# Overcoming Barriers to Innovation

## in the Home Building Industry

U.S. Department of Housing and Urban Development | Office of Policy Development and Research

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U.S. Department of Housing and Urban Development Office of Policy Development and Research

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# Foreword

As we celebrate the 50th anniversary of HUD's Office of Policy Development and Research (PD&R) this year, I am reminded that one of the reasons PD&R was created was to seed innovation and support adoption of new technologies that could improve the quality and affordability of the nation's housing. Title V of the 1970 Housing and Urban Development Act, authorized the creation of PD&R and directed the HUD Secretary to "require, to the greatest extent feasible, the employment of new and improved technologies, methods, and materials in housing construction, rehabilitation, and maintenance . . . with a view to reducing costs, and . . . encourage and promote the acceptance and application of such advanced technology, methods, and materials by all segments of the housing industry, communities, industries engaged in urban development activities and the general public."[1] The need to leverage innovation and technology to support HUD's mission is as great today as it was when PD&R was created.

This report, "Overcoming Barriers to Innovation in the Home Building Industry," contributes to the discussion on what we have learned over past decades and where we can go from here to continue to innovate in the home building industry. This report provides a literature review and summarizes research findings about four key barriers to innovation:

- education—the lack of sufficient technical information, training, and instruction from product innovators;
- risk—potential to experience losses when adopting new products and practices;
- industry fragmentation—the diffusion and complexity of the homebuilding industry; and,
- behavioral factors and biases—thought processes that lead housing market participants to resist innovations that would be in their best interest.

The report also summarizes panel discussions on these topics with leaders and experts from government, architecture, research, and housing development fields.

The report offers ideas and examples, drawn from the literature review and panel discussions, that could help tackle three big challenges:

- How to support continuing education for workers in the homebuilding industry to facilitate the adoption of new technologies;
- How local stakeholders can work together to remove zoning and land use barriers to building more energy efficient and affordable housing where it is needed most; and,
- How to reduce financial risk for builders and homeowners, while also educating both groups on the benefits of new technologies for improving energy efficiency and long-term affordability.

[1] See: Housing and Urban Development Act of 1970, Pub. L. No. 91-609, 84 Stat (1970). https://www.govinfo.gov/content/pkg/STATUTE-84/pdf/STATUTE-84-Pg1770.pdf.

Building housing that is affordable, healthy, and resilient requires the shared involvement of government, developers, architects, and builders. This report is useful to each of these groups as HUD continues to explore what each can do to increase adoption of new technologies that can improve housing quality, affordability, and energy-efficiency. It clearly describes the barriers to innovation, reviews other research on the issues, and offers specific examples and recommendations to support widespread adoption of innovations in building technology.

Only by identifying and overcoming the barriers to innovation in the homebuilding industry will HUD be able to meet its mission to "provide quality affordable homes for all." PD&R looks forward to continuing to support and apply research and evidence-based insights to help HUD and our partners understand and accelerate innovations that address our nation's housing needs in the years and decades ahead.

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Principal Deputy Assistant Secretary for Policy Development and Research
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# Executive Summary

Mainstream adoption of innovative technologies and processes make homes more affordable, energy efficient, and comfortable. Building professionals have long recognized that the building industry faces major barriers when it comes to bringing innovation to market. At the same time, homeowners often lack information and access to innovations that cost effectively improve home performance, reduce energy use, and reduce energy and maintenance costs.

The good news is that there is plenty of innovation happening, and there are effective strategies to disseminate innovations and hasten adoption, including across the industry, within firms, or among homeowners. Types of innovation that can enhance affordability might include new products or building technologies, as well as management practices and procedures to streamline efforts, and software innovations.

This report captures 2021 activity, funded by the Department of Housing and Urban Development (HUD) and led by RNN Architects of Denver, Colorado, to revisit the state of innovation in the homebuilding industry.

In April 2005, the Department of Housing and Urban Development sponsored a study called: "Overcoming Barriers to Innovation in the Home Building Industry,"[2] by Building Technology Incorporated. This study was based on the work previously conducted under PATH by Rand Corporation in 2003, which culminated in the report "Building Better Homes: Government Strategies for Promoting Innovation in Housing."[3]

Building on this previous work, in summer of 2021, HUD sponsored a series of working groups to explore the current landscape of innovation in housing technology and process, to identify barriers that continue to thwart innovation, and to explore opportunities for collaboration and future research. A major focus was to identify strategies that are already working and opportunities to disseminate those strategies.

The RNN Architects team worked with HUD and a broad cross-section of representatives within the industry to evaluate four key areas in the housing industry: education, risk, industry fragmentation, and behavioral factors and biases. Critical issues in these key areas impact the industry's ability to deliver better, more efficient, more durable and, most importantly, affordable housing to the private and public sectors. Most significantly, these issues impact the ability of the housing industry to deliver these houses at scale.

