Family Homebuilders

When looking solely at the builders of new single-family homes, the recession took a large toll on the sector; nearly one-third of single-family homebuilders left the business after the 2007 peak. Since 2012, the number of new establishments has been relatively constant. The notable story in this new business world is the type of establishment that remains (Figure II-10).

Among all single-family builders, the total number of establishments with four or fewer employees first declined significantly in 2006, a drop of approximately one-fourth from 2005. The total number of establishments with 5 to 9 employees and with 10 to 19 employees experienced similar decreases from 2005 to 2006, although not as large, and establishments with 100–499 employees and with 500 and more employees slightly increased in 2006. After dropping again from 2008–2010, the number of establishments across all categories has been consistent since about 2011.

FIGURE II-10

New Single-Family Builder Establishments by Number of Employees



Note: Includes new single-family construction builders and operative builders.
Source: U.S. Census Bureau Statistics of U.S. Businesses (S.U.S.B.) Data

The continued growth and market-share of the "production builders"—that is, the large, multi-state homebuilders that are typically publicly-traded corporations—received much attention and were projected to decrease in importance and market share during the boom. However, these builders continue to increase land holdings and production numbers during the recovery (often through mergers or acquisitions of other builders). Market share among the top 10 builders has exceeded 25 percent since the recession (27.4 percent in 2016, NAHB, 2017). These firms have numerous comparative advantages because of their ability to access capital through shareholders and lending institutions, their command of material price reductions from bulk purchases, their land inventories, and internal efficiencies and operational economies of scale (Apgar and Baker, 2006).

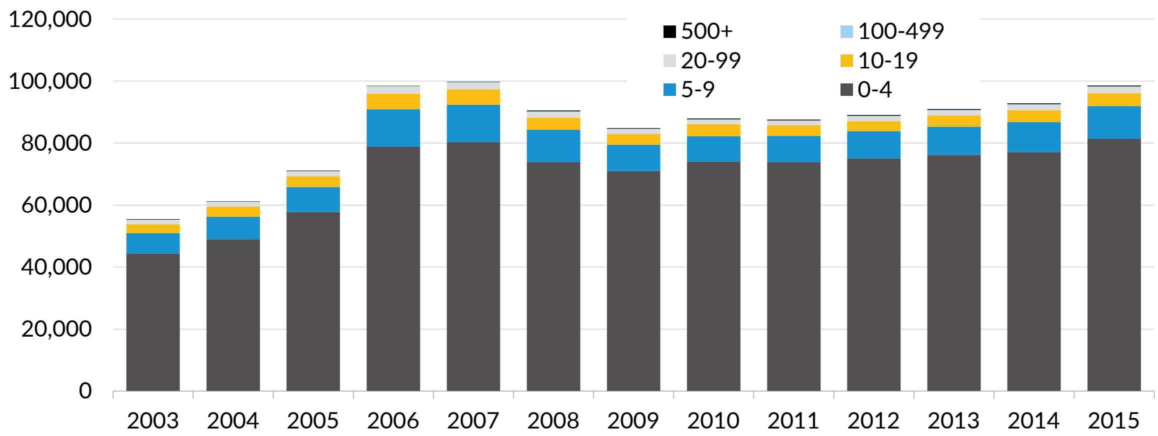
These advantages were put into use throughout the boom years and, presumably, in the present. Their potential for innovating, however, is not fully realized, with an unclear investment in process innovation (Abernathy et al., 2011) but a higher potential for formal R&D investments (Koebel and Cavell, 2006). Although small builders—as defined by employee size and total annual product value—still dominate the sector, the trend of production builders' slowly growing market share continues. At least within the new single-family residential construction sector, the persistence of fragmentation as a primary barrier to innovation begins to fade.

Remodelers

This same pattern has not held for remodelers, however. In fact, the number of remodeling establishments has increased to the point of surpassing the peak housing boom levels, although many smaller new single-family homebuilders likely joined their ranks. The number of remodeling firms of all sizes dropped after the recession, yet their distribution as measured by numbers of employees has remained steady (Figure II-11).

FIGURE II-11

Remodeling Establishments by Number of Employees



Source: U.S. Census Bureau Statistics of U.S. Businesses (S.U.S.B.) data

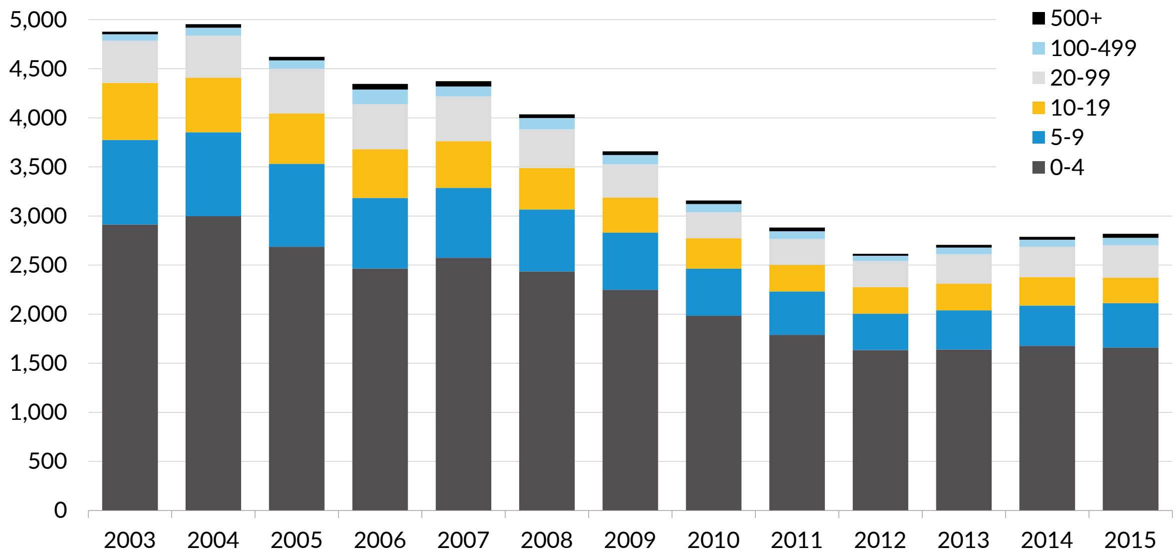
Since 2009, the number of remodelers with four or fewer employees hit a period peak of slightly more than 81,000 in 2015. The number of remodeling firms with 500 or more employees has doubled since 2007, although to a smaller absolute number (285 firms in 2015). The growth in numbers of small remodeling establishments was also reflected in their proportional increase in production, with many smaller firms performing work valued at less than $50,000 than before the bust. For remodeling, then, the innovation barriers associated with sector fragmentation likely still hold.

Multifamily builders

Although the recession had its impact on the supply and availability of multifamily housing, a transformational effect from the downturn has not been seen regarding sector composition like that for new single-family builders (Figure II-12). The number of new multifamily establishments decreased by more than 17 percent during the recession—not as large as the single-family builder drop. Since 2013, though, the number of establishments recovered, surpassing early boom levels in 2016.

FIGURE II-12

New Multifamily Housing Construction Establishments by Number of Employees



Note: Includes new multifamily construction builders and excludes operative builders.
Source: U.S. Census Bureau Statistics of U.S. Businesses (S.U.S.B) Data

The multifamily sector tended to have a wider diversity of establishments by number of employees than did single-family establishments, although establishments with four or fewer employees still represented most multifamily builders every year. These firms, however, produced a smaller share of the value of construction in relation to larger counterparts who have consistently held the larger market share. The multifamily sector, therefore, likely never maintained the same levels of fragmentation, defined in both the traditional sense of distribution of firms by size and by more comprehensive definitions of the supply chain within and across geographic markets.

Within the three primary residential building sectors, then, some evidence indicates fragmentation is still a likely deterrent for investment in R&D, access to information regarding new technology within their supply chains, and its adoption and diffusion across geographic markets. However, its effect as a barrier varies by sector, with remodelers appearing to be the most affected currently. Its effect also may mature over time; the potential embodied by large single-family production builders during the post-recession dust-settling may catalyze investments in the next few years. Compounded by the lack of vertical integration of the industry, particularly the reliance on subcontractors and trades, fragmentation within and across all sectors and stakeholder groups of the housing industry, then, is still likely an inhibitor of innovation—but an increasingly tenuous one.

COMMUNICATIONS AND INFORMATION

Numerous scholars have argued that gaps in knowledge and in access to neutral knowledge resources across key industry stakeholders are a core barrier to the creation of innovation by the industry's production stakeholders (that is, manufacturers, builders, trades, material suppliers, and labor). These information asymmetries prevent the robust and equitable access of its benefits by consumers and other housing transaction stakeholders (such as lenders, realty agents, appraisers, and inspectors) (NRC, 2002). In turn, the inability to share information hinders diffusion (Slaughter, 1993).

Based on the review of scholarship and the professional literature, communications and information gaps continue to pose a significant barrier to innovation. This finding holds particularly true when considering the more robust definition of industry fragmentation described previously; dissimilarities in the level and quality of information persist between players of the same sector in the same market but vary even more markedly between supply chains and between markets. Two major trends, however, that have solidified since the RAND publication in 2003 are equalizing the traditional information asymmetry and reducing this theme as a barrier.

The first is that information about specific technologies or housing performance topics is slightly more accessible due to the reliance on internet sources and search tools. The downside of that expansive information and communications vehicle is that now an overwhelming plethora of information is available, and most of it is commercially-produced (and potentially biased). Public and neutral commercial sources compete with private information sources that are typically better resourced. Thus, the barrier reduction about access to information is a mixed bag.

The second trend chipping away at the information barrier to innovation is the ability to interpret information accurately. A core challenge for rebalancing the information asymmetries in the housing industry has been translation—that is, the ability for one set of actors to communicate their technical knowledge about innovations and technological performance to others who likely have very different sets of knowledge and potentially different languages for them.

Few notable transformations in translation have occurred in the last two decades. For example, among industry insiders, sophisticated manufacturers' development of worker-accessible installation and performance information and use of new information media (for example, with window and envelope installation videos) bridges key constituents in an innovation's path to the job site along with overcoming the de-skilling of the workforce.

The federal government's efforts during the recession have helped translation, as well. DOE and its national laboratories developed the Home Energy Score during the recession to provide home owners and buyers with comparable information about a home's energy use and likely costs. The Home Energy Score more succinctly and accessibly translated housing energy performance in a way that detects changes in any specific material, product, or technology, and advances consumers' awareness beyond the previous building label and certification programs.

Neither of these trends—stakeholders' increasing access to information from electronic media and the increase in technological "translations"—have been quantitatively measured, although they have been well-documented in the industry press and qualitatively noted in contemporary studies. As such, the impact of these trends on innovation rates has yet to be assessed. Given recent developments in building technology information and access to information, the previous view of an information gap as a barrier to innovation appears to be giving way to the view that information and information access are enablers for innovation.

Innovation Enablers

In contrast, a preponderance of evidence suggests several industry characteristics once described as barriers to innovation in previous literature that may now qualitatively encourage innovation or expedite innovation rates—that is, they enable innovation.

REGULATIONS

The United States is one of the few developed nations with a privatized building code developed at the national level that becomes public law at the state or local level. Technical standards, as opposed to the building code which references the standards, generally are descriptions of specific technologies or their performance developed by consensus that are the result of efforts to ensure minimum health and safety for occupants, minimize environmental impacts, or another defined benefit. Involvement in this regulatory process by federal officials typically is for the latter purpose and not for the promotion of specific innovations.

Building codes have been described in the past as a significant barrier to innovation in housing because of 1) the specification-basis of most codes and their inability to permit the approval of new technology, 2) the belief that codes vary significantly across geographies, and 3) the continuously increasing regulatory framework that complicates planning for construction (Field and Rivkin, 1975; Oster and Quigley, 1977; Cooke, 1977). Although increased stringency in regulatory adoption and enforcement adds costs, in general, the current evidence suggests that it consequently benefits innovation rates.

The first barrier condition, the fixed specification of technologies in building codes, only partially holds and can reasonably be considered an ongoing barrier only to the extent that codes remain specification-based in nature (Blackley and Shepard, 1996). In several key subject areas, building codes have also moved toward a performance base, as well; voluntary building standards that are increasingly integrated into regulations also typically have performance-based compliance channels. In fact, efforts to speed up the code approval process for specific technologies (where codes remain specification-based) expanded soon after the 2003 RAND publication (National Evaluation Service, 2004), and now cover a wide variety of product testing and compliance areas.

Regarding the second barrier condition, geographic variation in codes continues to diminish as more statewide codes are adopted and a near-universal reliance on a single model code in the United States exists since the drafting of the first International Building Code in 2000. Building departments' increasing use of electronic reviews and third-party contractors for permitting and enforcement, respectively, has created further standardization in regulatory practices. The software and individuals' training and certification are based on national standards. Although states and municipalities have adopted variations, the near uniformity in adoption and enforcement in practice has reduced the need for any innovative manufacturer or builder to replicate documentation for compliance across markets.

To the third concern, increasing regulatory constraints, building codes have increased in stringency during the past two decades, particularly in the areas of energy efficiency, green building, and structural protection from natural hazards that are mandated due to policy external to the industry rather than traditional building code adoptions (Jaffe and Stavins, 1995). Bond and Devine showed that different types of public policy encouraged the adoption of eco-labels in multi-housing markets (2016). Recent Virginia Housing and Development Authority policies have incentivized the use of green building policies for new Low-Income Housing Tax Credit properties, leading to growth in market demand for green technologies (McCoy et al., 2015). Although regulations do add costs to the current ways of producing homes, recent scholarship argues that they also spur innovation by forcing manufacturers and builders to produce qualitatively better products with quantitatively more efficient processes (Von Hippel, 2005; Grösser, 2012; Noailly, 2012). These findings markedly contradict past scholarship on the role of regulatory practices in housing innovation.

STAKEHOLDER MOTIVATION

RAND provided an extensive list of stakeholders whose motivations vary regarding new process and product technologies; alternately, these stakeholders contribute to possible innovative activities or detract from them. However, the 2003 report suggested no consistent pattern across these stakeholders' motivations toward innovation either within or across their groups other than the sheer number of stakeholders—an industrial reality that still holds and, in theory, continues to shape the industry's capacity to innovate.

As the number of stakeholder groups in the current industry has not changed since the time of the RAND report, we can assume that this barrier to innovation remains unchanged. However, the roles, practices, and regulations of some of these groups have slightly changed in the post-recession era, which may suggest a performance risk aversion (such as, poor energy efficiency or disaster mitigation) rather than an aversion to new technologies.

For example, new product manufacturers who extend their relationship with consumers beyond purchase (such as small-scale renewable energy service providers) have changed user perceptions about the value of new technology. Real estate agents, another example, were described as a key stakeholder group whose motivations impede innovation because of their concern for comparability between homes and their ability to filter information for consumers. The transformation of multiple listing services (MLS) to provide more detail about properties, including historical energy use and disaster exposures, directly to prospective homebuyers has taken off in multiple regions. This effort has been supplemented by the creation of private online realty sites designed to meet home occupants' increased home purchase needs.

Appraisers' motivations were also noted as an innovation barrier two decades ago. However, in response to appraisal quality concerns during the housing bust, the Appraisal Foundation also created the Appraisal Practices Board in July 2010 to develop voluntary guidance for "Recognized Valuation Methods & Techniques." Although terminated in 2017, the board developed many valuation advisories, including ones for green building. These efforts could assist in securing more professional and technically accurate appraisals that account for technological innovations and benefits.

In addition to the reduced strength in these groups' motivations as a barrier to innovation, other groups whose motivations are likely enablers of innovations have entered the housing industry since 2003. Other players have shown themselves to be formidable influencers of housing trends, including being advocates for performance improvements and technological change. In the energy efficiency arena, energy raters and auditors and utilities themselves have proven to be as vested in the outcomes of housing innovation as the traditional groups. Insurers and reinsurers have become promoters of improvements in disaster mitigation technologies, policies, and funding assistance. Public health advocates have been vigilant reviewers of air quality, lead exposure, and other environmental conditions in new and existing homes. The rise of these stakeholder groups suggests a shift in this industry characteristic from a blanket judgment as barriers, to one that may enable innovation.

CONSUMER DEMAND

A final reason for low innovation rates commonly cited by practitioners is that interest is negligible among consumers– "demand-pull" does not exist–for new technologies. Indeed, the stakeholder group that is most commonly described as the least motivated to support innovation are the end users or consumers: homebuyers, owners, and occupants. Due to both traditional, cultural perceptions of housing performance and an unwillingness or inability to afford potentially added costs of technologies, market transformation has been inhibited, particularly since most homebuyers are not repeat customers for the same homebuilders (Slaughter and Cate, 2008). To start, consumer demand is a somewhat moot barrier in relation to the vast other opportunities for innovation: the processes by which homes are built or remodeled that do not result in a qualitatively different product.

Regarding product innovations, during the past two decades, much has changed. Whereas some product technologies are likely not well received by consumers or are too expensive, evidence has increased since the RAND publication of consumers' willingness to purchase innovative housing and housing products. This finding has been particularly noted in the technological performance areas of energy-efficiency, indoor environmental quality, and disaster mitigation.

Efforts to translate technical performance to consumers in the last 15 years have been fertile. Series of consumer preference surveys produced by the major trade associations (for example, National Associate of Home Builders, Urban Land Institute, and National Association of Realtors) over the years show greater awareness of housing performance topics in general and specific techniques. This awareness manifests itself in realized price premiums (Kahn and Kok, 2014; Brounen and Kok, 2011), particularly in the areas of energy-efficiency and green building.