The workshop panelists discussed strategies in each of these four key areas which could potentially accelerate the adoption and dissemination of innovations which have the potential for improving the affordability and sustainability of homes at scale. Here are a few of the working groups' key findings:

- Creative strategies that can leverage technology and make it practical for workers in the field to pursue continuing education to help build the skilled workforce needed to deploy efficient, durable, and affordable homes.
- When architects, builders, and developers work with jurisdictions to remove zoning and land use barriers, they can deploy more energy efficient and affordable housing where it is most needed.

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[2] http://www.huduser.gov/Publications/pdf/OvercomingBarriers.pdf.

[3] https://www.huduser.gov/portal/publications/Building-Even-Better-Homes.html.

- Reducing the financial risk and educating homeowners about the benefits of innovations can help persuade them to make decisions which improve energy efficiency, comfort, and long-term return on investment (ROI).

This study was broken into three primary tasks: conduct a literature review, convene expert panels in the four topical areas, and summarize findings and recommendations for short-, medium-, and long-term research and coordination. HUD and RNN Architects developed this report to summarize their efforts and make recommendations for the path forward. It is divided into two sections: a literature review, and then key findings and recommendations from the expert panel discussions and working groups.

The following general observations and key findings by topic area were captured during the course of this project:

## General Findings and Recommendations

- All parties need to share in the responsibility of education and training. This includes government, developers, architecture firms, and builders.
- When developers and other organizations work with jurisdictions to remove zoning and land use barriers, they can deploy more energy efficient and affordable housing where it is needed most.
- Government can play a key role in sponsoring and incentivizing innovation, especially when government teams up with manufacturers and research institutions.
- Government plays a special role in nudging the private sector by creating policies, processes, and incentives around affordability, resilience, and energy efficiency. The federal government needs to reevaluate its guidance and incentives regarding the homebuilding industry.
- Government can play a key role in sponsoring and incentivizing innovation, especially when government teams up with manufacturers and research institutions.
- A key next step for HUD would be to analyze what actions have been taken since the 2005 study, to determine whether tactics or lack of action is the primary reason that barriers still exist, and determine a course of action for federal agencies.

# Background and Approach

In April 2005, the Department of Housing and Urban Development (HUD) sponsored a study under the same title: "Overcoming Barriers to Innovation in the Home Building Industry,"[4] by Building Technology Incorporated. This study was based on the work previously conducted under PATH by Rand Corporation in 2003, which culminated in the report "Building Better Homes: Government Strategies for Promoting Innovation in Housing."[5] The study was driven by the fundamental research findings that "while new technologies and production processes could help overcome serious problems for housing producers, realizing these benefits on a broad scale is considerably hindered by characteristics of the housing industry that inhibit the development and diffusion of innovations'(Building Technology Inc., 2005).

Innovation in housing—both technology and process—has important economic, energy, environmental, and resiliency impacts that affect builders, homeowners, financial institutions, and government agencies. In the past two decades (since these studies were conducted), significant efforts have resulted in progress to bring innovation to the homebuilding industry. However, many of the same challenges noted in 2005 remain.

In summer of 2021, HUD sponsored a series of working groups—and the development of this report with RNN Architects of Denver, Colorado—to explore the current landscape of innovation in housing technology and process, to identify barriers that continue to thwart innovation, and to explore opportunities for collaboration and future research.

Key findings in each of the four topic areas were identified in both 2005 and 2021, suggesting areas for concentrated focus going forward:

On the topic of risk, it is still true that builders are reluctant to assume the marginal risk that comes with trying out new innovations, and that larger firms have the advantage when it comes to adopting and promoting innovations. Finding ways to share and minimize that risk, whether through the development and testing of innovations by trade associations, research and government partners, or other mechanisms, remains key to fostering a culture within firms where innovation is embraced.

Both panels identified the importance of communicating with and educating customers about innovations, and both stress the importance of understanding customer motivations—for example, greater energy efficiency may not always be the driver.

The lack of skilled labor and recruitment into the industry remained a problem in 2021; if anything, the crisis has only grown more acute. As was the case in 2005, existing education channels are insufficient to meet the current needs of the construction industry, let alone support new innovations, and the industry is not attracting enough young people who see construction industry as offering viable and attractive careers.

Both in 2005 and 2021, panelists identified the importance of working across the industry to promote innovations. Builders, developers, large-scale owners, subcontractors, and building code officials are primary decisionmakers who must be persuaded to implement an innovation. At the same time, innovation can spread from the ground up, if subcontractors are able to convince a builder to test drive an innovative practice or product.

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[4] https://www.huduser.gov/portal/Publications/pdf/OvercomingBarriers.pdf.

[5] https://www.huduser.gov/portal/publications/Building-Even-Better-Homes.html.