Other studies note that the purported hesitancy of the traditional American household toward change in its immediate built environment and the way it is produced is, for all intents, inaccurate. The reception to modular and prefabricated systems has warmed, and whole-house information systems and controls have grown in popularity (Temkin et al., 2007; Global Industry Analysts, 2015). Such phenomena suggest both an untapped market for housing innovation, and that information vehicles about those innovations' benefits developed since the 2003 report have moved positively.

Implications for Innovation Policy

In summary, many of the originally identified structural barriers to technological innovation in the housing industry persist. Most of these barriers, however, have not been fully evidenced with rigorous and peer-reviewed analysis either at the time of the 2003 publication or since. Further, little scholarship has reexamined them. Nevertheless, no evidence suggests these factors are not still relevant and reasonably included as potential barriers requiring industrial and policy intervention. However, a few other encouraging signs remain; the needle has moved positively for some of the traditionally perceived barriers to innovation.

Three strategies for current housing innovation policy arise from the groupings of housing characteristics into barriers or enablers described in this chapter. The first is simply to strengthen the relatively weak and anecdotal evidence based for these barriers and enablers through additional research. Much more work needs to be advanced in this area for other R&D policy interventions to be pursued regardless of whether the intervention hopes to deal with that barrier directly or not. Defining and measuring barriers' impact on innovation rates could help identify the next steps for policy action.

The second strategy is to focus on reducing specific barriers through public-sector R&D and related investments. Examples of these efforts could include improving workforce training programs to address the innovation barrier caused by poor technical skills or encourage greater statewide code enforcement to address any remaining challenges with the variable interpretation of an innovation's compliance. Much like PATH attempted after its program redesign, investments along these lines would need to be highly strategic and could require substantial resources and partnerships with multiple public-sector entities beyond those focused on housing. Explicit theories of change for reducing each barrier would need to be advanced. Because some barriers are intractable, the strategy may focus on the "lower hanging fruit"—that is, the characteristics with fewer stakeholders and more cost-effective practical solutions.

The third strategy is simply to be conscious of these barriers as a specific housing performance R&D investment is made. This final strategy approaches the barriers as constant, structural characteristics that simply need to be worked around. For example, a project or program for investing in hurricane-resistant housing technologies should be conscious of the local building codes that shape the current technology landscape, the feasibility of new technologies complying with those codes, and the incentive structure for consumers and insurers to generate market demand.

In all cases, the industry characteristics described in this chapter that either impede or empower innovators must be identified, understood, and addressed for any R&D investment to yield returns.

III. The Evolving Housing Innovation Model

A. P. McCoy

As previously documented in the literature, innovations in housing can follow multiple paths on their way to market that are more iterative across the supply chain than in other industries. The traditional, linear model of innovation does not hold in relation to housing technology.

The researchers reviewed the scholarly literature with a special emphasis on work produced since the 2003 report for any new insights into how the industry innovates. This literature review on the nature of the innovation process affirms the more complex, non-linear model of the innovation process presented by RAND in 2003 and suggests that its complexity can be applied on the innovation processes of individual innovations as well.

Key Observations

This review corroborates the theory that housing innovation follows a more iterative path than other industries, but also notes multiple performance areas (for example, energy efficiency) and markets (by sector, geography, consumer preference, and over time) that appear to influence the number and quality of iterations. Previous models did not consider the risks that are often associated with being a first-mover to adopt technology—and benefits from being a follower—in these local markets.

The process of innovation varies by technical specification, performance area, and the market context in which it is introduced.

Previous models also lacked the capability to account for the idiosyncrasies of a specific innovation's relevant technological performance area, supply-chain, market, costs (relative to both the technology it replaces and other technologies and even other functional performance areas), and consumers that the RAND model now permits. These market-based characteristics create information asymmetries that affect the innovation adoption decision and, depending on their state, could be either enablers or barriers to innovation. However, research quantifying the state of innovation productivity, adoption, or diffusion in the residential construction industry during the past two decades to enable testing alternative models has been scant.

Recent studies do suggest an even more nuanced model than previously accepted. The context of each innovation is somewhat unique. The path for any one innovation competes with other technologies within the broader, complex processes and systems in homebuilding. Applying the more general innovation model to a specific innovation accommodates the peculiarities of each innovation's context and market and allows for the mode's practical implementation.

Past models of housing innovation pertain to the whole industry as the unit of analysis and are therefore too generalized to shed light on any specific innovation's development.

Studies suggesting this nuanced perspective on the innovation process, however, have been conducted only in three residential performance areas: energy-efficiency, green building (beyond energy), and building information and manufacturing (BIM). Innovations in other performance areas such as disaster mitigation, moisture management, and accessibility appear in recent literature but not in the context of the industry's innovation development processes or production rates.

A more accurate model should integrate the fragmented or decentralized nature of the industry, the variations in local supply chains, and the roles of multiple "brokers" in the decision to innovate or adopt. However, only a few studies have begun to note these various pathways to date.

The Housing Innovation Process

Since the 2003 publication, scholars have sought to explore the process of *how* the housing industry develops and promotes innovation, in addition to improving our understanding of the motivations behind innovating, which were discussed in the previous chapter. Researchers continue to struggle with understanding this aspect of the innovation process (Gann and Salter, 2000; Koebel et al., 2004; Woudhuysen and Abley, 2004). Scholars have focused on market factors influencing the process, particularly in relation to competitive advantages for specific firms (Porter and Stern, 2001). Others point to factors such as the lack of resources dedicated to innovation, low risk tolerance, and failure to develop a sector of firm culture that is favorable or open to innovation (Gambatese and Hallowell, 2011). Much of this work is biased toward “successful” innovations, an implicit assumption that innovation drives industrial growth, and that benefits accrue to stakeholders that are first at the table (Koebel and McCoy, 2006).

Innovation Stages

Regardless of these barriers, recent literature suggests that innovation does occur in the housing industry, but that accelerating innovation requires a deeper understanding of factors affecting decision-making across the residential supply chain. As Rogers (1995) notes, the distribution of diffusion can be typified by the “innovators” (those who generate innovation); the “early adopters” (the first individuals to adopt); the “early majority”; the “late majority”; and the “laggards.” However, the composition of these categories in housing remains the source of debate. Consequently, the scholarship has refined the definitions for the stages in that process.

- *Invention* is the development of a novel idea, product, or process for the firm or individual utilizing it to a *useful state*.
- *Commercialization* is the execution of all necessary processes by the inventor or innovator within the technical and business functions to bring an innovation to market.
- *Adoption* involves the decisions of individual users in a group to accept innovative products.
- *Diffusion* relates to the spread of innovative products across groups over time.

Research has shown that many contextual factors can influence the commercialization, adoption, and diffusion of an innovation. Such factors include time (Rogers, 1995), a building firm’s responsiveness and creativity to its clients, climate (Andrews and Krogmann, 2009; Kok, McGraw, and Quigley, 2011), industry structure or relationships, attributes of the built environment (Ewing and Hamidi, 2013; Ewing et al., 2014), communication networks (Rogers, 1995), market-area control variables (Koebel, 2008), and spillover effects between markets (Simcoe and Toffel, 2011). Industrial economics literature highlights the importance of complementarity—the adoption of substantively or functionally related innovations—for the adoption of innovation (Cassiman and Veugelers, 2006; Freeman, 2002; Miravete and Pernias, 2006; Gilli, Mancinelli, and Mazzanti, 2013). Scholars have noted, however, that assessing causal relationships from complementarity may be a challenge given the timing of adoption and available data (Fagerberg, Mowery, and Nelson, 2006; Greenhalgh and Rogers, 2009).

Industry-Wide Factors

Empirical studies of factors that shape the innovation process and that influence innovation adoption in residential construction are scant (Slaughter, 1993; Toole, 1998; Koebel et al., 2004; Koebel and Cavell, 2006). Hence, research on diffusion of innovations typically focuses on modeling the outcomes associated with employing a technology more than the factors associated with the decision to adopt. Some diffusion modeling has occurred in the work of Koebel et al. (2015), who established a model specific to residential construction products. This model was tested on specific high-performance-housing (HPH) products to determine the level of product use over time (see also Sanderford, McCoy, and Keefe, 2017).

Research has identified the factors that appear to shape movement along the path of innovation. Koebel et al. (2004) proposed a general model for the adoption of housing innovation that included nine characteristics: adopter's human resources; adopter's organizational structure; adopter's organizational culture and decision process; adopter's market context; industry characteristics; communication channels and social networks; technical attributes of the innovation; economic attributes of the innovation; and supplier/vendor characteristics. Weidman, Dickerson, and Koebel (2015) integrated the model by Koebel et al. (2004) with characteristics of health and safety innovation diffusion and in residential construction.

Housing is comparable to other industries in many ways yet has distinct characteristics regarding the process of innovation (Koebel, 2008). Characteristics unique to homebuilding that shape the innovation process include the following.

- *Site variability*: Construction is a site-specific, project-based activity implemented by multi-party networks. Therefore, decision-making is often decentralized, and production is not standardized for efficiency and quality (Dubois and Gadde, 2002; Blackley and Shepard, 1996; Koebel and Cavell, 2006; Toole, 1998).
- *Longevity of warranties*: Housing's lifecycle extends well beyond typical warranty periods, and the use-life is longer than products of many other industries, thereby complicating the risk profile (Blackley and Shepard, 1996; Koebel et al., 2004).
- *Supply chain variability*: Many stakeholders along the housing development process can resist innovation adoption (McCoy et al., 2010).
- *Path dependency*: Homebuilders resist changing processes that have worked well in the past (BTI, 2005; Koebel and Cavell, 2006; Toole, 1998).

- *Uncertainty of technology adoption*: Residential construction does not necessarily reward risk-takers (McCoy et al., 2009; Koebel et al., 2004; Ball, 1999; Slaughter, 1993).
- *Code compliance variability*: Site locations may differ in standards for codes and degrees of enforcement (BTI, 2005; Koebel and Cavell, 2006), although, as noted in the previous chapter, this appears to be a diminishing reason for not beginning the innovation process.

Ultimately, housing is a complex system spanning multiple industries including materials (raw and finished) producers, manufacturers, suppliers, designers, contractors, financial institutions, insurers, regulators, and consumers. Winch (2003) defines these complex industries as those where traditional risk models do not fit; they are not composed of a few large firms with similar product designs striving for the customer's attention (for example, auto, shipbuilding, or aircraft manufacturers).

In Reichstein's discussion of the construction industry's adoption of sustainable development, risks precipitated by the inherent complexity of an industry so highly reliant on collaboration are materially different from risks discussed in a typical business sense (Reichstein, Salter, and Gann,2010). Lepatner (2007) also discussed the industry's divergence from common business practice through asymmetries of information that drive risk and influence decision-making processes. Therefore, approaches and capacities for risk management are extremely variable and directly influence the transition from invention to application.

Those in the homebuilding production supply chain that broker innovation introduce risk in terms of labor, materials, firm characteristics, and industry fragmentation (Keast and Hampson, 2007) across the wide supply chain in housing. Labor risks include costs, knowledge and training, availability, and concentration of builders (Toole, 1998). Material risks include costs, availability, lack of product integration, commitment length (that is, inadequate opportunity for testing new processes or technologies prior to committing resources), and path dependency (that is, reliance on established processes and products; Koebel et al., 2004; Slaughter, 1993).

Homebuilder firm characteristics that affect risks of innovation adoption include firm orientation and capacity, business operations and size (that is, larger operations mitigate risk through multiple markets and opportunities for regulatory acceptance whereas small firms often lack capital and require quicker returns), and internal functions and influence (divisions of the firm driving decisions; Blackley and Shepard, 1996; Koebel et al., 2004 Oster and Quigley, 1977; Slaughter, 1993). Industry fragmentation includes important influencers external to the organization (for example, the cooperation of suppliers, subcontractors, manufacturers, and project managers), resistance by stakeholders (for example, architects, homeowners, manufacturers, and subcontractors that resist products and processes), knowledge driven by distributors and suppliers, and lack of integrators (Blackley and Shepard, 1996; Koebel et al., 2004; NAHB Research Center, 1998; Toole, 1998).

Industries like homebuilding rely on supply chain stakeholders to act as brokers who facilitate the flow of information and transactions. As noted previously, the homebuilding process is decentralized, variable, and contains many such brokers who directly influence the type and flow of information. At a local level, the actions of these stakeholders can increase risk for the homebuilder who makes key decisions about the product design, process, and assembly. The builder or remodeler, more than any other group, decides how to balance the risk factors with market demand. Regardless, the combination of these brokers dramatically shapes the innovation process.

Stakeholder-Specific Factors

A large body of scholarship on innovation outside of housing exists (see, for example, Fagerberg et al., 2006; Rogers, 1995; Wisdom et al., 2013; and Chor et al., 2014), and much of the recent work on decision-making for innovation adoption relies on defining uncertainty for those choosing to adopt (Singh, Jain, and Tyagi, 2007; Chachere and Haymaker, 2011). Studies have focused on improving decision-making models that incorporate multiple criteria and prescriptive uncertainty (Pan, Dainty, and Gibb, 2012), which rarely factor into the decision-making process.

Research shows factors that influence adoption of an innovative residential product include the attributes of the local built environment (Ewing and Hamidi, 2013; Ewing et al., 2014), communication networks (Rogers, 1995), the internal management of decision-making processes (Mitropoulos and Tatum, 1999), market area (Koebel, 2008), and spillover effects between markets (Simcoe and Toffel, 2011). Construction innovation research has often noted the importance of the diffusion of innovation frameworks and models (Koebel, 2008; Larsen, 2005; Pries and Dorée, 2005; Sargent, Hyland, and Sawang, 2012).

Much of this work has focused on the internal dynamics of production builders, finding vulnerabilities to risks of scale typical of any supply chain as well as risks specific to the housing sector. The following characteristics are some of those unique to large national production homebuilding (Koebel and Cavell, 2006).

- *Size and vision*: Large homebuilders are historically more innovative, and they understand the long-term benefits despite the possibility of the risk of innovation. Many large builders view innovation as an opportunity to differentiate their product in local markets.

- *Firm orientation*: Decisions on innovation adoption are typically made at a national level.
- *Purchasing*: Innovation adoption decisions by large homebuilders are heavily influenced by purchasing agents.
- *Sources of information*: Large homebuilders rely on information throughout the supply chain (that is, from manufacturers to local offices).

Depending on a homebuilder's culture, the organization can resist adopting certain kinds of innovation, for example those that reduce health hazards, while prioritizing innovations that improve production speed and product quality (Kramer et al., 2010).

Housing construction occurs at a point in the process where the homebuilder has committed to decisions and resources, making it difficult to mitigate technology-related risks that may differ among sites (Barrett and Sexton, 2006). Large-scale developers and builders often attempt to design for and manage to local conditions as early in the process as possible, reducing variability across the entire process, and cannot respond nimbly to other types of variability later in the process such as innovative materials and means. Resistance protects the firm from adoption of new processes that may result in poor decisions (BTI, 2005).

Similarly, McCoy, Badinelli, and Thabet (2009) distilled a list of risks for individual builders including the consistency of installation due to site and project variability and product lifecycle such as the ability of the product to be durable, serviceable, maintained, reliable, and disposable. Firms may differ in their comfort level with speculative risk versus pure and financial risk (NAHB, 2017). Homebuilders generally place greater emphasis on aesthetic improvements, total quality practices, subcontractor dependability, marketability, and reducing call-backs on products rather than on reducing costs and liabilities through investments in new products and processes (Koebel et al., 2004).

Innovation processes will continue to face resistance unless they can limit product and process risk. Blayse and Manley (2004) point to fragmented supply chains as an ongoing pressure in residential construction, resulting in most residential construction firms building to a known set of plans and offering limited groupings of options. Standardization of products requires each home to be built like others in a company inventory rather than a unique product. In contrast, commercial builders and luxury homebuilders entertain options for clients or designers and offer a range of tens or hundreds of thousands of options within one building program. Limiting product and process risk, by reducing options, reduces uncertainty on levels from product concerns to other stakeholders along the supply chain and is important to innovation models.

Literature also suggests that individual supply chain stakeholders do not fully comprehend the benefits of new-product adoption (BTI, 2005). Recommendations for developing a new product require the coordination of all relevant stakeholders through concepts such as concurrent engineering, a process the requires the involvement of all stakeholders across all stages of product development. McCoy et al. (2010) extend that concept by advocating for a process of for concurrent commercialization that involves all supply-chain parties in the design and development of a new product from the earliest stages and broadens the scope of product-development decisions beyond considerations of technology and product performance to all business decisions and functions.

Technology-Specific Factors

Several studies have advanced empirical diffusion of innovation models for specific technologies relative to their respective innovation-adopting organizations. These studies analyzed innovative software (Kale and Arditi, 2005), concrete technology (Kale and Arditi, 2006), and road construction product adoption (Rose and Manley, 2012; Rose and Manley, 2014). Confirming results outside the construction domain, these studies illustrate that internal and external factors strongly affect firm adoption. Kale and Arditi (2005) observed a strong effect from internal attributes of adopters, whereas Rose and Manley (2012), like recent non-construction diffusion models (for example, Brounen and Kok, 2011), focused on external factors related to the technology's general performance area.

Technical performance areas include the resulting home's energy efficiency or its durability in a disaster but can also include the efficiencies in the process of constructing the home, such as improved material integration and construction speed. Evidence from the building science and construction literature suggests that selection of both individual and clusters of building technologies can significantly affect energy performance (McCoy, Pearce, and Ahn, 2012). These more focused innovation studies provide much more nuance to past models of the innovation process. This work has developed in three main technological performance areas: energy efficiency and green building; building information modeling; and prefabrication.