This report is a summary of the 2021 HUD-sponsored working group efforts. By no means is this an exhaustive study, but rather it is an opportunity to revisit the topic of the diffusion of innovation in the housing industry, and help set a collaborative path forward for HUD, other federal agencies, policymakers, housing researchers/advocates, and private industry.

The goal is to bring together key stakeholders to advance technology in housing at a critical juncture in the market.

To revisit the current state of innovation in housing, the RNN Architects team worked with HUD and industry to evaluate four key areas in the housing industry: education, risk, industry fragmentation, and behavioral factors and biases.

The target audiences for this report are internal HUD staff, other federal and state housing research and policy development organizations, external housing advocacy and research organizations, and the building industry as a whole. The intent of this report is to reinvigorate collaboration in public and private sectors and to catalyze a more formal coordination effort within these organizations around the topic of advancing innovation in housing.

This study was broken into three primary tasks: conduct a literature review, convene expert panels in the four topical areas, and summarize findings and recommendations for short-, medium-, and long-term research and coordination. At this point the report turns to federal research progress up to now.

## Innovation in Housing: Federal Research Progress to Date

In the mid-1990s and into the early 2000s, U.S. Department of Housing and Urban Development Office of Policy Development and Research (PD&R), U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE), and the Environmental Protection Agency (EPA) invested in research, demonstration, consumer and industry outreach, and education programs intended to catalyze the advancement of technology in housing. These programs retain similar goals with a focus on creating more affordable, efficient, safe and healthy, and resilient housing solutions for the nation.

Primary federal programs were born during this time that have been integral to the development of innovative housing solutions. These programs have also catalyzed and supported the development of an industry focused on affordable, high-performance, energy efficient housing that is currently the primary marketplace for new housing innovations.

At HUD, the Partnership for Advancing Technology in Housing (PATH) was formed in 1998 within PD&R. PATH inventoried technical solutions to a wide variety of housing issues and catalogued them on their website. PATH was phased out in 2008, but some of the programs content has been digitally archived at www.Pathnet.org.[6] PATH was a broadly focused program that interacted with multiple points on the innovation pipeline. At one extreme PATH co-funded foundational research grants with the National Science Foundation (National Science Foundation, 2005, 2003). At the other end, PATH conducted public facing demonstrations to showcase innovative housing technologies for consumers and builders.[7] PD&R current innovation efforts were initiated by the publishing of "Building Even Better Homes: Strategies for Promoting Innovation in Home Building" (Martin and McCoy, 2019) which updated the 2003 RAND report. Specific activities include HUD's 2019 Innovative Housing Showcase was a 5-day event on the National Mall displaying innovative, factory built housing solutions for public viewing and tours[8] and the Cooperative Research in Housing Technology program which has funded innovation research on a variety of topics including 3D concrete printing and off-site construction.

DOE created the Building America Program to research and develop technical and process-related improvements to improve energy efficiency in housing. In 2015, Building America completed and fulfilled the *Building America Research-to-Market Plan*[9]*,* which addressed key energy and non-energy technical issues in high performance housing. Solar Decathlon, a collegiate program motivating teams to design and build energy-efficient housing, was launched in 2002 to catalyze collegiate-level education and innovation in residential solar, and subsequently both commercial and residential building science and energy efficiency. Building America and Solar Decathlon continue to operate within the Building Technologies Office (BTO), Residential Building Integration Program (RBI). In addition to these historic programs, RBI has recently invested in other public-private partnership programs, including the Advanced Building Construction (ABC) Initiative and Collaborative, and the Buildings Energy Efficiency Frontiers & Innovation Technologies (BENEFIT) (ABC, 2022; DOE, 2021). Significant future focuses of these programs are workforce development as well as innovation in off-site or "manufactured" buildings and building systems to create scalable, affordable innovation in building performance. Other focuses are building-grid integration and beneficial electrification.

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[6] https://www.pathnet.org/.
[7] https://www.finehomebuilding.com/2008/01/17/a-better-home-right-now.
[8] https://www.huduser.gov/portal/pdredge/pdr-edge-trending-081919.html.
[9] https://www.energy.gov/eere/buildings/downloads/building-america-program-research-market-plan.

At EPA, the ENERGY STAR qualified products program began certifying home systems, and the ENERGY STAR for New Homes Program was formed in 1992 to provide an energy certification for new homes. Home Performance with ENERGY STAR was launched as a joint program with DOE to address efficiency in existing homes. Subsequent programs have focused on water efficiency, and HVAC system efficiency. Administration of these programs is still divided between DOE and EPA.

Over 25 years, these programs have catalyzed the development of an industry comprised of home performance incentive and delivery programs (i.e., utility demand-side management programs), contractors, products and new product manufacturers, quality assurance, certification, education, and training programs.