ENERGY EFFICIENCY AND GREEN BUILDING

Energy efficiency has received considerable scholarly attention in the past two decades, as have corollary performance areas like green building and high-performance housing. Much of this is due to obvious changes in practice. In a general survey, 94 percent of all survey respondents believed that sustainable building trends were growing (Jackson, 2010). Many representatives within the construction and building industry have been exposed to green building projects; at the time of the recession, approximately 67 percent had certified green buildings and 21 percent planned to pursue a green building certification (Ahn and Pearce, 2007).

Many factors have contributed to the diffusion of housing innovation in the energy-efficiency and green performance area. Improved operating performance and reduced initial adoption costs increased the probability of adoption (Harvey, 2013; Beerepoot and Beerepoot, 2007; and El-Shagi, Michelsen, and Rosenschon, 2014). These improvements have been increasingly factored into the prices of residential buildings by various technology brokers along the supply chain (Aroul and Hansz, 2011; Bloom, Nobe, and Nobe, 2011; Dastrup et al., 2012; and Kok and Khan, 2012).

Studying the recent acceleration of diffusion, McCoy, Koebel, and Sanderford (2013) defined a diffusion model for energy efficiency and high-performance housing building products. The work by Koebel et al. (2015) expanded on this work with a similar empirical model for high-efficiency windows that reflected adoption and diffusion theory, research on impediments to innovation in construction, valuation research (hedonic models for pricing residential and commercial buildings), and research on adoption of building construction innovations. The model included product, firm, industry, and market area characteristics, as well as climate, public policy, and time. A major contribution of this research was that it could analyze data on product use in residential construction for a large national sample of individual firm respondents, geo-coded by location and integrated with aggregate measures for industry and market characteristics, climate, public policy, and time. The research team included the following factors (previously noted in the literature review).

- *Product attributes*: cost advantage, price point, performance measures, and the local cost of doing business using a builder panel survey that rated the attributes of all technologies deemed appropriate for modeling environmental goals.
- *Efficiency measures*: productivity values for technologies and the cost of insurance (that is, worker compensation insurance fees separated by the division of work may affect the use of technologies, as some divisions are considered riskier than others).
- *Firm characteristics*: size, organizational capacity and human resources, R&D investment, and presence of technology champions.
- *Industry characteristics*: concentration, supply chain, subcontractor networks, and efficiency.
- *Market area characteristics*: measures for population size, income and wealth (that is, median income and median house value), and location within a network of market areas as an indicator of potential contagion effects.

- *Public policy*: measures for federal stimulus funds (for example, state-level American Recovery and Reinvestment Act (ARRA) funds per capita), green building certifications, utility rebates, state grants, and a variety of other state and local incentives for energy efficiency (EE). This includes the state's sales tax as a potentially negative impact owing to higher costs for green building products.
- *Time effects*: Year is used either as a continuous measure or a discrete dummy variable measure to capture the bandwagon effects reflected in positive impacts of time on use. The innovation chasm shows no effect of time beyond the early adopter stage, and maturation or peak saturation show that time also has negative effects.

Although not focused on the full set of factors that influence innovation processes per se, many other studies of energy efficiency innovations point to one or a subset of factors, typically end-user behaviors. For example, one study of thermostat-set points noted how resident consumption behaviors affect the performance of mechanical systems and thermal enclosures, as well as innovation adoption rates (Brandemeuhl and Field, 2011). Zain et al. (2007) focused on the nexus of humidity, comfort, and energy efficiency. Studies reviewed the use of appliances (Parker, 2003; Hoak et al., 2008; Ek and Söderholm, 2010) and educational campaigns (Fischer, 2008). Zhao, McCoy, and Agee (2017) found that more than 50 percent of energy savings could be attained through a combination of innovation and behavior.

Sustainable property studies examining the value of adopting energy or green certifications ("eco-labels") have also contributed to understanding how the technological complexity of an innovation influences its commercialization, adoption, and diffusion process. Although commercial buildings are the focus of most of these studies (Eichholtz, Kok, and Quigley, 2010; Fuerst and McAllister, 2011; Wiley, Benefield, and Johnson, 2010; Harrison and Seiler, 2011; Gabe and Rehm, 2014; and Bond and Devine, 2016), analyses of the value of eco-labeled housing exist too (for example, Brounen and Kok, 2011; Kahn and Kok, 2014; Bloom, Nobe, and Nobe, 2011; Sanchez et al., 2008; Deng, Li, and Quigley, 2012; and Pivo, 2013). In both housing and commercial property, certified buildings command price premiums and are associated with lower probabilities of mortgage default than similar unlabeled buildings. Eco-labels have become a standard metric of energy efficiency collected by property data services firms and are a key distinguishing attribute (Robinson and Sanderford, 2015). This body of research consistently shows that brokers along the supply chain played a central role in shaping an innovation's progress.

INFORMATION MODELING

Innovative software technologies in the construction sector, such as building information modeling (BIM), are rapidly expanding the potential of decision models and analysis in construction (Golparvar-Fard, Peña-Mora, and Savarese, 2012; Glaser and Tolman, 2008; Ku and Taiebat, 2011; Azambuja et al., 2012; and Pikas, Sacks, and Hazzan, 2013). Furthermore, the construction industry expects future employees to have BIM knowledge and skills (Ku and Taiebat, 2011; Pikas, Sacks, and Hazzan, 2013). BIM software and its use have therefore become the gold standard and one of the most promising innovations in the design and construction industry (Azhar, 2011), supporting many industry technological trends.

Kale and Arditi (2005) developed an empirical model to study the adoption of innovative software for firms in heavy construction. Becerik-Gerber and Kensek (2010) identified the technological and institutional changes of BIM and the resulting challenges within the AEC industry. Although limited to those sectors, many of the lessons learned could be applied to homebuilding innovations.

PREFABRICATION

Construction prefabrication has moved the construction site for most of the building to a manufacturing facility (often termed “off-site” construction). Prefabrication improves predictability and productivity and reduces the risks from site constraints and labor variability. Prefabrication saves costs because components are made in climate-controlled manufacturing facilities where the quality and quantity of material is inspected before it goes to site (University of Washington, 2012; Dougherty, 2018).

The concept of prefabrication in housing construction is not new, but more recent innovations relate to processes in offsite assembly of components of a larger building and its installation (Mullens, 2008). Schoenborn (2012) groups offsite construction benefits in ways that imply more transparent information for various brokers’ involvement in the diffusion process: labor cost reductions, material inventory reductions, overall construction time reductions, and consistent quality. Like other innovations, the decision to adopt prefabrication techniques by an individual stakeholder—and then the patterns across a whole group of stakeholders—depend as much on the idiosyncrasies of their markets at the time of the decision.

Modeling the Housing Innovation Process

Although limited, the recent literature on the housing innovation process and the factors internal to the industry that shape the process' timing and quality provides more nuance to past models. The researchers reviewed the evolution of innovation process (or "pipeline") models to assess their fitness for the contemporary housing industry.

The Traditional Model of the Innovation Process

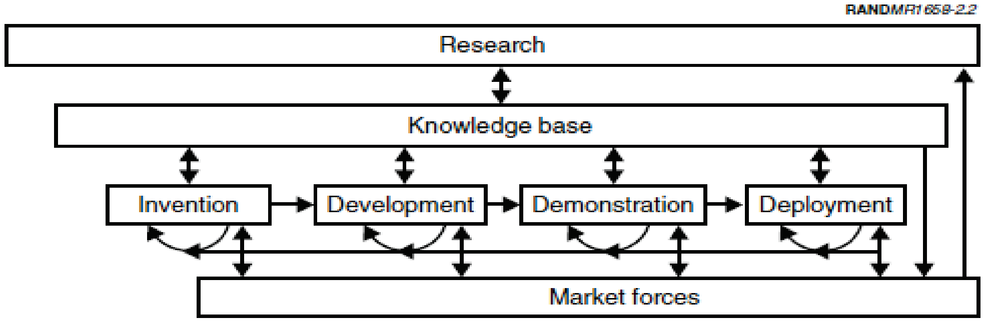
Utterback (1994) discussed three distinct phases of traditional industry innovation models through time: 1) early fluid: product enhancement is critical, 2) transitional: dominant product designs emerge, and 3) specific: competition happens between a few large firms through performance improvements. As RAND previously showed, such linear models of innovation have typically developed within the context of large, integrated firms with abundant funding for R&D and commercialization and with somewhat guaranteed and mature markets.

The RAND "Better" Model

Compared to other industries, residential construction does not follow a traditional model of innovation. RAND discussed several limitations of the linear model for housing, including fragmentation and resistance across the supply chain. The RAND study sought a model that "better addressed the unique characteristics" of the housing industry. Finding no ideal models for the study, the RAND "created a new model that included the best features of others yet was simple enough to inform the policymaking process about ways to better support and accelerate housing innovation" (Figure III-1).

FIGURE III-1

RAND Innovation Model



Source: RAND (2003)

The new model altered the linear progression, replacing research with invention. Other major observations are that 1) research, knowledge, and market forces influence every stage; that 2) consistent interaction is at all stages of innovation; that 3) innovation stops until available knowledge is acquired; that 4) market forces are added for funding needs; and, that 5) feedback is introduced between every stage of the process. The feedback between each stage and both the knowledge base and market forces makes RAND's innovation model distinctly non-linear. The new model sought to accurately explain how research, knowledge, and market forces influence the overall pace of innovation, and abandoned the metaphor of a "pipeline."

Elaborating the RAND Model

Recent studies of the housing innovation process further confirm that the homebuilding industry challenges traditional, linear innovation models (Gann, 2000). The supply chain of housing spans across industries that includes materials (raw and finished) producers, manufacturers, suppliers, land developers, engineers, architects, builders, specialty contractors, financial institutions, insurers, marketers, and consumers (Kahkonen, 2015). Therefore, homebuilding relies on a multiplicity of stakeholders as innovation brokers—organizations that do not originate or implement the final innovation but must engage with innovation to advance its diffusion. The residential building supply chain is decentralized as well, and its stakeholders along the path can strongly influence the information innovations' outcomes.

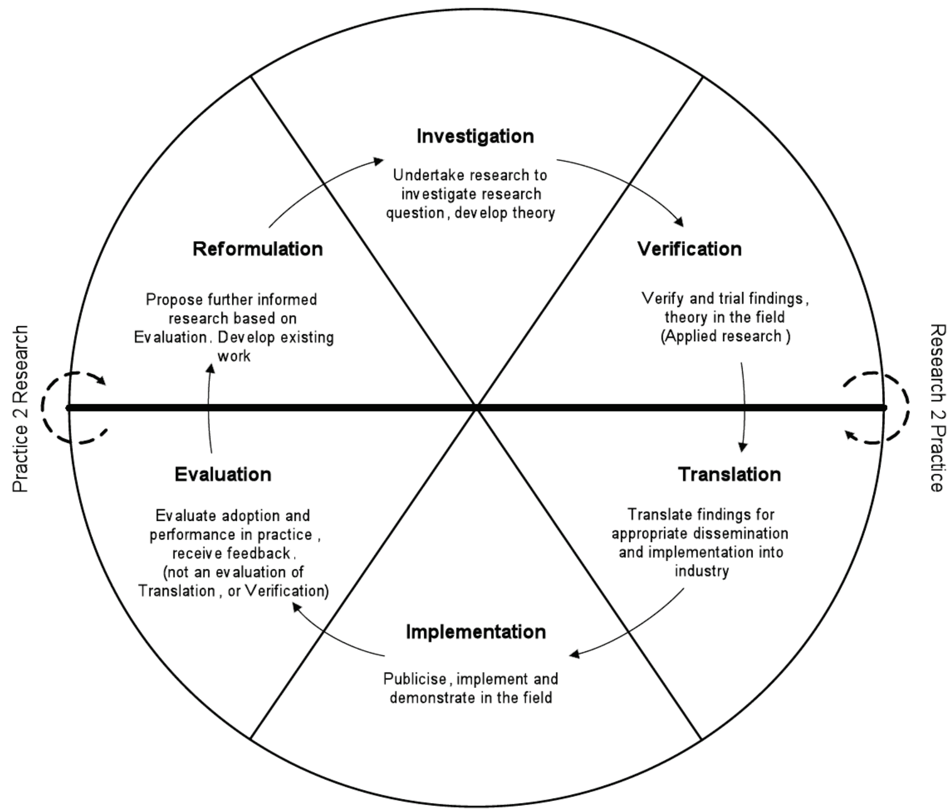
Asynchronous liability also exists, as each stakeholder is not motivated by similar risks and rewards. The decentralization of resources, knowledge, and projects often creates uncertainty and reduces risk tolerance. Further, many housing stakeholders do not fully comprehend the benefits of innovation (Lines et al., 2015). In complexly structured industries, the ability for innovation to draw on the knowledge of multiple stakeholders along the way to market is necessary to reducing risk. Larger firms could serve as brokers of knowledge through material suppliers, manufacturers, distributors, retailers, developer/builder firms, installers, regulatory bodies, and end users to improve the process of innovation adoption.

Since the RAND model was developed, other researchers have also criticized the traditional linear models for practical applications of innovation theory and translation into practice. Bielak et al. (2008) disputed the notion of a linear progression from scientific research to a dissemination phase for a wider audience to adoption and practice by end users, such as industry and/or government. Butcher and Jeffrey (2005: 1273) argued that the generation and transfer of knowledge are “non-linear processes of problem identification and analysis, communication, interaction and learning by and among the various partners in the innovation process.” This new understanding of research translation for construction management research topics is persistent across the literature.

Blismas, McCoy, and Lingard (2009) developed a “translational research model” that described an optimal relationship between industry and academia in the construction industry (Figure III-2). Where RAND’s model delegated feedback loops to specific stages of the innovation process (that is, “invention;” “development”; “demonstration”; and “deployment”), Blismas’ model delineated research aspects (“reformulation”; “investigation”; and “verification”) and market forces (“translation”; “implementation”; and “evaluation”) for one overall feedback loop between market forces and research processes. One might consider Blismas’ model as an expansion of RAND’s feedback loops by stage. Blismas’ model relied on consistent interaction between industry and academia to provide a knowledge base for effective translation and success. Cyclical model of translational research may better facilitate research into practice than traditional linear models (Ledford, 2008).

FIGURE III-2

Research to Practice Cyclical Model



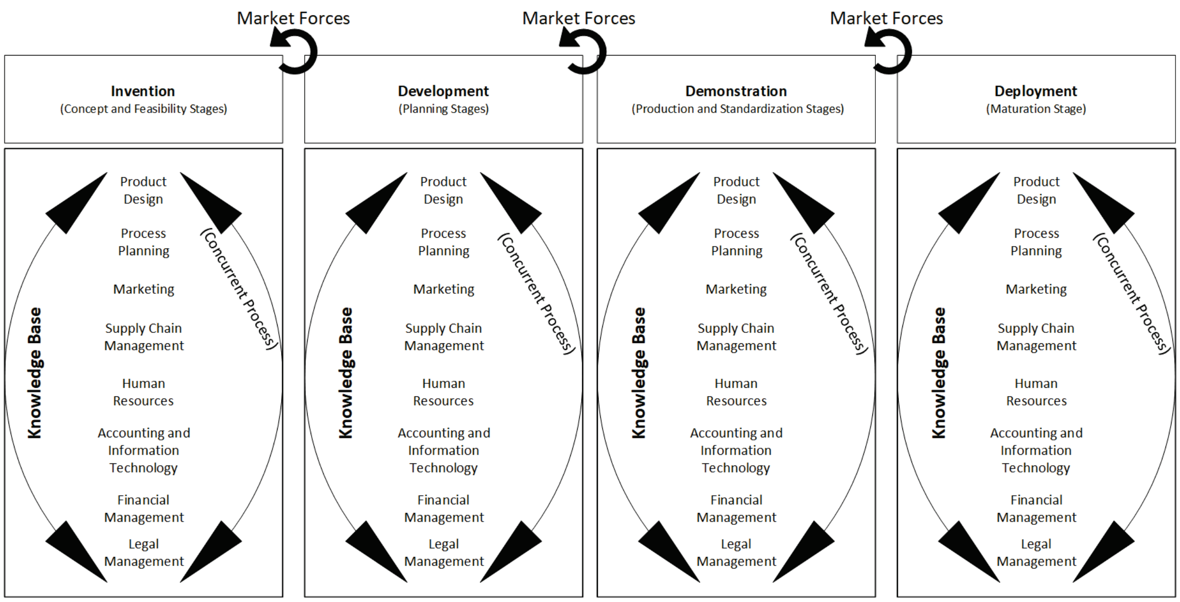
Source: Blismas et al. (2009)

Although the translational cycle model might apply to academic methods and processes, it doesn't necessarily fit with alternative types of innovation brought to market without theory or research. Considering the decentralized nature of the residential building supply chain with individual stakeholders who do not fully comprehend the benefits of new-product adoption, developing a new product in homebuilding requires key brokers to coordinate knowledge across all relevant stakeholders. Building on the concept of concurrent commercialization, we elaborate on the RAND model with a process that involves feedback loops between research and market processes in the design and development of a new product from the earliest stages.

Expanding the RAND model requires product-development decisions to a knowledge base of all business functions: product design, process planning, marketing, supply chain management, financial management, human resource management, accounting and information technology, and legal and regulatory management. Expanding the model also requires the brokering of knowledge and feedback from market forces across all stages of development: concept, feasibility, planning, planning review, early production, early production review, and standardization. Drawing on RAND, concurrent commercialization and Blismas' models of innovation development, we posit the following expansion of existing models for the homebuilding industry.

FIGURE III-3

Homebuilding Innovation Model



The homebuilding innovation model (Figure III-3) requires that each stage of product development contain a broad set of knowledge across all necessary business functions and a concurrent process of sharing important information for success. The model also interfaces from research to practice with feedback from market forces that is required before moving between stages of development.

Implications for Innovation Policy

Ultimately, the current report's review of the few scholarly monographs that have been produced over the past two decades on the subject provides one lesson to this audience: anyone planning an investment in innovation must understand the factors that shape how an innovation gets to market. Rather than depending on the idiosyncrasies of the housing market, innovations can follow a path to market that reduces information asymmetries that increase risk. Success in housing innovation is achieved by considering the innovation context more broadly (functional areas) and increasing the integration of market forces and concurrency of knowledge in the process.

IV. The Contexts of Past Federal Efforts for Technological Innovation in Housing

C. Martín

The preceding chapter explores how individual technologies and technical performance areas within the world of housing design, building, and remodeling have unique innovation paths that vary based on technological specifications, local supply chains, and geographic markets. As this chapter suggests, however, public-sector interventions into these paths are also idiosyncratic.

The researchers reviewed the historical record to better understand patterns across the political, policy, and industrial contexts in which the public sector has chosen to intervene in housing R&D and innovation adoption, and the outcomes of those interventions.

Key Observations

Three core patterns were identified in the historical review. The first pattern noted across these programs has to do with political philosophies associated with public funding of applied research. RAND (2003) noted key policy rationales for intervention at all stages of the housing innovation process, from basic research through commercialization. The historical review suggests that the use of these justifications has varied. In several instances, policymakers argued against public-sector intervention in the housing industry's operations and products. For many, this included prohibitions on funding applied research and development. In other instances, public intervention at later stages of the innovation process has been justified by policymakers because of the perceived persistence of information asymmetries between key stakeholder groups (such as manufacturers and builders and, in turn, builders and consumers). However, despite some tension, the record suggests that the philosophical argument in favor of intervention has dominated.

Regarding political philosophy, the record suggests that arguments in favor of federal intervention in housing innovation have largely dominated.

Regarding policy context, the timing of interventions' starts provides the most revealing trait. These moments have been marked by calls for a pressing national emergency or perceived societal need. A housing crisis (poor quality or affordability) or external danger (energy costs or climate change) are common rallying calls for housing innovation. Investments in housing innovation presumably bring returns in the form of numerous societal benefits, or the aggregated improvements in productivity, growth, health, and non-quantifiable changes to wellbeing (Tewksbury et al., 1980). Support of R&D for its own sake or because of the industry's significance alone have not resulted in long-running R&D programs, nor have programs that attempt to address too many issues.

Policy contexts also matter. Programs typically launch during a perceived national emergency or for which an urgent societal benefit is desired—such as substandard housing in the 1960s or the 1970s' energy crisis.

A third pattern is notable across these programs regarding the state of the housing industry as well. These programs typically started during periods of industrial growth; stakeholders tended to call for R&D when the industry had the financial and knowledge resources to participate.

Periods of growth have typically marked the industrial context in which R&D programs begin.

The combination of the three factors—political agreement on industrial research, a perceived policy crisis or challenge, and a growing housing industry—marked virtually every instance of public-sector interventions into the housing innovation process. This is particularly true of those that existed beyond any one executive branch administration. Specific policy and market contexts play a critical role in determining whether any innovation intervention is conceptually feasible, underlined by political philosophies regarding the role of government in promoting industrial innovation as applied to housing.

Past Public-Sector Housing Innovation Programs

RAND (2003) provided a useful history of housing-specific R&D efforts involving the federal government. Written at a time when multiple housing R&D programs flourished, the 2003 report argued that the evolution of public R&D investment had been for the better. However, why and how these programs came to be were questions left unanswered, and whether their perceived success or failure was due as much to the policy conditions and industrial context at the time as to their effectiveness.

Responses to these questions must begin with a historical understanding of the capacity of scientific, engineering, and related disciplinary research to provide societal returns in exchange for the public-sector investment—and private returns to business investment—which runs throughout the modern American era. When Vannevar Bush first proposed institutionalizing a national R&D policy and creating what would become the National Science Foundation after the Second World War, few, fragmented applied research programs were within the federal government (Zachary, 1997). Bush valued the significance of applied research and development enough to note that one function of national policy would be "to devise and promote the use of methods of improving the transition between research and its practical application in industry" (Bush, 1945).

However, the depth of the belief in publicly-supported applied R&D has varied significantly over time based on policy conditions and the state of the housing industry. In turn, how that belief manifests into operational and effective public-sector R&D programs or private-sector laboratories and commercialization efforts also fluctuates. At peak levels in the late 1990s, for example, federal funding for applied R&D and other commercialization programs related to housing technological innovation averaged over $200 million annually—a sizable investment although still less than 1 percent of the national non-defense R&D budget.

RAND (2003) reviewed two historical and four contemporary housing R&D programs in the federal government. Others (Martín, 2015) have supplemented these reviews with more detailed documentation of authorizations, appropriations, and internal reviews of these and a handful of other programs. Below, we update these reviews to better illuminate the relationship between policy and industrial contexts and resulting housing R&D programs.

Three eras of housing R&D programs emerged from this review. The first includes all the early housing interventions between the creation of HUD and the energy crisis, that is through the 1960s and 1970s which include the Civilian Industrial Technology Program and Operation Breakthrough. The second group are those that emerged during the expansive housing growth in the 1990s, including the U.S. Department of Energy's (DOE) Advanced Housing Technology Program (1991) and Building America (1995), the U.S. Environmental Protection Agency's (EPA) ENERGY STAR for HOMES (1995), and HUD's Partnership for Advancing Technology in Housing (1998). The last group of programs include those developed after the housing downturn, primarily DOE's Better Buildings program (2010).

Early Housing R&D Programs

After the post-war establishment of a public-sector research and development policy in the 1950s, the federal government launched a handful of programs that address the housing industry's innovation process or adoption.

CIVILIAN INDUSTRIAL TECHNOLOGY PROGRAM (1962)

The first R&D program established to address housing technology was proposed in 1962, as part of a larger cross-sector commercialization program President Kennedy's economic advisors proposed to increase economic productivity in the industries "which are not adequately stimulated by private market opportunities" (Kennedy 1962). Although never implemented, the Civilian Industrial Technology Program (CITP) anticipated supporting both applied research at universities as well as dissemination activities to local industries and stakeholders.

The construction industry was an early focus of CITP, although the residential construction industry was neither experiencing extreme growth or contraction at the time. The policy argument for CITP's role was largely based on the potential economic gains from any public R&D investment regardless of sector and sector conditions at the time. The case for public intervention was further strained when improvements in the costs, delivery time, or quality of new housing were not apparently needed—at least according to industry leaders. Ultimately, the CITP was never authorized as a formal program that included the construction industry (Nelkin, 1971).

Two reasons have been suggested for the CITP proponents' failure. First, some had fundamental concerns regarding public funding for the later stages of civilian technology innovation as a substitute or even complement for private-sector funding. This difference in policy philosophy around the role of government had not been aired during the post-war military-industrial R&D buildup up to this point. As the first effort proposed by the federal government to work on the specific industry's technology development, commercialization, and adoption rates for general consumer benefit, CITP suffered from the lack of resolution to the disagreements about the kinds of investment needed to spur research in technological innovations.

Ironically, it was the construction industry itself that lobbied against the CITP, partially because the program would infringe on the industry's affairs and disrupt the market (Teich, 1985). As the second and more political reason for CITP's demise, the builders argued that other policy challenges beyond innovation were more pressing. Product manufacturers were also fearful that federal research products could compete with theirs because CITP had no provision for public-private research partnerships. Thus, without the buy-in of industrial partners, CITP was doomed.

Because CITP for housing was never authorized or implemented, the only operational lesson is the role of early and robust partnerships in establishing effective programs given CITP's oversight in understanding the motivations of industry stakeholders. A related contextual lesson from CITP comes from its proponents' disengagement with these stakeholders: CITP had no clear industrial or societal motive for institutionalizing an R&D program beyond general economic productivity. CITP could not articulate a compelling vision for innovation to the very industry it intended to innovate.

OPERATION BREAKTHROUGH (1968)

A few years later and after the formal establishment of HUD, Operation Breakthrough built on the lessons learned from the CITP experience while presenting a more compelling policy justification for the federal government's investment in housing research (Martín, 2015). Breakthrough also was seeded at a unique moment in the housing market cycle; when the program was first proposed in 1968, the housing industry reached a peak in both production and home values. The desire to overcome perceived production constraints served as the rationale for technological investments, but Breakthrough was also designed with an eye to providing societal benefits from "mass housing" of up to 10 million new units—a goal aligned with concerns surfaced in the national discussion about urban housing at the time.

The combination of industrial capacity to foster R&D partnerships with the societal mission presented cemented the opportunity for a new housing program. Although the Johnson administration established the goals and priorities for a housing R&D agenda and appropriated funds to that end, its design and operations were left for the next administration. The Nixon administration proved to be broadly supportive of applied research—a fact that would be confirmed in its 1971 proposal for a New Technologies Opportunities program (Block and Keller, 2011). By 1969, Operation Breakthrough was fully implemented with active involvement by HUD leadership under Secretary George Romney, a former auto industry executive.

Where CITP failed to partner with industry, Operation Breakthrough used two tactics to develop a mutually satisfying relationship. The first involved convincing an industry that had been suspicious of governmental meddling only a few years before to support an R&D program. Breakthrough's proponents articulated a set of R&D activities that intervened at all points of the innovation process and not just direct research funding. Operation Breakthrough proposed to address not only the barriers to housing innovation, but also the numerous bottlenecks for overall productivity in the housing industry (HUD, 1970). R&D would be a means to an end that the industry could support.

The second tactic was the direct involvement of organizations from the building industry via public procurement. Teams of construction firms and engineers bid to develop and demonstrate new large-scale housing system prototypes that would be incorporated into new HUD-owned housing. These systems would integrate all aspects of the design and construction process, including zoning assessments, multiple-use designs, streamlined mass-produced building materials, and expedited construction methods. Direct financial incentives for participating in Operation Breakthrough complemented the intrinsic benefits to the industry from partnering with the public-sector.

However, the same strategies used to justify Operation Breakthrough's creation would become the program's downfall. Breakthrough had grander ambitions than it could execute well. Attempts to address all challenges to housing production while grappling with the R&D process proved to be too difficult, even with the substantial funding the federal government appropriated to HUD in the program's duration (about $72 million at the time). As a 1976 RAND report suggested, this approach to R&D was "several orders of magnitude more complex than simply funding R&D projects" (Baer, 1976). That complexity was far more than the program's resources and leadership could absorb (GAO, 1976).

Breakthrough provides other key operational lessons beyond appropriateness of resources to mission. HUD had virtually created laboratory conditions by creating an artificial, non-market demand for housing innovations. Although technological spillover from public-sector investments was common in other industries, consumer or industry demand was simply not enough for Breakthrough's technologies. Further, the waivers that HUD enforced were essentially loopholes from the traditional state and local building regulations that created another artificial condition, despite HUD's attempts at monitoring innovation constraints. By creating an artificial R&D pipeline parallel to the industry's reality, Breakthrough ultimately "did not create the large, continuous markets necessary for efficient industrialized housing construction" (GAO, 1976). Combined with a major industry downturn in 1973, perceived failures in the program's short-term results led to the program closeout the next year.

In short, Breakthrough offers several lessons for future applied R&D programs in housing: 1) to accurately and regularly assess market demand in light of different housing markets and fluctuating cycles; 2) to design an appropriate number of activities that could be feasibly undertaken within the desired policy timeframe and appropriated budget; 3) to coordinate the activities in partnership with industry and other stakeholders in the areas in which the research would be applied; but also 4) to operationalize that partnership within the actual supply chain and its labor, material, and regulatory constraints.

DOE ENERGY POLICY AND CONSERVATION ACT PROGRAMS (1975) AND OFFICE OF CONSERVATION AND RENEWABLE ENERGY (1981)

Many of the assessments of Operation Breakthrough were conducted at a time when other agencies in the federal government were considering their own versions of housing R&D and demonstration programs. After Nixon's warning of an impending energy crisis due to the first OPEC embargo in 1973, the Energy Research and Development Administration was created under President Ford's 1974 Energy Reorganization Act. The new unit within the then Federal Energy Administration was charged with consolidating all energy-related research projects, including those focused on renewable energy sources and possible energy conservation techniques (Fehner and Holl, 1994). These remained relatively limited, and a handful of states created their own policy and research agencies such as the New York State Energy and Research Development Authority and the California Energy Commission.

Both the crisis and substantial national research investments in the building sector's energy use did not fully materialize in the federal government until Carter's 1977 declaration of a national energy emergency as the "moral equivalent to war" (Carter 1977). The Department of Energy (DOE), established that same year, further consolidated all federal energy-related research into one agency, but established a structure for the staff and resources according to stage along the R&D developmental process rather than by energy source or use; specifically, the Office of Energy Research coordinated basic scientific projects, the Office of Energy Technology led applied research, and the Offices of Resource Applications or Conservation and Solar Applications focused on commercialization.

Early building-related research was limited, although solar renewable research projects received significant funding. By 1979, the peak year of the Oil Crisis, the administration began expanding R&D efforts to focus on consumer demand concerns with proposals for a loan bank and tax credits for residential solar installation. Rather than a call based on housing needs, the federal government articulated an urgent need for investing in R&D with potential housing applications for energy consumption reasons. The housing industry had also recovered from its Breakthrough-era contraction by then, although the energy R&D proponents had not articulated a role for them as much as renewable energy providers.

Amid the crisis, DOE was reorganized again to better address sector-specific needs, including a distinct energy conservation office that later would become the Office of Conservation and Renewable Energy under the Reagan administration. Under new leadership by Secretary Edwards, the R&D focus shifted in 1981 from applied research and commercialization to basic research.

With continued bipartisan congressional support for R&D funding in general, however, the administration moderated its cuts to focus on industry education ("technology transfer") and consumer awareness campaigns in addition to basic research, while steering clear from applied research and commercialization. DOE described energy conservation and efficiency efforts as one of the "energy triad" of resources (along with coal and nuclear energy) to be further tapped. A minimal funding stream to technology transfer efforts was sustained, although without explicit support from the housing industry. Appliance standards were the primary housing-related focus of these conservation efforts. Although modest, the development of energy efficiency standards persisted as both operationally manageable and politically acceptable efforts. By the mid-1980s, the housing market had once again turned downward. Decreasing energy prices further disincentivized energy-efficiency R&D.

The Federal Housing R&D Boom

It was not until a decade later that housing innovation resurfaced in national policy circles, and it did so across agencies and private partners, and with massive resources.

DOE ADVANCED HOUSING TECHNOLOGY PROGRAM (1991); OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY (1993); BUILDING AMERICA (1995)

President George H. W. Bush announced the development of a new national energy policy early in his administration, and held hearings throughout 1989 and 1990, eventually reporting that the "loudest single message was to increase energy efficiency in every sector" (DOE, 1990). Combined with energy price shocks from the Gulf War, these comments led to modest attention to residential energy efficiency R&D and related commercialization efforts that led to the 1992 Energy Policy Act. The Act increased regulatory requirements across numerous industries, while incentivizing new R&D. With the housing market heating up again, the DOE under the Bush administration supplemented its appliance efficiency and awareness campaigns with funding increases for conservation every year through 1993.

New funds were used to set up additional residential construction energy efficiency pilots and demonstrations with private-sector partners and the national laboratories, including seed funding for the Advanced Housing Technology Program (AHTP), modeled after the National Institute of Standard and Technology's Advanced Technology Program, launched in 1991. Although only a component of the Department's broader energy-efficiency portfolio that eventually merged into others because of the change in administration, the AHTP program attempted to pick up where Breakthrough left off with comprehensive assessments of the industry's innovation rate. AHTP also built on Breakthrough's lesson not to attempt addressing too many of the industry's other productivity challenges. AHTP planted the seed for what would become a broad set of programs across the federal agencies.

The Clinton administration's push to fund a wide range of R&D programs centered especially on energy-efficiency efforts, reflecting a policy perspective that societal benefits would result from integrating reductions in energy use and environmental impacts with economic growth. Applied housing research suits this objective well because of both the sector's size (which, by the early- and mid-1990s, was formidable and ever-growing) and the potential to yield significant gains in energy efficiency with relatively small but pervasive technological changes.

DOE's newly renamed Office of Energy Efficiency and Renewable Energy cast a wide net in its programming, tying the Department's previous energy efficiency R&D and commercialization work to the administration's new Climate Change Action Plan through the pursuit of voluntary public-private partnerships. By 1994, the budget for energy efficiency applied R&D, technology transfer, commercialization, and awareness programs in general increased dramatically. This increase was reflected in the unprecedented public-private cooperation in R&D, as well. The number of Cooperative Research and Development Agreements (CRADAs) between the federal government, industry, and university researchers doubled, for example.

The emphasis on the later stages in the innovation stages from applied research departed from the traditional emphasis on basic research. Centerpieces of this work have been advocacy for DOE's Building America and Building Energy Codes programs (the development and demonstration partnership with procured housing consultants and builders), along with technical assistance to EPA's ENERGY STAR for Homes program (the certification and awareness campaign program). These three programs were designed to serve as interventions along the length of the housing innovation developmental process.

In contrast to previous housing technology programs, these DOE activities were created at a time when the industry was recovering from a modest contraction, although the recovery yielded increasing production and growth for the industry for over a decade to come. Industry support resulted from the immediate returns to consultants, energy raters, and builders who participated in

Building America teams, the competitive advantage of marketing energy-efficient homes, and in the operational preparation for likely regulatory changes. Policy support for these public-private partnerships in housing R&D persisted during the administration transition in 2000; the George W. Bush administration added supplementary programs such as the Zero Energy Home program and demonstrations of water management and indoor air quality technologies during the next few years.