However, as concisely noted in the "Building America Research-to-Market Plan" related to the adoption of innovative energy technologies:

> Despite significant advancement of energy-efficient home technologies and best practices, including voluntary market advances and adoption of advanced codes such as International Energy Conservation Code (IECC) 2012, large technology and information gaps remain. These gaps prevent further advancement and mainstream adoption of the high-performance home technologies and systems for both new and existing homes that are needed to achieve DOE's energy-savings goals. A highly fragmented and resource-constrained housing industry (e.g., ~100,000 home builders and remodelers) lacks the skills and funds to invest in research, which has led to gaps in market adoption. Increased energy performance brings new technical challenges and can increase risk to builders and contractors. Real and perceived risks associated with adopting new technologies, combined with a general lack of understanding by housing industry stakeholders of business models that can create profit from improved home performance, prevent quick uptake of new energy-saving technologies and design approaches. Without proof that these new technologies and business models are safe, effective, and provide real business benefits, the market will not move forward with energy efficiency at the rate required to meet DOE's long-term energy savings goals.

It is obvious that although technical progress has been made, there are still significant barriers to innovation in housing that must be explored and overcome to deliver affordable, high-performance housing solutions at scale. In the next section, a discussion of the background and methodological approach is provided.

# Literature Review

The purpose of the literature review was to evaluate the key findings of publications which addressed the four key areas of education, risk, industry fragmentation, and behavioral factors and biases. The following sections summarize reviewed publications. For a full table of publications in the literature review, please see appendix A.

## Education Literature Review Summary

Education in the homebuilding industry refers to all aspects of skill and knowledge acquisition of individual workers to the level of the company. Lack of education can prevent companies from adopting new techniques, products, or materials that could make their projects more sustainable. Lack of skilled workers hampers the productivity of the industry as a whole. The literature reviewed touches on aspects or lack of workforce education and suggests possible remedies.

"Reinventing Construction: A Route to Higher Productivity" suggests seven specific improvements that could increase productivity by 50 to 60 percent (Barbosa et al., 2017). One of these is reskilling the workforce and a top-down re-education of the industry as a whole. The study stresses the importance of adopting technologies both on the jobsite and in the manufacturing of low-energy products and materials to reduce waste and energy, but it also points out that today's unskilled and non-nimble workface is a barrier to adoption.

"Framework for Measuring the Rational Clarity of AEC Design Decisions" looks at how design decisions are made and argues for the adoption of a design decision model that considers all stakeholders, including residents, owners, tenants, maintenance staff, and neighbors (Chachere and Haymaker, 2011). The authors acknowledge that this is a new concept for most firms and would require comprehensive education before it can be adopted.

"Characterization of the U.S. Construction Labor Supply" addresses an increasing problem in the construction industry: the lack of skilled or educated workers (Gilbert, 2012). It evaluates the composition of the construction labor force and how it is changing over time. It also examines how labor flows in and out of the construction industry from other industries, and how the skills required and workers' skill level changes with wages. One important conclusion is that the construction industry has trouble attracting highly skilled workers because such workers can earn more in other industries. The decline of unions has reduced the pool of skilled craft workers.

"Innovation in Homebuilding and the Future of Housing" looks at how innovation is disseminated in the homebuilding industry by examining trends, including the increasing concentration of production in larger and national firms (Koebel, 2008). These large firms are tasked with the diffusion of innovation and knowledge. Fortunately, these firms also have more access to resources such as the ability to invest in research. They are also better able to integrate their services and incorporate innovation into their brand identity.

"Effects of Lean Construction on Sustainability of Modular Homebuilding" discusses the Safety and Lean Integrated Kaizen (SLIK) method (Nahmens and Ikuma, 2011). This is a five-step process used to identify problems, implement and refine process improvements, present and celebrate results, and plan the next event. Three case studies support the thesis that construction companies could use this method to address barriers to sustainability.

"Overcoming Barriers to Sustainability: An Explanation of Residential Builders' Reluctance to Adopt Clean Technologies" attempts to identify why builders do not adopt low-cost off-the-shelf technologies

that could reduce a project's carbon footprint (Pinkse and Dommisse, 2009). The study focuses on replacing gas-fired boilers with heat pumps or solar boilers. The study concludes that firms that did not make the switch lacked personnel with the knowledge to implement the new technologies. Because construction firms rather than end users drive whether sustainable technologies are adopted, education is critical.

"Barriers to Implementation of Sustainable Practices in the Homebuilding Industry: A Case Study in Rochester, NY" examines barriers to sustainability in residential construction in a single community by interviewing builders and consumers (Tomkiewicz, 2011). The study found that the biggest barrier was "educational failure." Builders had little confidence in submitting unfamiliar new products and materials. A key barrier for builders was "the lack of affirmed respect and understanding of sustainability." The study suggests that education in green building certification and professional development seminars could help fill some of the information gaps.