EPA ENERGY STAR FOR HOMES (1995)

Building off its successful appliance and electronic product labeling program, the U.S. Environmental Protection Agency (EPA) launched the ENERGY STAR for New Homes program in October 1995. Housed within its climate change response programs, ENERGY STAR for New Homes was designed as a voluntary energy-performance certification and label relying on proven design, materials, and construction techniques. In many cases, though, the performance criteria became standards for national housing programs late in the 1990s and were adopted into state and local building codes. Because of the proliferation of energy regulations meeting the originally voluntary performance criteria set by the program, ENERGY STAR revised them in 2006—a year of near-record housing construction and home prices in the U.S. Like its DOE counterparts, ENERGY STAR expanded to include programs for other EPA goals, such as water conservation and indoor environmental quality.

Although not a housing R&D program, ENERGY STAR for New Homes was the most successful of the housing technology programs coming out of the 1990s as measured by the number of housing units directly affected (tested and labeled)—a testament to the effectiveness of voluntary partnerships in meeting both the productivity gains desired by industry and the public sector's societal goals. The program's known capacity to leverage modest public funding with industry marketing and promotional resources and, in turn, private R&D capacity, provides an operational lesson about the appropriate sizing of public efforts, while highlighting how market demand influences innovation.

HUD PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING (1998)

The operational lessons regarding collaboration with industry within housing R&D were not taken on solely by the federal departments of energy and the environment in the 1990s. The same year that DOE proposed the Building America program, the Subcommittee on Construction and Building in the National Science and Technology Council's Committee on Civilian Industrial Technology set forth a plan to collaborate with the private sector to develop a comprehensive national R&D policy (NSTC, 1994).

The original plan covered the entire construction industry and focused solely on the benefits to construction productivity and workforce safety. One year later, the plan expanded to include a broad set of ambitious goals for performance improvement in U.S. housing, such as a 30-percent reduction in “first costs” for residential construction (NIST, 1995; NAHBRC, 1998) that, in turn, expanded to an even wider and more aggressive set of goals when the Clinton Administration proposed the Partnership for Advancing Technology in Housing (PATH) in 1998 with robust and explicit industry support.

PATH was housed as a separate office managed under HUD’s Office of Policy Development and Research (PD&R). The proposed goals for improving both industry innovation rates and simultaneous housing and housing industry performance were immediately identified as too broad and insurmountable for a program allotted such modest resources and charged with coordination across numerous public- and private-sector partners (NRC, 2002; 2006). In the aftermath of the 2000 presidential election, the program’s administration reverted to PD&R staff. The goals were also restructured to follow along the housing innovation process without preference to any specific housing performance area (for example, energy efficiency or durability) for new single-family housing (PATH, 2005)—a strategy that was operationally appropriate and synchronized with industry, but not politically topical.

Continued industry support and advocacy on the program’s behalf supplanted administrative support for the program, resulting in diminishing appropriations until the program was terminated in 2009. PATH, then, was ultimately the least sustainable among the suite of federal housing R&D programs coming out of the 1990s. Although it implemented several of the fundamental policy lessons learned from the previous programs regarding partnerships and political support and existed at a time of growing industrial capacity, it failed to articulate a compelling societal need that could translate into a political catalyst for support. Combined with the massive downturn in the single-family housing sector in 2008, the policy and industrial conditions under which PATH was justified no longer existed.

Post-Recession Federal R&D

The recession left a mark on all the boom-period programs, particularly those focused explicitly on the housing innovation process like PATH. However, one set of R&D activities was retooled for the new context.

DOE BETTER BUILDINGS (2010)

In contrast to other programs, the various DOE residential R&D programs received a boost in the aftermath of the housing market crash. This expansion came on two fronts. First, the infusion of massive resources from the 2009 American Reinvestment and Recovery Act (ARRA) provided DOE with resources to expand many core technology tools and research efforts (such as home energy scoring tools). ARRA's $40 billion for energy efficiency and renewable energy programs, including $2.9 billion to weatherize low-income homes, expanded research programs such as the Better Buildings initiatives, which included the Neighborhoods Program's substantial state and local energy block grants and the Residential Network of housing and energy-efficiency service providers; and a host of other market-supporting efforts that secured an ongoing demand for current and future energy-efficient innovations. The efforts focused on existing homes—the sole growth area in the depressed industry and the focus of broader national recovery goals.

Despite the downturn in the housing market, the administration made the policy case via executive initiatives, such as the Vice President's "Retrofit Ramp-Up" that continuing—and dramatically expanding—federal support for housing R&D and related housing innovation programs was needed to respond to the merging national emergencies of an underemployed workforce, persistent energy and environmental impacts, and a markedly altered housing industry. Support from industrial sectors, such as energy-efficiency service providers and remodelers, buoyed this effort. Viewed against past housing R&D programs, the post-recession DOE residential programs broke the pattern of industry support for federal intervention only during times of growth and peak production.

DOE also restructured the operations in its Office of Energy Efficiency and Renewable Energy to better align its historical R&D and demonstration programs like the Emerging Technologies and Building America programs with such demonstration and commercialization programs as Zero Energy Homes, Solar Decathlon, and Home Performance with Energy Star, and with the marketing and regulatory pull of its building code advocacy, ENERGY STAR (with EPA), and the new ARRA-funded assistance programs. These programs pivoted from their previous focus on technological change in new single-family housing construction to the remodeling and multi-family housing sectors (DOE, 2015). This new "Residential Building Integration" involved an alignment of activity specifications across the scope of residential energy R&D needs. By 2010, DOE envisioned the effort as an opportunity to "road-test" building science measures targeted for the next new homes specification while attempting to promulgate technologies and best practices established in their Building America research program" (EPA, 2010). Taking this iteration of operations as the latest stage in a continuum of programs and activities, then, the DOE residential energy efficiency programs have been the longest running housing R&D programs in federal history and the most comprehensive regarding the number of touches along the industry's innovation path.

Implications for Innovation Policy

In the review of past programs, three patterns emerge regarding the context in which publicly-supported applied research is conceptually justified and realistically developed. These patterns involve philosophical rationales, policy contexts, and industrial contexts.

Philosophies on government support for applied research

First, underlying all contextual conditions is a philosophical tension around funding applied research with public-sector resources. Conflicting economic, policy, and political reasoning has been put forth for several decades about whether public intervention in applied research is justified (Mokyr, 1990). Three core themes arise in these debates (NRC, 1986; 1992b). First, the social value and economic benefits from public investments must exceed the cost of intervention—with the argument being over what is measured and how. Second, some are concerned about which economic area is worthy of public investment and whether a social or economic reason why supporting innovation in a specific sector exists. Third, economists and policy analysts disagree over whether the intervention distorts markets by conducting the R&D work that the private-sector (and then, only certain private players) could do and from which it will directly benefit but which any one player cannot readily carry out on its own—that is, that the problem is market failures or transaction cost challenges (Weimer and Vining, 1992; Zerbe and McCurdy, 1999).

Regardless of the nature of the failures, they have been used to justify alternate types of public interventions, such as regulatory policy (White House, 1993). They were also instrumental in establishing a series of R&D policy that helped define when and how the public sector should intervene in applied research. From the Stevenson-Wydler Technology Innovation Act of 1980, 1984 National Cooperative Research Act, and the 1986 Federal Technology Transfer Act to the 1989 National Competitiveness Technology Transfer Act, several laws were passed to encourage public-sector intervention in innovation processes. More recently, the current administration has asked federal agencies to refine their assessments of R&D programs to focus on basic and "early stage" research while reducing "overlaps with industry in later-stage research, development, and deployment of technologies" (OMB, 2017a).

For housing, the inability of individual firms to protect intellectual property and obstinate information asymmetries are two types of market and transaction failures noted in the literature (NRC, 1992a; RAND, 2003). The failures of public goods, externalities, and information asymmetries were explicitly referenced in the creation of PATH, for example (NRC, 2000). Ultimately, the above historical record suggests that the philosophical arguments in favor of federal intervention in applied research in housing have dominated. With rare exception, government resources being used for applied research purposes has generally had bipartisan support, and specifically for housing R&D, since the establishment of scientific and engineering research policy in the post-war era.

In this chapter, for example, we discussed the first program, and the only one to have not launched because of stated ideological differences sheds some light on these arguments: CITP. Supporters argued that, at a fundamental level, the industry was an innovative laggard and technologically obsolete, so public intervention would improve technology transfer. Opponents, however, argued that the industry was already productive and sound, innovation in housing occurred through the market already, and applied R&D programs would threaten the balance between public and private sectors. CITP, arguably, overextended the federal role. The success of CITP's opponents was short-lived given Operation Breakthrough's publicized launch. Beyond CITP and the reductions in energy-efficiency and renewable energy research in DOE in the early Reagan years, however, support for investments in housing innovation have largely been bipartisan. Even Operation Breakthrough, signed into creation by a Democratic administration and Congress, was enthusiastically implemented under a Republican one.

One potential explanation for this evolution has been the increased economic justification for public-sector R&D intervention. As early as the 1950s, Vannevar Bush noted "the benefits of basic research do not reach all industries equally or at the same speed" (Bush, 1945). However, the fundamental disagreement about the public involvement in free markets and their stakeholders' innovations persisted (NRC, 1986). Advanced economic exploration of the broader societal benefits from investment came in the early 1990s and soon served as fundamental defenses for public decisions to venture into housing R&D (Romer, 1990; Jaffe, 1996; NRC, 2001; Martín, 2006). Peer reviews of building industry R&D investments confirmed these barriers and the need for public investment to overcome them (NRC, 1992a), presciently seeing programs later that decade.

A second argument in favor of supporting housing R&D is that the government has a substantial procurement interest in the eventual product (Nelson and Langlois, 1983). Proponents of Operation Breakthrough and PATH often noted the budget significance of federal housing assistance and military housing as a justification for investments in cost-saving and performance-enhancing housing technologies. Control over the physical quality of these housing sectors has waned over time (such as through HUD's Rental Assistance Demonstration), but federal rental subsidies have reached $40 billion annually. The growing shortage of affordable housing for very low-income renters represents a significant federal policy interest in technological solutions that could expand the privately produced supply of naturally affordable housing.

Over time, then, the fundamental argument over whether housing R&D has a public role has been substituted by differences over the form and substance of that role. The core policy decisions now center on the appropriate balance in activities between basic research, applied research, and commercialization activities, and between direct public funding of research versus creating financial and other incentives for industry research. By 2007, for example, the federal non-defense R&D budget across all subject areas was evenly divided between applied and basic research efforts (Congressional Budget Office, 2007).

The transition to the Trump administration presents a new chapter in this philosophical debate, with policy statements in early budget proposals taking a position against applied research. For example, a proposed cut to DOE's program funds "reflects an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies and focuses resources toward early-stage research and development" (OMB, 2017b).

Policy Contexts

A second core pattern has to do with the policy context—that is, the social, economic, and political circumstances in which needs arise and rules, regulations, laws, and resource allocations are developed. Like philosophical arguments, policy contexts have varied widely since the first housing R&D interventions were proposed. However, the timing in which this pattern has manifested in housing R&D is revealing.

These moments typically have been marked by a pressing national emergency or perceived societal benefit. The articulation of this urgency by policymakers has served the dual purpose of framing the goals and activities of the program, but also presenting a rallying cry for industry participation and consumer demand. This trait has especially marked the programs that are either particularly impactful in terms of U.S. housing quality changes or sustained over time and administrative transitions. An early challenge presented to CITP, for example, was its inability to articulate a national goal and resulting program mission for its existence beyond the conceptual returns to the general economy from research investments in major industries.

Several subsequent programs fell into similar traps either during their development stages or after only a few years of implementation, from Nixon's 1971 New Technologies Opportunities to the demise of NIST's Advanced Technology Program (2005) and Technology Innovation Program (2012). PATH's 2009 termination can arguably be classified in this group too, since the program was unable to foment a broad industrial and policy constituency to support its revised goals. As Teich argues, however, they were political failures, not technical failures (1985).

The historical record suggests that the programs that articulated a clear and focused goal in relation to a pressing societal problem were more likely to be sustained in terms of financial and advocacy support, even when the expected societal returns to the public-sector investment are not realized for decades (when policymakers have changed and the causal links to the investment are blurry) or when the specific theory of change and consequent portfolio of activities were revised along the way. Proponents believed that investments in housing innovations could at least partially address the problem and result in other societal benefits. In the housing R&D world, the pattern of having compelling policy arguments started with the housing access issues in the 1960s followed by the 1970s' energy crisis.

The programs with any measure of success have also survived political transitions, suggesting that that the policy justification is compelling enough to overcome modest difference in political philosophies regarding the public-sector's role in applied research that are described earlier. As Noll and Cohen suggest, R&D efforts are those that are insulated—although not isolated—from changing administration priorities (1986). In fact, ideologically motivated projects or political pressures are reported causes of failure in R&D (Ahearne, 1986). Politics, then, are not as significant a determinant of housing R&D efforts as policy.

Industrial Contexts

A third pattern is also detectable across the fluctuating industry characteristics and market dynamics during which these R&D programs operated. The industrial context in which R&D programs were launched tended to be marked by growth in production. Whether on the upswing after a contraction or near the peak of the housing production cycle, stakeholders tended to call for R&D investment in both industry and public-sector only when they noted the industry had the financial and knowledge resources to participate. In contrast to other industries in which the R&D has been central to their organizations' business models during retrenchment, resources for R&D among housing stakeholders were typically allocated as distinct from regular operations—hence, the research investments only in market upswings.

Across the programs reviewed in this chapter, a positive state of affairs in the housing market overall appears to play a significant role in defining industry needs for R&D. In almost every program case, the industry's production was either on the upswing or (as we can see with historical perspective) at peak levels in the market cycle. Some qualitative historical evidence suggests economic fluctuations in the housing market partially determine the rate of innovation. This finding is supported by studies in economic theory, although actual empirical analyses are sparse (Myers, 2016; Bon, 1989).

Highs and lows in housing markets dramatically shape the ability to invest in research and development, to provide information, education and training in the industry, and bring attention to the industry's innovation rates to the point of enacting industrial or governmental policy responses. The argument supporting this pattern is that, during market highs, the housing industry has the financial resources for innovation investment but no time remains for solely private-sector innovation investment and commercialization, and incentive or advantage for a single stakeholder to take on the R&D investment because of high demand for the existing product is scant. During market lows, not only does the reverse hold, but no demand for housing means no demand for innovation.

In either case, little "demand pull" exists for innovations without an external policy-related prompt (like energy regulations, public health hazards, or housing affordability crises). "Supply push," however, could be a driver of housing innovation during both peaks and valleys when manufacturers and builders seek a competitive advantage. The question is whether the public sector can time interventions to match the magnitude and direction of the industry's upwards swing in a cycle and structure the intervention's operations and activities to ride out the downturn. A 1992 National Academies committee report suggested three dominant motives for public-sector involvement in new building technology and innovation: "1) to achieve an appropriate balance of cost, quality, and performance in government facilities; 2) to enhance quality of life in the United States generally… by encouraging better cost—initial or life cycle—quality, and performance in private sector building; and 3) to enhance the productivity and commercial success of U.S. construction-related industries in domestic and overseas markets" (NRC, 1992a).

Given the structure of the U.S. housing market—with most stock being privately-owned (even when accounting for housing assistance) and the lack of foreign competition in local construction markets—only the second motive seems relevant for contemporary policymakers. The historical record corroborates the strength of this single policy motivation's contribution. The policy challenges, then, are in 1) identifying the appropriate areas or technologies in which to intervene; 2) articulating an "enhanced quality of life" that addresses a societal problem *and* the needs of industry constituencies that stand to gain from the innovations; and 3) developing the intervention such it is feasible, operational, and does not crowd out private-sector R&D. As another National Academies report suggests: "Pragmatic criteria outweigh philosophical concerns in the final analysis, and the politics of research will be more constructive when those involved can focus on details of specific programs, including the industrial and policy environments in which they must operate" (1986).

V. Operations and Strategies for Promoting Technological Innovation in Housing

C. Martín

The previous chapter reviews the conceptual justification for public-sector housing R&D programs and references the programs' general outcomes. However, no studies have looked at how programs are managed and how specific R&D strategies are selected—that is, all the activity that occurs between the original justification and the eventual program outcomes.

The researchers reviewed the administrative records and activity selections in past programs, and conducted in-depth, structured interviews with staff of current and past federal housing innovation programs to 1) better understand how R&D operations shape programs, compared to the policy and industrial context; and 2) document the range of strategies in past public-sector interventions. With this information, the researchers provide guidance for decisions in future innovation programs.

Key observations

A few studies, including the 2003 RAND report, review the strategies available to the public sector to encourage housing innovation, many of which are also applicable to the private-sector's decision to invest. However, no studies delve into the programmatic operations and components—or, the policy "ingredients"—of past and current housing research and development initiatives.

As the general scholarship on policy during the past three decades argues, the inability to assess—or the purposeful dismissal—of operational constraints could lead to ongoing challenges during a program's implementation. The omission could also result in inaccurate decision-making, program failures, and a diminished appetite for pursuing innovation efforts later. Interview respondents corroborated this observation, noting a list of potential stumbling blocks they encountered that could alternately lead to a program's success or failure if not addressed.

A program, therefore, must carefully review its operational constraints in relation to any possible project, program, or collection of R&D interventions. Before selecting any strategy for public intervention into the housing industry's innovation path, a fundamental and often-neglected step is making decisions on the basis based on core operational criteria.

Operations are a significant contributing factor to a program's outcomes—from the executive support for selected strategies that a housing R&D program employs to its day-to-day progress. Operations are as critical as the strength of the three contextual traits defined in the last chapter: philosophical support for applied R&D, a compelling societal need for policy intervention, and an industrial partner ready to commit its resources.

The researchers reviewed the organization makeup of past programs and interviewed a purposive sample of past and current federal program officials to identify these operational criteria, which include the following.