## Risk Literature Review Summary

The construction industry is fraught with risk that potentially reduces already small profit margins. Companies must consistently mitigate risk with an eye on cost, and this can stifle long term innovation for short term gain. There are many strategies to mitigate risk, ranging from increased education and training, knowledge of innovative products, and government support for research, development, and demonstration to incentives for product adoption and collaboration between public and private sectors. The literature reviewed addresses various aspects of risk in the homebuilding industry and in some cases offers strategies for minimizing risk and fostering innovation and adoption of technologies that make construction projects more sustainable and energy efficient.

"BIM in the UK House Building Industry: Opportunities and Barriers to Adoption" looks at why United Kingdom builders do not adopt Building Information Modeling (BIM), despite its touted advantages (Burgess, Jones, and Muir, 2018). The study also considers barriers to innovation and identifies several that reference risks. For example, builders are reluctant to make the financial investment necessary, and they are not confident that the innovations will be commercially rewarding. A lack of information sharing (between industry players and between industry and innovators) was also identified as a barrier. Specific to BIM, firms interviewed for the study reported that lack of in-house knowledge was a barrier, and that manufacturing firms often lacked the capacity to produce BIM-compliant documentation.

"Overcoming Codes and Standards Barriers to Innovations in Building Energy Efficiency" recognizes that local codes and standards have trouble keeping up with industry-wide innovation (Cole and Gilbride, 2015). Agencies having jurisdiction are required to balance risk with innovation and often choose to mitigate risk. The reference includes case studies that suggest how to get innovations approved through existing codes and how to update codes to reflect innovative practices.

"The Economic Motivation for Innovation in Small Construction Companies" discusses the benefits and risks of innovation and the motivation for businesses to adopt innovation (Abbot, Jeong, and Allen, 2006). The study looks specifically at the relationship between university research and business innovation. It includes a case study of Amara, a London-based firm with close collaborations in academia and that has demonstrated a willingness to innovate. The study reports that the firm used an innovative methodology to move beyond "survival mode" to the developmental mode and used the case study to affirm three propositions: that owners play a pivotal role in innovative capacity, that methods which contribute to the overlapping of phases during the design and construction process encourage innovation, and so leading indicators can be identified and correlated with success in innovation.

"Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects" examines barriers to homeowners in the UK pursuing deep energy retrofits (D'Oca et al., 2018). In particular, the study identifies the risks perceived by homeowners; namely, the cost/payback time, trust that the results will be predictable in the value received, and funding issues and incentives. The study provides guidance on how a trusted entity can guide and educate the homeowner through a very complex process, helping them make educated decisions and instilling trust in the process and expected results.

"Defining a Commercialization Model for Residential Construction Innovation" uses 15 case studies to identify and validate a successful commercialization model (McCoy, Thabet, and Badinelli, 2011). The model can be used to mitigate risk, which is the primary barrier to innovation among manufacturers.

"Stimulating Construction Innovation in Singapore through the National System of Innovation" seeks to understand whether a government-funded research program can boost innovation, in part by mitigating risk (Na, Ofori, and Park, 2006). Innovation in Singapore's construction industry has been lagging, and contractors are not willing to take on the risk of innovation by doing their own R&D. The National System of Innovation takes ownership of this risk, creating a forum for innovation that brings together builders, suppliers, research institutions, and government.

"Zoning as a Barrier to Multifamily Housing Development" examines how Geographic Information System (GIS) and the means to analyze it could be used to quickly assess a region's trends, including the need and opportunity for new multifamily housing development (Knaap et al., 2008). The study concludes that zoning impacted multifamily development, but that the impact was local and varied widely. The implication seems to be that using GIS data could help overcome the zoning barrier and develop high-quality housing where it is needed.

"Adoption of High-Performance Housing Technologies Among U.S. Homebuilding Firms, 2000 Through 2010" examines the choices among U.S. homebuilders to adopt practices that lower the environmental footprint of their residential projects (McCoy et al., 2015). The study looked primarily at external parameters that were likely to influence builders' decisions, and whether these external parameters were driving environmental performance to be a "central component of diffusion" in the homebuilding industry. The researchers relied on a large dataset from the annual Builder Practices Survey conducted from 1996 through 2010. This survey asks respondents about the use of more than 1,000 individual products within 40 clusters of building products. One of the choices was between high-performance argon-filled windows and double-pane windows without argon. The study concluded that although the construction industry is slow to change and embrace innovation, there has been a more recent trend of embracing high-performance technologies in new homes. Government plays a strong role in adoption through policies, promotion, and incentives.