- Public executive and congressional support for housing R&D if the scale of the issue or problem in the performance area warrants it.
- Financial support in the form of public appropriations, with a budget appropriate to the task, accurately estimated, proportional to the housing agency's budget, stable, and continuous.
- Partnerships between industry and government, involving explicit descriptions of the timing, content, division of R&D labor, cost-sharing, and proportional burden of costs to benefits.
- Agency or departmental support, such that the investment is relevant to the agency's underlying mission and its resources do not take from other activities within the same department.
- Appropriate placement within the agency to tap into the appropriate expertise and knowledge.
- Explicit goals that are realistic and scaled to the issue and placed within the landscape of other relevant public and private efforts.
- Capable program leadership with the ability to define research agendas independently, and enough knowledge of the industry and past public policy to guide staff and contractors.
- The appropriate number of staff with matched research skills and housing technology fluency.
- Capacity and authority to select and revise the appropriate mix of program activities (including having the right breadth and depth of intervention vehicles or strategies described previously).

- Commitment to monitoring and evaluating efforts to ensure that the strategies are producing the right outputs and outcomes over time.

Consequently, operational capacity should be assessed prior to a formal housing innovation program's launch and periodically thereafter at all levels of operations.

The critically obvious component of launching a formal housing innovation effort of any size is the careful selection of activities and projects across the R&D continuum. Too often, an activity is selected that is not well suited for the task either because of institutional expedience or habit because of familiarity with that activity. Fortunately, a wide selection of activities is viable, but each comes with a specific fit in relation to the context and operations described in this report.

The public-sector has tried a wide pool of individual activities or mix of activities for intervening in housing innovation in the past. These must be selected to: 1) meet the current political, policy, and industrial needs, and 2) fit well within operational capacities.

For example, the public sector has most commonly used transparent and direct funding of basic research, such as that done by university researchers through the National Science Foundation, and applied research like that done by DOE national laboratories or consultants. This funding strategy is the least controversial, although it is among the costliest. It is also the least likely to directly address a societal or economic urgency because its timeframe is long and its outputs are open-ended. In combination with other strategically selected activities, however, traditional R&D funding can bring innovation to light.

However, a mix of R&D activities can only be implemented if enough operational resources exist. The historical record demonstrates that the tension between program vision and operational reality can sink a program. However, these concerns can be balanced.

Operational Considerations

The patterns across philosophical, policy, and industrial contexts noted in the preceding chapter suggest opportunities for defining the timing and circumstances under which housing R&D support may be successful. However, another set of programmatic questions regarding decisions and operational structure also play a critical role. Some scholars speculate that "pragmatic criteria outweigh philosophical concerns in the final analysis, and the politics of research will be more constructive when those involved can focus on details of specific programs" (NRC, 1986). The general literature on public-sector R&D interventions not specific to housing combined with an analysis of transcripts of interviews conducted for this report identified the following 12 core operational considerations.

Leadership

As many have noted previously, housing R&D programs are among the research initiatives that must walk a political tightrope between near-term technical payoffs and the long-term innovation gaps in the industry. However, this struggle is only realized after a program is launched. After a clear societal need is framed in policy terms as noted earlier, key policy leaders in either executive or legislative branches of government must have a sustained commitment in support of the program's vision and operations. In short, a technological champion or group of champions is needed within government just as champions are needed within the private sector (Nam and Tatum, 1997).

In addition to the general policy support, this backing must be operational, including continual commitments for press events and policy announcements, general involvement in resource allocation and program structure, and interest in the program's outputs and outcomes. In past examples, this support always involved at least one of the government branches, typically involved multiple individual champions (for example, members of Congress and a cabinet-level executive) and were often bipartisan. In turn, the champions for programs were involved beyond ribbon-cutting but without approaching micromanagement.

Although not consistently observed, bipartisanship appears to be a particularly important factor for ensuring political orientation does not introduce bias into the structuring of the program and technical, economic, and other evidence-based assessments are the primary determinants of program management, location of research, and interpretation of research findings. Bipartisanship also insulates (but does not isolate) the R&D program from political concerns and changes in political leadership. Political factors and special interest groups are never completely avoided, but program leadership's awareness of the positions and politics of champions or detractors can help mitigate them.

Partnerships

A second but just as significant operational pattern across housing R&D programs is the early and active involvement of partnerships, particularly with the housing industry sectors for whom the program is meant to benefit (for example, window manufacturers, single-family home remodelers, energy retrofits, and so on). Successful partnership not only benefit these industry stakeholders, but also build a natural constituency to advocate for the public-sector efforts.

The importance of industry partnerships was the first lesson taken from CITP, and it was a lesson that has been consistently employed by all programs since, that has been affirmed in numerous studies (NRC, 1992b; 2003a), and that was described as an essential program ingredient by all interview respondents. The balance of this program's advocacy between the partners should be appropriate to the expected benefits—meaning that the industry partners must have a vision for the future of their industry that includes technological change as much as the public-sector and research community does.

The timing, project content, division of labor, cost-sharing, and representativeness of partnerships were identified as critical components for ensuring that a public-sector housing R&D program is appropriate to the specific industry or sectors it will serve.

- Regarding ***timing***, early collaboration in project initiation and design were critical, even before launch. This ensures that the industry can articulate its R&D challenges and inscribe them into the program activities well, but also that mutually beneficial roles are established early on.
- Partnerships should also identify specific program or ***project content*** areas or activities relevant to industry but justify public intervention. Examples of this kind of content development and negotiation came in the manufacturing agreements with EPA and DOE for appliances and lighting, and in the "technology roadmap" process of the 1990s' programs.
- The ***division of labor*** must also be critically defined to specify deep and active partnering tasks such that the public role does not replace private R&D opportunities. This division of labor includes allocating review and dissemination roles for both public and private partners if a third party (like a university or laboratory) is contracted to conduct work.

- Appropriate ***cost-sharing*** between the public and the appropriate private partners across the supply chain (that is, manufacturers and builders) for either general funding or specific projects, and in cash or in-kind services, must be articulated with estimates of the sector's likely returns. Several scholars argue for the control of funds, subject-matter approvals, and review of activities to be conducted by an advisory group including stakeholders and neutral parties to balance between the partners, and between advocates and unbiased experts (Ahearne, 1986).
- Finally, regarding ***representativeness***, the literature suggests careful attention be paid to the direct recipients of public R&D funding within an industry to assess whether 1) the industry is actually sharing the costs of applied R&D that will benefit them, and 2) the benefits that those recipients reap are or will be shared with the broader industry such that the program's original societal goals are met. In many cases, an industry group or trade association can be a helpful intermediary if industry innovators are represented, the organization's staff are technically proficient, and the organization has the fiduciary capacity to coordinate cost-sharing.

In some cases, partnerships across government agencies are also critical, but never for management of the program. Most respondents suggest that different governmental entities should not be charged with managing each other's programs or activities. These partnerships should be structured only for coordinating activities across agencies to reduce redundancies and technical conflicts.

Funding

Assuming programs are authorized within their policy and industrial contexts, public-sector funding to the program vision is another core operational decision. In many of the previous cases, appropriated funds had little to do with budget projections based on financial estimates or activities' scope; in several cases, housing R&D programs have been simply carved out of agencies' larger budget appropriations. This reality undermines four core principles noted in the literature:

- ***Appropriateness to the task***. Budgeting accurately is a challenge given the need to both "right-size" for a program or individual project's goals while ensuring that the public-sector investment provides enough incentive to hold researchers' and innovators' attention. In the review of past and current programs, budgets were typically ill-suited for both purposes with only a few exceptions (such as ENERGY STAR). Barring clear signals from the industry about financial gaps in an R&D agenda or estimates of returns from similar investments, experiments with budgets early could identify the appropriate funding value for specific tasks.

- ***Accurate cost-sharing with industry***. Cost-sharing is a stated requirement in all the literature regarding applied research investments in the public sector, yet the literature rarely assesses how much a cost-share should be for any given activity. Arguably, industries with less of an R&D history and more noted barriers to conducting R&D like housing are less likely to be willing and able to procure a larger proportion of the costs of in a public-private R&D partnership. As noted previously, however, public-sector agents must gather as much information as possible when forming partnerships with industry at the onset to be able to specify and negotiate cost-sharing on individual projects and determine the government's share.

- ***Scaling of program to agency's mission***. The size of a housing R&D program's budget can overwhelm the government entity in which it is housed, leading to questions regarding the displacement of entity budgets as well as overall public-sector allocations. As Deutch (NRC, 1992b) notes, large R&D programs are easily suspect and can become both political footballs among elected officials and operational targets within government offices. In many cases, moderately-sized programs with modest budgets appear to have the greatest longevity because they are viewed as proportionate to other agency or department decisions.

- ***Stability and continuity***. Numerous scholars of R&D policy and governmental officials that administer housing R&D programs noted that a major aspect of budgeting is that budgets remain as stable and continuous as possible (Fundingsland, 1983). This aspect affects all other operational conditions, from the confidence of partners, to the identification of R&D activities (which, by definition, requires long-term planning), and to the capacity of managers and staff. One scholar even speculates that unstable and discontinuous funding of public R&D programs is as detrimental as low funding (Ahearne, 1986).

Mission

As noted in the discussion of policy context, a clear and articulated societal problem such as poor housing quality or climate change and a consequent vision for addressing the problem are essential external factors in a housing R&D program's duration and outcomes. How that vision gets operationalized into a programmatic mission that is feasible while still true to the vision, however, is often a stumbling block. As a bridge between the context and operations, a programmatic mission must be articulated well and adhered to. In PATH's case, for example, the original vision came with a mission statement that involved targets that were untenable, and disproportionate to the inputs allotted. Teich (1985) recommends "modesty" in defining and promoting the program so that the program is compelling to external stakeholders like appropriators or the general public and to internal partners. A general mission is also suggested so that a program has room to pivot and revise as industry or policy contexts change (for example, the DOE's turn to retrofitting existing homes in addition to its previous programming around new single-family construction after the 2008 housing crash). Specific targets are better left for more operational goal statements and individual projects.

Goals

A clear theory of change that maps mission-driven goals back to actual resources through reasonable and appropriate activities is a critical, but historically overlooked component of R&D operations. In the case of innovation, as noted in Chapter III, it is not linear, and a causal sequence leading to a goal is not straightforward. However, specific activities can be placed in a generalized sequence such that outputs are predictable and their link to outcomes are supported by evidence.

Two critical flaws involved in goal setting for R&D programs are often the assumptions about 1) timeframes, and 2) the direct causal links between a program's activities and economic or societal outcomes. Due to political pressures or exuberant optimism, results and dissemination of innovations are estimated to occur much more quickly than is realistic based on the pace of the housing innovation processes. The danger of setting completely unrealistic goals is not just operational, as programs will be perceived publicly and by governmental and industrial leaders as not having met promises.

When they have been employed, goal-setting and logical models for housing R&D programs often have overlooked or purposely avoided placing a program within the world of other R&D activities and incentives that exist in other parts of government or in the reality of the private sector. In too many cases, goals and their targets or other criteria for success will likely be shaped by many other factors (such as the housing market cycles) and not by the technological requirements or feasibility of the activities in question (Ahearne, 1986).

Goals, then, must always be contextualized. The use of an advisory board or unconflicted peer review (such as the repeated use of National Academy committees by R&D programs in the past two decades) may be helpful at an early stage.

Activities

Identifying the correct mix of R&D activities as explored later in the next section to meet the goals requires careful planning not just because each activity may involve different stakeholders (and, hence, different partnerships) but also because a variety of possible activities or paths of activities could, in theory, produce the desired outcomes. The danger of overextending a program based on the number, breadth, and depth of activities is as real as having too fantastic a mission or too many goals.

For a housing R&D program, the focus on either 1) a specific stage of the innovation process in depth, or 2) providing a clear path for innovations along a more robust spectrum of R&D activities are justifiable options, assuming adequate resources are provided for either. Some scholars argue for the latter, suggesting that a diversification of investments will help weather future changes in the marketplace or political conditions. Programs like DOE's Building Integration efforts support that model and have been sufficiently resourced to do so.

However, most programs have not had that kind of support. Fortunately, the literature and current program practices provide additional insight into the specific stages appropriate for housing R&D interventions, particularly since innovations in this applied research area can easily venture into proprietary territory that unfairly advantages certain parties over others (NRC, 1986). One tactic for overcoming this challenge is concentrating on the valley between basic research and development (for example, through open research calls and transparent joint research findings), and then on the specific barriers to housing R&D (such as information gaps). In many cases, the selection of the appropriate activities for a specific stage in the innovation process rests largely on whether other programs or public interventions are already in place beyond the designated program. In these cases, coordination is essential.

The range of potential activities are further elaborated in the next section.

Coordination

As noted in the partnerships discussion early, the outcomes of programs are partially dependent on the range of governmental activities that affect the industry in question. This includes efforts and actions, then, extending beyond partnerships with other governmental entities that are conducting similar or complementary housing research. For housing R&D, this also means monitoring and revising a program's activities within the broader industrial and policy context where building regulations, R&D tax credits, other R&D programs not explicitly tied to housing innovations, and overall housing market shifts also play a role in justifying governmental involvement, and the involvement at a specific stage.

Coordination with other agencies involved in housing—not just housing technology—could also be a productive activity as they may determine procurement demands or housing quality requirements that could have research implications. These external factors change frequently, and a program must take their presence and likely duration into account at the start to determine whether a long-term investment is possible and monitor them to ensure that investment is still needed. This lack of regular industry and policy tracking—and willingness to revise or even terminate an activity—was noted as a key factor in an overall program's demise.

Agency

In addition to the previously discussed substantive operational factors, five areas of logistical operations were noted as playing substantial roles in a housing R&D program's outcome. The first of these has to do with the placement and support of the implementing agency or department, particularly when that entity is not R&D-focused unlike other agencies whose sole purpose is R&D, such as the National Science Foundation (NSF). Interview respondents noted questions over which agency should house PATH surfaced during that program's creation, for example. Mission-driven agencies like HUD, DOE, or EPA are "promulgators of polices" that affect the very industries whose innovative capacities their R&D programs are meant to improves (NRC, 1992a). In some cases, those objectives may be in conflict and could pose a problem in partnering.

Program

Even more deeply, the placement and support for an R&D effort within a specific office of that department or agency can be even more material. Office-level budgets and staff resources are smaller than those of the entire agency or department in which they exist. A housing R&D program could then be perceived as taking away from other office missions. The tension can occur whether the program is housed in a research office (where the proposed technology research program vies with unrelated research projects and their respective researchers) or in non-research functions such as public-sector grant or service offices or private-sector sales or engineering functions (where the proposed program must explain the purpose of research in addition to sharing resources). In a few cases, respondents noted that this tension led to competition for resources, active dissent against the R&D program, and reduced overall support from the larger agency or department over the long term.

Management

The instability of research direction especially because of changing policymakers was a noted cause of failure from a policy perspective (Ahearne, 1986). However, capacity throughout an organization's hierarchy can be just as critical for a program's outcomes. Operational managers who can inform senior leaders and policymakers while maintaining the day-to-day communications with industry and other governmental partners are critical to ensuring that any one R&D activity produces its expected outputs. The significant of management capacity increases with the size of the R&D effort.

Given current perceptions of governmental efficiency, the potential for any program to be denounced as a failure due to the discrepancy of one activity is particularly challenging. Along with well-versed managers, the inclusion of frequent and well-organized reviews that provide management guidance along with subject-matter expertise can help mitigate this factor.

Staff

The quantity and skills of housing R&D program staff were described as another key logistical impediment. R&D program staff with a poor understanding of the current state of technology were identified in past efforts as ingredients for failure (Ahearne, 1986). However, other scholars and officials pointed to the need for technical staff capable of analyzing the marketplace and industry as much as the physical design, engineering, and construction areas in question (NRC, 1986). Both skill sets were described as necessary to design and monitor appropriate programs and activity interventions, flesh out balanced research work scopes and products, and procure fair industrial partnerships.

As a complement to the governmental staffing capacity, respondents also noted the skills of industry staff, researchers, and third-party investigators in being able to deliver quality research or research guidance. Where the eventual research quality was compromised, it was difficult to maintain robust industry partnerships except for the immediate beneficiaries of research funds. Design programs and activities to permit the participation of the maximum number of industry staff and scholarly researchers, and promoting peer review at all stages, was noted as mitigating strategy for this.

Monitoring and Evaluation

Finally, the proof of research results and contributions to mission outcomes—and, more importantly, positive and significant impacts to a program's broader societal goals were noted as another key logistical component of program operations. In many of the early program cases, formal monitoring and evaluation has been conducted only after a program's demise.

More recent programs have established both internal and external reviews more systematically, due largely to government-wide requirements such as the Government Performance and Results Act (NREL, 2009; NRC, 2001; 2002). This can include peer-review and advisory panels for individual projects or smaller innovation programs at the early stages of implementation, or more robust and systemic evaluations later. Regardless, the creation of a monitoring and evaluation plan at a program's launch, however, was consistently described as helpful for goal-setting as well as documenting changes in the industrial and policy landscape.

Strategy Options

The 2003 report specified a list of potential strategies for federal R&D intervention in housing technology that could be employed at different stages of the R&D or innovation process and at different levels of attention or resources. These strategies were categorized into four groups. Overall, this list was specific to the industrial and policy context at the time of the RAND publication. Since then, a few of the strategies have either been proven to have minimal success compared with others or have been taken off the policy table altogether.

The variability of any one strategy and its relevance in the current industrial and policy contexts are important considerations for policymakers. Some of the RAND-listed strategies, such as the direct funding of applied research in academic or industrial laboratories under RAND's "research" category, date back to the earliest days of public involvement and are common in many industries and across the federal government. Others are more foundational to innovation in general, like coordination and educational programs RAND specifies under "knowledge base" and "pipeline" activities—the latter term used as the shorthand of for the innovation process despite the study's explicit attempt to move away from that metaphor. Others are incentive and assistance programs designed to share or reward industry for taking on R&D, such as strategies RAND categorizes as "pipeline" and "market linkage" activities. This last group of strategies tend to be temporal and fluctuate frequently across policy and industry contexts. The following discussion reviews the four groups of proposed strategies.