## Fragmentation Literature Review Summary

Fragmentation in the construction industry refers to the divisions and fracturing among and within organizations that are involved in building projects. Fragmentation arises in part because of the inherent segregation between the design and construction phases of a building project, and in the use of disaggregate trades to build. Each stage has its own goals and timelines, stakeholders, and professionals, and communication among them is often limited. Fragmentation can result in delays, inefficiencies, cost overruns, and mistakes; it can also inhibit innovation and the adoption of practices and technologies that could make building projects more sustainable and energy efficient. The literature reviewed addresses various aspects of fragmentation.

"Enabling and Measuring Innovation in the Construction Industry" discusses how the structure of an organization can best support innovation (Gambatese and Hallowell, 2011). Best practices include support from upper management, good communication within the firm, and overlap between the design and construction phases. The article identifies three components that must be present to foster innovation: idea generation, opportunity, and diffusion. It also identifies factors that are positively correlated with innovation. These factors include support from upper management, the presence of an innovation champion, a knowledge management system, and support for R&D.

"Discourse and Innovation Journeys: The Case of Low Energy Housing in the UK" discusses how discourse among a broad and diverse group of stakeholders can help simplify a complex problem and disseminate accurate information to the public (Lovell, 2008). The article stresses the importance of how ideas are communicated from an entity to the general public, and the potential damage done when information is misleading or false.

"Towards Establishing Diffusion Barriers for Innovative Green Building Products" relies on interviews with builders to understand barriers to the adoption of Structural Insulated Panels (SIPs) as a building method—for example, the incongruency between manufactured products (SIPs) and industry habits (McCoy, Ahn, and Pearce, 2012). The survey helps evaluate barriers to wider adoption of SIPs. Identifying the barriers and accelerators can help shorten the diffusion period for products, which can meaningfully impact the ecological footprint of the building industry.

"Towards Establishing a Domain Commercialization Model for Innovation in Residential Construction Industry" discusses the development of a "commercialization model" for residential construction (McCoy, Thabet, and Badinelli, 2008). The authors acknowledge that the distinguishing characteristics of residential construction pose challenges for the diffusion of technology. For example, in residential construction there tends to be more one-off projects, the necessity of unique solutions for specific sites, and isolated knowledge that does not flow upstream.

"Introducing Innovation into the Home Building Industry" identifies obstacles for innovators in the homebuilding industry and discusses potential approaches to marketing innovation (Moore et al., 2010). For example, building code officials are often reluctant to adopt innovations that deviate from the norm. The article discusses ways innovators can work with manufacturers to bring their ideas to market, using a case study about a chemical company that developed a hurricane-rated glazing compound. Because the company did not have connections or experience in the construction industry, it teamed with an established manufacturer of glass sealants to market the new product.

"Innovation and the Big Builders" uses mega-builder Pulte Homes as a case study in how builders overcome barriers to bringing sustainable technologies to market (Pauly, 2005). The article compares two strategies: incremental change versus radical and disruptive change, and it draws conclusions on how to foster innovation—for example, partnering with product suppliers, the need for government support, and focusing on small to medium-sized firms rather than large mega-builders such as Pulte.

"Service Innovation Through Linking Design, Construction, and Asset Management" discusses service-dominant logic as a possible alternative to the traditional approach practiced by most construction firms (Smyth, Razmdoost, and Mills, 2019). The authors conclude that builders create barriers by focusing on short-term goals rather than long-term user experience. The service-design approach could counteract fragmentation because it is an inherently open process that focuses not on outputs but on long-term service and innovation exchange.

"A Review on Building Renovation Passport" discusses how building passports could possibly boost the availability of information to a wider range of market participants in Europe (Sesana, Maria, and Salvalai, 2018). A building passport is a certificate displaying the most important performance characteristics and technological data of a building. It also can refer to a comprehensive collection of various building-related documents. The concept evolved from Energy Performance Certificates (EPC), which the EU requires of all member states. EPC are currently among the most important sources of information on the energy performance of the EU's building stock. This paper also surveys three initiatives currently underway that are using some version of a building passport to disseminate information to a wider group of stakeholders.

## Behavioral Factors and Biases Literature Review Summary

Human behavior is a critical but often underrepresented factor in the adoption of high-performance homes. Understanding behavior and the many factors that influence it is key to driving innovation and change. Governments can drive behavior by implementing policies and incentives. Technology can drive behavior by providing customers with feedback on their energy usage. Architecture and construction firms can drive behavior by modeling best practices and educating clients. Consumer retailers can drive behavior through education and advertising. Understanding the importance of cost-to-end users can help craft policies and incentives that put high-efficiency choices on equal footing with conventional code-compliant practices. The following reviewed literature referenced in the appendix looks at various aspects of behavior and how they can act as barriers to innovation, and in some cases how understanding these barriers can help to overcome them.