Enhance Research Activities

RAND notes the importance of directly funding basic and applied technological research, particularly higher-risk basic and exploratory research and early-stage applied research. In the federal government, traditionally, direct funding for basic research through established agencies (for example, the National Science Foundation, or NSF) or for applied research (such as what DOE supports through its national labs or pool of contractors). The work is typically awarded to university-based or national laboratory researchers and managed via peer review.

The policy advantage of direct research project funding is that it tends to be politically neutral and non-controversial. The challenge in the housing industry context is that, by definition, housing is largely an industrial application. Basic research projects that may eventually be applied in housing are the purview of technical disciplines such as material sciences, structural, thermodynamic, and mechanical engineering, and so forth. This blurriness poses three policy challenges.

The first is in determining the appropriateness of how far public investments should go into the later stages of applied research—such as demonstration and commercialization—and is further discussed in the following. The second challenge stems mainly from placing the investment in basic research within a public-sector entity whose mission is an application, such as housing, rather than a general basic research funder, like NSF. Advocating for basic research in materials, thermodynamic modeling, structural integrity, and other more fundamental technological areas within a housing agency, for example, is difficult to justify. The third challenge is that direct funding of technical research projects is a costly strategy that may not directly address a social or commercial need because of its timeframe and open-ended outputs.

The value of direct research funding comes from the attention and momentum a solicitation creates in the research world beyond the eventual single award or group of awards. However, the dollar value of that award and the frequency by which related solicitations are repeated determine the resulting level of interest in the short term. With the general decline of federal resources as monitored in Chapter 2, research funding needs to be even more strategic to be able to support ongoing interest in the researcher and practitioner worlds. As such, while RAND's original strategy still holds as a valid innovation strategy, then, the recommendation could be nuanced to ensure specific policy actors are supportive of efforts by other and potentially appropriate public-sector funders and program officials that can deliver the research product effectively without raising the specter of mission drift.

Strengthen the Knowledge Base

A fundamental role for the public sector has been to fill gaps in basic information access, dissemination, and value-added use – expanding the range of players who can then use the information to innovate. The 2003 report identified four strategies in this general: 1) network building, 2) coordination of federal efforts, 3) disseminate federal R&D, and 4) enhance education and training. All four activities are well within the pubic-sector purview today, with similar disclaimers as the research strategy regarding the appropriateness of a specific agency or entity being the central network hub, coordinator, or disseminator. To this list, we add research on the state of industrial practices and innovation rates as a fifth subgroup of strategies that strengthen the housing innovation knowledge base explored here.

NETWORK BUILDING

Federal agencies have played a helpful role in establishing research networks (the first subgroup), even when they only involve informal gatherings that lead to connections between potential innovators. Convening workshops or panels is a low-cost activity that can foment new and productive networks between multi-sector stakeholders, particularly if they are longer-term endeavors between knowledgeable and active individuals. PATH's past and DOE's recent "research roadmaps" provided opportunities for industry-wide consensus building that also resulted in industry ownership of research agendas as well as these informal connections. In essence, this kind of public-sector convening significantly leverages private-sector action and creates interest in the research community, as well. Network-building works for both a focus on a specific housing innovation barrier (such as, product liability) or a technical area (like disaster mitigation retrofitting techniques).

COORDINATE AND DISSEMINATE FEDERAL R&D RESULTS

The second and third subgroups of coordinating activities across government efforts and disseminating governmental research are invariably public-sector roles, but they are predicated on being able to: 1) identify the efforts and the research upon which action needs to be taken; 2) place these efforts within a meaningful and technologically accurate whole; and 3) having the resources and instruments with which to effectively communicate them. Where RAND focused its attention on reducing redundancies, however, this suggestion highlights the additional importance of ensuring that the various efforts are aligned strategically—for example, that one entity's research does not contradict another's market linkage work.

This tension has occurred in the past, with DOE's and EPA's goals of reducing housing environmental impacts in conflict with HUD's goals for improving housing affordability. Barring the creation of a singular entity focused on housing innovation, this cross-organizational coordination is imperative. Technical areas in which there have been long-standing federal research programs (such as healthy housing or energy efficiency) could benefit from periodic convening and coordination.

Most public-sector agencies with any housing-related R&D activity have improved their transparency and communications capacity, and are often enthusiastic about sharing project status and findings. However, those with larger resources or research networks may feel the need to share information with others less. Like the industry convening for research roadmaps, developing a consistent platform across public entities—potentially including some state-level entities as well—like those used to establish the National Construction Goals or in PATH's federal partnerships may secure a cohesive and integrated public R&D strategy. Such an effort could precede industrial gatherings to directly share federal and state research findings as well.

EDUCATION AND TRAINING

The importance of education and training at all levels of housing practitioners and professional in helping spur technological knowledge and creativity was noted as the fourth grouping of strategies that strengthen the knowledge base in housing. This continues to be a critical public good that the public sector can and should invest in, though it is typically done via the workforce training programs (such those supported by the U.S. Department of Labor) and university-based research and educational opportunity programs like those at NSF. Private-sector worker training and apprenticeships are also the terrain of local industry and organized labor though, as noted earlier, these efforts have significantly diminished in resources and coverage, Trade associations among builders, realtors, appraisers, energy auditors, architectural designers, and engineers typically take up the role of ongoing training and accreditation, too. Given the size and number of housing professionals, the resources associated with this effort would need to be targeted and leveraged.

DEFINING THE HOUSING INNOVATION "PIPELINE"

A final strategy within the "knowledge base" category is the role of public-sector data collection and market research to give insight into gaps and opportunities which the private-sector could then fill. These industry studies strengthen the knowledge base about the housing innovation developmental process itself. Because so little is known about the operations and behaviors of housing actors, fielding frequent business and industry surveys could assist both the public programs interested in intervening and inventors and innovators seeking to enter the marketplace.

Fundamental surveys of actual housing quality, production, and performance such as that currently gleaned from the American Housing Survey, the Energy Information Administration, and other related U.S. Census primary data collection instruments provide needed information about the industry's products. Supplemental information about the industry itself, including the U.S. Economic Census and housing productions statistics, along with targeted yet periodic practitioner surveys for special projects provide a common language for all innovators without needing to wade into the selection of specific topics for basic research funding or technologies for applied funding. The provision of information and data is, ultimately, a core way to advance the knowledge base for future housing innovation.

The political and cost implications of this group of innovation strategies varies by specific strategy. On the whole, though, they tend to be as politically non-controversial as direct research funding, but much less costly. Supporting activities that strengthen the knowledge base, like network building (convening, technology roadmaps, etc.) or the dissemination of previously supported public R&D products, have also been employed by many federal agencies at minimal cost.

However, they require intensive familiarity with the subject matter by program leadership and staff. Unless focused on a specific technological issue or category, further, their activity is short-lived since their focus is in taking a snapshot of the state of knowledge at a specific time. The exception is in enhancing education and training of professionals and the workforce around innovation, though these activities have only been successful when they are tied to other strategies (such as direct funding, dissemination, or regulation). Otherwise, they require huge investments in curricula and dissemination.

Support the Process

Technology transfer and demonstration programs are employed by federal R&D programs to bridge the "valley of death" between research and commercialization. RAND classifies these strategies under the "pipeline" category, which this report renames more generally as the innovation "process." Yet these strategies tend to be very costly, and they face a more complicated contemporary policy environment. That case has become more difficult to make in the current policy environment and given the specific strategies that RAND suggested fifteen years ago.

TECHNOLOGY TRANSFER AND DEMONSTRATION

Two strategies especially, supporting technology transfer and supporting development and demonstration, cross the line beyond the comfort zone of those who philosophically disagree with public funding for industrial purposes. Based on the industry's formidable innovation barriers, however, a reasonable case might be made for moving that line provided a clear and transparent review of stakeholder capacity and interests is made—and a clear line towards measurable impacts on housing quality. Clear and transparent roles between public and private actors must be defined.

RAND suggests certain vehicles for this innovation process support, such as the competitive small business innovation grant programs in agencies with larger research portfolios, or through industry consortia akin to the cooperative research and development agreements (CRADAs) described in Chapter IV. Because investments in innovations at this stage will likely have clear beneficiaries both among the innovators (typically, product manufacturers) and the early adopters, additional exploration regarding those organizations' capacity and a proportionate assessment of their share in development and demonstration costs would be needed. Cooperative research and development agreements have been executed between public- and private-sectors to share the burden. They require extensive cost-sharing and commitments from senior leaders in both sectors, with detailed research agendas and delegations.

FINANCIAL INCENTIVES FOR PRIVATE-SECTOR R&D

Modifying and affirming the research and experimental tax credit is a third proposed strategy, and one that comes in the midst of large revisions to tax policies. Industrial incentives for investing in or adopting housing innovations, respectively, have significantly primed the innovation process. RAND suggested that the credit be modified to account for the smaller R&D investments that are typically made in housing technology rather than the then-permitted larger investments. These incentives, however, are costly and, in some cases, no longer tenable. The 2017 revised tax bill maintains this credit, but requires longer research-expense write-off periods (up to five years)—a change that disadvantages smaller R&D investments. As such, this strategy is even less tenable now than in 2003.

The remaining public-sector incentives for the housing industry to adopt innovation are state and local regulatory benefits from voluntarily meeting performance standards; examples of these include expedited permitting or density bonuses for meeting green building standards that many jurisdictions offered in the last two decades to mixed effect. The costs of managing these incentives were modest, though the development of the standards around which incentives were based often required intensive resources; voluntary labels and certifications later, require massive investments in development and credentialing since they lack the infrastructure of municipal or state building departments. Further, these incentives have often been precursors to regulatory adoption and enforcement later.

As such, the incentives for innovating are entirely market-based competition advantages to the cost of construction, the sales prices of homes, or the improvement in housing quality.

PUBLIC PROCUREMENT INCENTIVES FOR R&D

A fourth strategy, the use of public procurement to create scale economies and, in turn, incentivize innovation has been promoted as a construction innovation vehicle for decades, particularly in relation to heavy civil and infrastructure construction where government is typically the primary client. In housing, this strategy has always been weak given that most housing is not publicly owned.

In general, the public procurement function in housing has been reduced. In the past decade, the privatization of military housing and the attempts to employ market-based tools for public housing preservation, building system upgrading, and development (like HUD's Rental Assistance Demonstration) have become much stronger. However, public-sector rules such as those found in HUD's Community Development Block Grants or in state housing finance agencies' Qualified Allocation Plans for Low-Income Housing Tax Credits are still viable opportunities to integrate higher performance standards and incentivize housing innovation, albeit with likely modest effects on the greater housing stock.

REGULATORY ASSISTANCE

Another proposed strategy that has diminished in its potential to affect change in the industry's innovation rates is the provision of information or explanation of the regulatory process. As noted in Chapter 2, the regulatory barriers to housing innovation have reduced somewhat for reasons ranging from the increased adoption of performance-based codes, the uniformity of building codes across the nation, and the preponderance of testing and regulatory compliance servicers.

The federal government could use its influence to ensure that local code officials readily accept regulatory compliance certifications, for example, as a requirement of its compliance for other grants and assistance. Alternately, the federal government could become involved in the drafting of model building codes, though the public-sector intervention in the regulatory drafting, adoption, and enforcement processes might increase housing innovation rates but also increase housing costs.

Though complex, undergoing the process is in many ways the innovator's cost of doing business. Studies about how complex and cumbersome the process is and how it might disproportionately affect firms with smaller resources, however, is a topic that could be included in the provision of industrial data and research noted earlier.

Improve market linkages

Two other proposed strategies continue to be relevant provided they meet societal goals: 1) creating linkages among markets; and 2) creating financial incentives for end users. Ultimately, both activities could spur market demand for improved technical performance or specific technologies in housing, respectively, but can be resource intensive.

MARKET LINKAGES

The first subgroup of market linking activities refers to the creation of funds, investment resources, or regulations in another sector (or "market") to housing. Examples of this include tying the reduction of a home's energy performance to carbon reduction markets (such as currently being experimented abroad), or to its qualifying mortgage such as energy-efficient mortgages or housing financial products of the last few decades, or even its property tax assessment (such as the property assessed clean energy, or PACE, programs of the past). Such a linkage can apply to other performance areas where the innovation's benefits can be monetized for other financial tools; improvements in a home's durability in a likely disaster could be used to justify reduction in its property insurance premiums and policy coverage, for example. Even healthcare providers have begun showing interest in healthy housing improvements that may reduce their clients' need for services.

In most of these cases, however, there are significant gaps in rigorous evidence that links one housing performance area (e.g., energy efficiency) to the benefit in the other sector (such as, housing finance). The contribution of a specific technological innovation to that benefit is even more tenuous. Should these exist, further, the costs and resources required to match individual housing units to their monetizable benefits that can then be aggregated with other units' benefits to justify the linking may be exorbitant—though not necessarily prohibitive. Specialized staff with familiarity in housing innovation, housing markets, and the resulting market would be needed. Otherwise, convenings and other knowledge-building activities such as those described earlier may be a cost-effective approach to this strategy.

PROPERTY OWNER INCENTIVES

End-user financial incentives, as opposed to those for the industry noted earlier, are tax credits, subsidies, rebates, or similar incentives provided directly to the consumer, or property owner in housing's case. Examples of these past incentives include national energy-efficient retrofit and renewable energy tax credits for consumers, or local utility rebates. These market-based strategies contrast with regulatory sticks for meeting a social imperative retained.

As the review of consumer demand in Chapter 2 suggests, this can be a potential tool for spurring innovative activity upstream in the housing supply chain. Though less likely to produce as universal or robust an outcome, they can meet impressive targets. The opportunities also refrain from the selection of specific innovations that is required in the other strategy categories, but can be very costly to public coffers and require legislative action that is typically beyond the purview of housing agencies and programs. Further study of these programs' outcomes may be within reasonable scope, though.

In short, many of the strategies recommended for supporting the innovation process at the time of the 2003 report are less tenable now. Among those that still potentially hold, the bar for justifying their use is higher. The justification for "pipeline support" strategies is potentially even weaker in the current context given that they benefit specific innovators and innovations and tend to fit squarely within the private-sector purview. Further, few of the strategies have been implemented consistently and repeatedly enough so that they could be evaluated rigorously.

Even while accounting for these concerns about what the public-sector could do in the current decision-making context, however, there are opportunities well within the scope and mission of current public sector entities.

Implications for innovation policy

The focus of this report has been to describe *how* a public-sector should go about making decisions, and not in doing the analysis or making recommendations about *what* the decisions should be. Yet, a cursory review of the contemporary state of housing's context and federal R&D efforts offers an opportunity to apply the report's lessons for HUD's Office of Policy Development and Research (PD&R):

- ***The industrial context***. As detailed in Chapter 1, the housing industry is on a general upwards trend—suggesting an opportune moment for private-sector investments into innovation activities. Productivity especially continues to be strong in sunbelt states, suggesting certain areas of innovation that are market relevant such as prefabrication and disaster mitigation.
- ***Barriers and enablers of innovation***. Chapter 2 notes the diminishing role of certain previous enablers, particularly via modest increases in the efficiency of information sharing and consumer demand and early signs of consolidation and reduced supply-chain and geographic fragmentation in some sectors. Simultaneously, however some barriers have entrenched, particularly the availability of a skilled workforce and reductions in public-sector R&D

investments. Depending on the policy goal (below), mitigating these barriers could be an explicit focus for a new program or a dimension of existing program monitoring.

- ***The current innovation process***. Similarly, if a technology or housing performance area are the focus, the program should take great pains in defining the supply chain of innovation that the innovation would face and any local variations as suggested by Chapter 3. This is especially true for innovations focused on remodeling markets. The process for existing technologies that have come to market but have not sufficiently diffused may be particularly worthwhile to document.

- ***The political and policy contexts***. Senior federal leaders have retrenched in their support of applied research both explicitly and in resource requests. As such, less cost-intensive strategies are more likely to launch with some readily measurable output. Additionally, as noted during the Stakeholder Workshop held for this report (Appendix 1), two areas of intervention are of special national import: technologies for disaster mitigation retrofits and new housing due to the significant number of severe disaster declarations in 2017, and healthy housing techniques from the increasing body of evidence demonstrating that housing quality is a major social determinant of health. Both current political constraints and policy goals in these areas may provide an environment that is conducive to new programs.