"Building Mass Customised Housing through Innovation in the Production System: Lessons from Japan" compares the advantages and disadvantages of small local builders with mass customized housing suppliers (Barlow and Ozaki, 2005). Large suppliers can offer customers choices in floor plans, finishes, etc., at an order of magnitude beyond small firms. However, small local firms have the advantage of long-standing relationships within their communities. Even though large suppliers have invested in in-depth customer interfaces, their approach is more costly.

"Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction" examines why large builders choose factory homes over stick-built options (Dainty and Gibb, 2012). While the study considered a number of criteria, including sustainability, cost, time, and quality, cost always trumped the other factors, followed by time. Sustainability was not high on the list of priorities unless forced by outside factors such as regulation.

"Managing Information to Unblock Supplier-Led Innovation in Construction" is a doctoral thesis undertaken to understand the role of the customer or client as decisionmaker in supply-led innovation (Engström, 2020). It focuses on Sweden's timber structure industry. The study identifies several behavioral barriers. These include long-term versus short-term gain and status quo bias. The research offers three lessons learned: building clients did not emerge as an apparent force for change; the information and understanding required for supporting clients' decisions did not seem to be readily available; and it was unclear how clients evaluate different options offered by an industrialized building process.

"Feedback on Household Electricity Consumption: A Tool for Saving Energy?" presents a model that explains why feedback on energy usage works (Fischer, 2008). The model is based on the idea that customers are more likely to change their behavior if they see tangible results or feedback.

"Building Integrated Photovoltaics (BIPV)" reviews the technology, compares it to Building Applied Photovoltaics, (BAPV), and explores myths and barriers to adoption (Heinstein, Ballif, and Perret-Aebi,

2013). The review helps identify the behavioral barrier by showing how innovation has been blocked in various ways. These include worries on the part of homeowners, misinformation promoted by the press and fossil fuel companies, persistent myths about the technology's cost and prestige, and architect objections to the technology's aesthetics.

"Diffusion of Green Building Technologies in New Housing Construction" analyzes builders' selection of high-performance windows in the U.S. from 2000 to 2010 (Koebel et al., 2015). The model found that climate, as reflected by the metric of heating degree days, was the biggest factor influencing the choice of high efficiency windows, followed by cost of energy. State and local energy grants ranked third. Building multi-family housing units had the largest negative impact on the selection of high efficiency windows.

"Valuing Innovation in Construction and Infrastructure: Getting Clients Past a Lowest Price Mentality" explores how firms can overcome the tendency for clients to value lowest cost over all other factors when making procurement decisions (Loosemore and Richard, 2015). Adoption starts at the top. Firms need to lead by educating clients, whether builders or homebuyers, to value innovation, and by finding ways to measure that value.

"Individual Liability and the Development of Defensive Engineering in Professional Practice" examines methods to avoid personal litigation in engineering practice, and how this has spawned defensive rather than creative practices (Maslen et al., 2020). The study relies on surveys of practicing engineers. Engineers seek to eliminate risk by sticking with "tried and true" methods and practices, which by definition discourage innovation.

"Teaching Engineering Students about Cognitive Barriers during Design" discusses how engineering students can overcome cognitive barriers and biases during design decisionmaking (McWhirter and Shealy, 2017). The students were educated about several cognitive barriers such as choice overload, status quo bias, and nudging. Using case studies, the students were able to use a certification program called the Envision rating system to identify and overcome these cognitive barriers. This reference is useful because it shows that cognitive barriers and biases may be encountered at every step of the decisionmaking process and thwart project goals. Now the focus of this report turns to panel discussions and working groups, including a thorough review of the methodology, key points, and recommendations.

The following are key findings from the literature review:

### Education

- Smaller the trade, the less education, and less productivity. More productive trades are outbid by cheaper, less educated labor. Industrializing the labor force and re-educating industry from top-down would increase productivity (Barbosa et al., 2017).
- The greater level of education, the less susceptible a person is to the business cycle of the construction industry. The shortage of skilled labor is linked to a decline in construction wages. Highly skilled construction workers can find higher wages in other industries (Gilbert, 2012).
- Emphasis should be made towards educating contractors and other building professionals who use codes on methods for getting innovation written into code. In addition, another pathway is to educate code officials on innovations to remove codes as barriers (Cole and Gilbride, 2015).

### Fragmentation

- Fragmentation between manufacturers, builders, and consumers is seen to be a barrier for the diffusion of Structural Insulated Panels. Builders see a lack of consumer demand, products are not compatible with industry habits, and manufacturers have not reduced these concerns according to builders (McCoy, Ahn, and Pearce, 2012).

- Despite the promise of attractive return on investment, the lack of transparency and prohibitive cost of due diligence for new technology leads to a substantial barrier to investors and building owners implementing innovations. A systematic approach for collating information in one place that all stakeholders can access is largely missing (Sesana and Salvalai, 2018).
- Construction firms focus on short-term thinking such as profits which isolates them from the consumers and their long-term user experience (Smyth, Razmdoost, and Mills, 2019).