- ***Operational capacity***. Several federal entities are conducting research and policy work in these two areas (e.g., FEMA and HUD Office of Lead Hazard Control and Healthy Homes or OLHCHH, respectively). With a small technology research staff, HUD is at some disadvantage when measured against the operational considerations listed earlier in this Chapter 5. However, PD&R could use its networking capacity with industry and these other federal entities, along with its influence on HUD's other program offices and its modest technology budget, to support these efforts in several key ways:

    - convening key stakeholders and developing contemporary roadmaps for housing disaster mitigation innovation and innovation barriers could provide desperately needed consistency across stakeholder motives and consolidate new resources for improving homes' resilience. Given OLHCHH's frequent coordination and convening, there is less reason for duplication for healthy housing efforts;

    - promoting existing technologies in these areas at HUD events and through public information channels. The provision of accessible sources of credible, independent information through HUD's existing information channels has been a frequent opportunity to promote current innovations on the market and spur interest in new ones. HUD already has many guidance and technical assistance tools in the areas of disaster mitigation and healthy housing which could be supplemented by those in other agencies;

- integrating mitigation and health performance standards into existing HUD programs. HUD has successfully encouraged standards in the past that lead to higher rates of adoption of technologies which, in turn, have the effect of increasing the rate of innovative ones. Energy-efficiency and green building requirements are the most known cases of HUD's leading by example (GAO 2015), but similar requirements for mitigation standards may apply to programs like CDBG for Disaster Recovery;

- supporting data collection on innovative practices and behaviors to support other federal R&D programs. The adoption patterns and innovation processes for other federal agencies' housing R&D programs are in constant flux, and could benefit from HUD's expertise in housing market knowledge. This strategy could apply to a general set of behaviors, or could apply just to stakeholders associated with the identified technology area of disaster mitigation. For example, surveying the diffusion of specific mitigation techniques and their market distributions, the skill sets of remodelers and builders in those areas, and the effects of regulatory frameworks on innovation practices there are all logical studies;

- funding rigorous outcomes analyses of technologies' effects—such as mitigation techniques on disaster recovery costs or health home improvements on asthma rates—to monetize the value of innovation. With limited funding for long-term research, studies of past technologies' effects contribute to the innovation literature and provide useful lessons for housing scholars and practitioners without resulting in one-off solicitations for basic or applied research that will likely not result in products that are timely or material enough to address the current societal need from the recent spate of disasters.

These preliminary recommendations are all based on the underlying process that this report puts forth—that is, that a thoughtful and authentically-executed assessment of the industrial, political, policy, technology, and operational frameworks must coincide with the goals for launching a housing innovation initiative for it to succeed. Much more analysis is possible, and is necessary.

Summary

In its review of HUD's research efforts, a National Academy of Sciences committee noted that PD&R is still capable of assuming "a leadership position in guiding technology related to housing" (NRC 2008). Based even on the experience of the former PATH program, HUD leveraged modest resources and a minimal staff to "bring to the table and provide direction and leadership to a large variety of housing technology stakeholders."

The committee pointed to several contextual, strategic, and operational factors that are necessary for future program success—all of which are identified in some fashion within this report. The most critical of these factors is the need for a sustained, stable, and supportive environment for housing research. This report finds that those factors are predicated on fundamental beliefs in the role of government and in conducive policy and industrial contexts. In turn, keen strategic decisions about the innovation interventions and attention to the operational logistics for their implementation need to align as well. This tall order has been met before, as the historical record shows.

The improvements in the housing industry over the last century and the increasing sophistication of federal and state housing R&D programs over the last few decades are a testament to the potential of future efforts and the dogged efforts of technology champions in both the private and public sectors. As this review suggests, the process towards successful housing innovation is complex but the reward can be significant. The challenges that now remain are in knowing when and how to foster the partnership between housing practitioners and policymakers that has evolved over this time. The lessons and criteria developed in this report are a step in that direction, and are summarized in Appendix 2.

Overcoming the perceived barriers to housing innovation, and fostering those factors and conditions that may enable it, has been an ongoing challenge among housing policymakers and industry leaders for decades. As participants in the stakeholder workshop conducted as part of this report's ground-truthing noted, however, there is often a false tension between the housing improvements that innovation brings and the perception of their increased costs to builders and consumers. Only with improved evidence—especially around the long-term benefits from innovation, be they financial or otherwise—can perceptions be quantified and appropriate public- and private-sector actions be made.

A final note regarding technological entrepreneurialism is also necessary, and one that was repeated by workshop participants as well as the report's core advisory group. In too many cases within industry firms and in government offices, there is a lack of information and entrepreneurialism to ensure that technology champions are acknowledged and encouraged. In heavy civil and commercial building sectors, large players have “chief innovation officers” who track process and product technologies daily. The presence of technology champions has been noted as a key factor for increasing the rate and quality of innovation in the private sector building industry (Nam and Tatum 1997). Interview respondents for this project also noted their presence in public-sector agencies. In housing, the champions exist albeit in vastly smaller circles of influence—*but they exist*.

Appendix 1. Stakeholder Workshop

Agenda

Strategies for Promoting Innovation in Home Building

Cohosted by the Urban Institute and the Virginia Tech Housing Research Center
Funded by the U.S. Department of Housing and Urban Development's
Office of Policy Development and Research
Thursday, March 29, 2017

8:00 a.m. Breakfast and registration

9:00 a.m. Opening remarks

- **Brian Kleiner,** Director, Myers-Lawson School of Construction, Virginia Tech

9:10 a.m. Introduction of Deputy Secretary

- **Margery Austin Turner,** Senior Vice President for Program Planning and Management, Urban Institute

9:15 a.m. U.S. Department of Housing and Urban Development welcoming remarks

- **Honorable Deputy Secretary Pamela Patenaude**

9:30 a.m. Overview

- **Christopher Bourne,** Senior Policy Advisor, U.S. Department of Housing and Urban Development
- **Carlos Martín,** Senior Fellow, Urban Institute
- **Frederick Paige,** Assistant Professor, Construction Engineering and Management, Virginia Tech

10:00 a.m. Break

10:15 a.m. Facilitated breakout sessions

- Developers, builders, and remodelers
- Manufacturers and service providers
- Affiliated professionals and media
- Scholars and government representatives

11:45 a.m. Break and plenary reconvene

12:00 p.m. Facilitator reports and summary remarks

- **Andrew McCoy,** Director, Virginia Center for Housing Research, Virginia Tech

12:30 p.m. Open discussion

12:45 p.m. Concluding remarks

Attendees

Attendees of the housing innovation stakeholder workshop represented four distinct groups:

- developers, builders, and remodelers;
- manufacturers and service providers;
- affiliated professionals and media; and,
- scholars and government officials.

To keep travel costs for attendees to a minimum, stakeholders from the Washington metropolitan area were preferentially selected, although some attendees were from outside the region. Most of the attendees had demonstrated previous experience with Federal housing innovation efforts, either via HUD's Partnership for Advancing Technology in Housing or DOE's Building America program. Other attendees were known for promoting innovation within the housing industry or were identified by participants that were known to HUD. The fact that the participants were experienced in innovation, particularly federal activities related to housing innovation, permitted the workshop to move quickly beyond orientation and into the brainstorming and problem solving phase. As a result, the workshop was able to accomplish more in a short time compared to other similar efforts.

First Name	Last Name	Organization
Philip	Agee	Virginia Tech
Jack	Armstrong	Structural Insulated Panel Association
Debra	Ballen	Insurance Institute for Business & Home Safety
Larry	Bartlett	Net Zero Building Systems, LLC
Tedd	Benson	Bensonwood & Unity Homes
Mike	Blanford	U.S. Department of Housing and Urban Development
Christopher	Bourne	U.S. Department of Housing and Urban Development
Liza	Bowles	Newport Partners
Dana	Bres	U.S. Department of Housing and Urban Development
Neil	Burning	International Code Council
Eric	Burnstein	Urban Institute
Steve	Chelette	HOPE Collaborators, LLC
Daniel	Chouinard	Earth Friendly Building Materials, Earth Friendly Block
Elizabeth	Cocke	U.S. Department of Housing and Urban Development
William Reginald	Colbert	Concepts With Solutions, LLC
Glenn	Cottrell	IBACOS, Inc
Judson	Duryea	Virginia Tech
Laura	Dwyer	DuPont

First Name	Last Name	Organization
Melvin	Forbes	Water Transit Solutions
Asa	Foss	The U.S. Green Building Council
Dr John	Francavilla	Net Zero Building Systems, LLC
Michael	Freedberg	U.S. Department of Housing and Urban Development
Lesli	Gooch	Manufactured Housing Institute
Rick	Haughey	National Multifamily Housing Council
Jerry	Hill	Ricky Hill Enterprises
Terry	Hill	Passive House Institute US
Trey	Hipp	U.S. Department of Housing and Urban Development
Franklin	Holmes	Randolph Acquisitions Inc.
Terry	Horton	Horton World Solutions
Glenn	Hourahan	Air Conditioning Contractors of America
Bryan	Howard	The U.S. Green Building Council
Ivy	Hunter	Urban Institute
Barton	James	Air Conditioning Contractors of America
Henry	Kelly	University of Michigan
Brian	Kleiner	Myers-Lawson School of Construction
Ted	Koebel	Virginia Tech
Gary	Krier	Prime G Commercial Construction, Inc.
Matt	Lockwood	Net Zero Building Systems, LLC
Michael	Luzier	Home Innovation Research Labs
Mary Tyler	March	Construction Dive
Carlos	Martín	Urban Institute
Andrew	McCoy	Virginia Tech
Ali	Memari	Penn State University and Institute
Barry	Merchant	Virginia Housing Development Authority
Mike	Meyer	Spray Rock Manufacturing / Net Zero
Alana	Morro	Urban Institute
Frederick	Paige	Virginia Tech
John	Peavey, P.E.	American Institute of Architects
Emily	Peiffer	Urban Institute
Andrea	Ponsor	Stewards of Affordable Housing for the Future
Richard	Randolph	Randolph Acquisitions Inc.
Sam	Rashkin	U.S. Department of Energy
Georg	Reichard	Virginia Tech
Marietta	Rodriguez	NeighborWorks America
Clare	Rosenberger	NeighborWorks America
Sarah	Slaughter	The Built Environment Coalition
T. Michael	Toole	The University of Toledo

First Name	Last Name	Organization
Margery	Turner	Urban Institute
Alex	Varonos	MinMax Spaces
Eric	Werling	U.S. Department of Energy
Theresa	Weston	DuPont
Stockton	Williams	Urban Land Institute
Larry	Zarker	Building Performance Institute

Appendix 2. Decision Steps for Housing Innovation Programs

The report reviewed the general reasons why housing innovation is needed, and why public-sector intervention in particular is needed to overcome certain innovation barriers—or promote certain enabling conditions for innovation. The current innovation process in industry is described, along with governmental efforts to intervene along it in the past and their underlying contexts. Those interventions—or strategies—are then tracked in the current context to assess their feasibility and the operational factors that should be considered for the strategies to be implemented effectively.

In this final discussion, we assemble the cumulative lessons from our reviews to assist decision-makers with considering the contextual scenarios and taking discrete steps when the opportunity for future interventions arises.

Context review

- ***Philosophical support***. *Does the current leadership at the highest levels of the entity in question support public-sector involvement in applied research in general, and for housing in particular?* Decision-makers must understand the underlying support—or explicit refutation—for investment in applied research areas in general. Administrative statements in budget proposals or R&D announcements for traditional funding agencies like NSF and DOE may help gauge whether there is any fundamental concern with investments in housing technology as well.

- ***Societal vision***. *Is there a compelling social reason for the public-sector's intervention?* In cases of larger R&D efforts, there is typically a call for a broader societal vision for housing R&D, such as increasing housing affordability, decreasing energy and environmental impacts, or reducing indoor health hazards. For smaller projects, there is rarely such a vision statement. In these cases, departmental mission statements prove helpful in gauging whether a project progresses.

- ***Industrial capacity***. *Does the industry currently have the capacity to be involved in housing innovation efforts, including committing its own resources?* Previous efforts argue that the housing industry (or, at least, the respective stakeholders relevant for a project) must actively endorse an innovation program's purpose and goals. This typically occurs at points in market upswings or near peaks, when industry participants have financial and knowledge resources. In turn, these stakeholders should also be prepared to partner accordingly.

Operational assessment

Once an enabling contextual environment is in place and reasonable strategies selected, ensuring a commensurate level of operational capacity and competence is essential.

- ***Leadership***. *Is there an empowered champion*? Explicit endorsement of a program or project from political and industrial leaders is essential for program launch and sustained resources. Even tepid enthusiasm can cause a program to flounder.

- ***Partnerships***. *Are the right stakeholders involved, and to correct level*? Realizing conceptual alignment between public and private roles in a housing innovation effort through contractual arrangement, financial splits, and administrative assignments reduces the perception that the public-sector is engineering the effort, along with ensuring that public funds are efficiently expended.

- ***Funding***. *Are there enough funds*? Appropriations and allocations from government budgeters must be realistic and corresponding to the scale of selected strategies. Adequate resourcing holds for industry too, and most be transparent and audited.

- ***Mission.*** *What is the problem and its ideal solution*? Operationalizing an overarching societal vision into a practical program mission may seem perfunctory, but the disconnect between dream and reality is often lost at this stage as past housing programs have shown. In many cases, the inverse of a problem statement is put forth without any assessment about how the specific program or projects and its intervention point along the innovation process solves the problem.

- ***Goals***. *How does the proposed solution turn into a program or project*? This disconnect is best overcome by clarifying the objectives and overall theory-of-change of the intervention. Even when there are unknown steps in a basic logic model, the articulation of a reasonable and evidence-based flow from inputs to outputs ensures that some thought has been given to outcomes. Basic narratives of expected stages help identify stakeholders needed to complete the R&D effort along the way, and likely assumptions about the conditions.

- ***Activities***. *What are the primary and most appropriate steps needed to create the intervention*? All the previously described strategies have specific activities that must be undertaken, regardless of the partner though particularly for public-sector efforts. Examples include the drafting and public release of research grant competitions, and the creation of tax code legislation and enforcement procedures for a tax credit incentive for consumers. Tasks, like research proposals, are too often selected because they are what is known or what is expedient rather than what is needed or appropriate. Though obvious, there are multiple, often pedestrian, tasks that must occur in a specific sequence that past and current innovation program managers have noted are critical to credibility and success.

- ***Coordination***. *How does the intervention ensure relevance over its lifetime*? Like the portfolio discussion, the operational need for coordination involves interactions and information-sharing across numerous stakeholders, be they various governmental agencies, or public and private stakeholder groups. Unlike the criterion for strategy selection, coordination involves ongoing and frequent updates and convening.

- ***Agency***. *Where is the program located within government*? Public decision-makers must be conscious of their organization's mission and their location within the broader governmental structure. Determining the appropriate home for a housing R&D program or project does not necessarily lead to placement in an organization with either "housing" or "R&D" in its title. In past cases, the organizing entity for some of the more successful housing R&D efforts had neither. The advantages or disadvantages must be weighed against the agency's mission and other agencies' perception of its capacity.

- ***Program***. *What are the challenges that the program will face because of its location*? Similarly, a publicly-supported housing R&D effort may be perceived as competing with other already existing programs and services for resources. Combined with lukewarm leadership support, the effort could become a target.

- ***Management***. *Are there effective day-to-day leaders*? Executive staff who can execute staff, budget, and contract needs must also be capable communicators to support partnerships.

- ***Staff***. *Are all staff skilled and knowledgeable about all aspects of the intervention*? At the same time, the knowledge and skill base must continue to be fostered. To meet industry counterparts, program staff must be technically proficient about the housing industry and its technologies along with being able to execute activities as assigned by managers.

- ***Monitoring & Evaluation***. *Is there a plan to stay on track*? Routine project monitoring through external reviews and assessments need to be developed as a program is launched to accurately measure its progress compared to its baseline, and to contribute to knowledge about how it compares to the other past and current housing R&D efforts.

Strategy selection

- ***Purpose.*** Decision-makers must ask the fundamental question of why a program or project is needed, but with an eye towards a specific strategies' contribution to that purpose. *Is the strategy reasonable for the desired goal*? What technical or industrial purpose does the strategy or activity address? Does this screen out political factors, the inertia from simply continuing prior commitments, or the bias and preference of individual officials?

- ***Costs.*** *How do the estimated costs of reaching an innovation program's goals compare to the available funds?* The basic question about how much a strategy cost is surprisingly more complicated than tabulating the level of effort for a scope of research work. There are typically numerous unknown or unquantifiable costs, and many of these cannot be known until after a program or project launch. A corollary set of questions must be asked about the public versus share private.

- ***Benefits.*** *Do the estimated benefits outweigh the costs?* Likewise, the ability to monetize societal benefits in relation to the financial rewards for industry stakeholders must be assessed. Societal benefits are more complex and challenging to measure in earlier stages of the innovation process, and for larger initiatives. In both cost and benefit analyses, identifying unknown or unquantifiable areas.

- ***Beneficiaries.*** *Who does a program or project benefit*? What are all the stakeholder groups that could potentially be affected and who should be splitting the costs and risks, beyond the projected benefits to society? Basic stakeholder analysis that includes an honest and accurate review of interests and resources is, surprisingly, an overlooked step in many governmental efforts prior to launch. Analyses of potential detractors are almost always avoided as well.

- ***Portfolio.*** *How does the specific project or comprehensive program fit yield its benefits?* Does it fit into a bigger portfolio of all private and public R&D efforts? Past analyses have focused solely on ensuring on minimizing redundancy in programs but this analysis should also consider the strategic relationship of the proposed work to other efforts.

- ***Expectations.*** The timing and magnitude of innovation outputs—let alone outcomes—are collectively a critical criterion for selecting strategies. Some strategies, like direct R&D investment, can be implemented immediately but their outcomes could take decades to be realized. Others, like market incentives, may require more planning and negotiation but yield fruit almost immediately after launch. Considerations of temporality also implicate frequent and deep reviews of the contextual scenarios throughout a project's or program's timeframe since the policy or market conditions that are necessary for its success may not exist at its completion. The expected magnitude of outputs or outcomes—essentially targets in the form of industrial, institutional, or physical housing changes—should also be made explicit and based on previous evidence or experience.

There are numerous examples from past efforts that suggest that a negative assessment for any of these criteria could result in later failure, but just as many showing that one negative criterion "score" could be balanced with highly positive ones in other criteria. There have simply been too few cases and in too varied of contexts to estimate with any level of certainty. However, achieving a balance across these would reasonably help mitigate from selecting the wrong strategy. The extent to which these criteria are employed—and the context scenarios assessed—should be proportional to the effort.

Ultimately, however, the decision to launch a housing R&D effort requires a certain amount of self-awareness, and an openness to honest and transparent conversations about each of the above analyses and their resulting decisions.

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