### Risk

- Homeowners weigh the following risks when considering a home renovation: cost, pay-back timeframe, getting a good value, reliability, government approvals, bank lending practices, and funding incentives. Contractors play a large role in guiding homeowners through the risks and the decisionmaking process (D'Oca et al., 2018).
- Code compliance and product liability that is unique to construction products is additional risk for innovators that needs to be effectively addressed early on in development of an innovation (McCoy, Thabet, and Badinelli, 2011).
- The risk of litigation has created an environment of defensive engineering in which creative engineering practices are not pursued (Maslen et al., 2020).

### Behavioral

- Long-term versus short-term gain and status quo bias when there are a number of alternatives are behavior barriers. Managing communication is a major component and the ambiguity or "equivocality" caused by poor communication is a major driver of innovation barriers (Engström, 2020).
- Using the example of Building Integrated Photovoltaics, behavioral barriers are shown to be mythical perceptions of products, psychological worries about warranties, technology being declared "dead" by the media and competing industries, designer objections to aesthetics, skilled installers seen as unwanted competition to contractors, waiting for better technology, and irrational behavior in consumers unless utilizing localized diffusion techniques (imitative instinct mentality/"keeping up with the Joneses") (Heinstein, Ballif, and Perret-Aebi, 2013).

# Panel Discussions/Working Groups

## Methodology

To implement the panel discussions/working groups in this study, RNN Architects partnered with the Housing Innovation Alliance (HIA). HIA frequently produces webcast discussions with four- to five-person panels on how to overcome difficulties in the industry. Public participation is encouraged after the experts weigh in during the discussion.

A 2-day virtual event consisting of panel discussions and working groups was conceived as a key component of this study. Four panels of experts were formed for each of the four focus topics: education; risk; fragmentation of the industry; and behavioral factors or biases. The panels were informed by the literature review and drew from the industry's broad spectrum of manufacturers, builders, developers, universities, research companies, and experienced innovators outside the home building industry.

The panel discussions and working groups for this event were built around a "decisionmaking" presentation method and industry best practices for implementing successful panel discussions.

The goals of the discussions were to identify ways that HUD, building code certification, local planning departments, and other entities can encourage innovation, boost the direct relationships between innovators and builders, and participate in removing barriers to innovation.

The panel discussions were held on August 17 and 19, 2021, with breakout sessions immediately after. HIA created an event page on their website to promote the event and provided Zoom links so that attendees could join the panel discussion events.

## Education Panel and Working Group Summary

*Equipping the industry with the resources required to understand, value, and execute innovation.*

### Introduction

Education in the homebuilding industry refers to all aspects of skill and knowledge acquisition of individual workers to the level of the company. Lack of education can prevent companies from adopting new techniques, products, or materials that could make their projects more sustainable.

According to the National Association of Home Builders (NAHB), the median age of construction workers is 41. The building industry is fraught with challenges when it comes to recruiting and retaining talented and skilled workers. Industry leaders need to address both the reality that recruitment is poor as well as the fact that skilled workers are aging out and leaving the industry. Only by understanding the reasons behind this lack of engagement can firms begin to address the problem.

Panelist Branka Minic recommended considering the resilience of the workforce in the face of technological and economic shifts and other disruptions. The industry as a whole should move away from labor needs and instead work toward building a "talent-centric" culture in which education can truly empower people to drive innovation, she said. The scope should include architecture firms, construction firms, and trades.

Individuals at all levels of education need to embrace moving forward with innovation while staying relevant until an innovation is fully implemented. Every facet of the industry shares the joint responsibility of ensuring that the workforce remains relevant and sustainable over time. Education itself needs to be innovative for this to happen.

**Key Findings:**

- All parties need to share in the responsibility of education and training. This includes government, developers, architecture firms, and builders.
- Industry leaders should consider creative approaches to both attract and retain workers and to accommodate working professionals. For example, lean on universities, community colleges, high schools, trade unions, and associations and seek to work with other institutions and organizations. It also is important to leverage digital technologies such as virtual reality and explore ways to encourage life-long learning. Finally, it is crucial to develop or discover opportunities for micro-learning and micro-credentialing.
- Firms that foster a culture of learning can encourage employees to continually upgrade their skills and knowledge.
- In today's climate, it is important to rebrand careers in construction in order to attract committed and well-skilled workers who are motivated to stay abreast of new technologies and innovations via continuing education.

## Panelists

**Greg Zick, Associate VP, Workforce Development, NAHB**

Greg is a certified association executive (CAE) and brings association management and program management expertise to the NAHB workforce development area. While at NAHB prior to working with student programs, Greg worked as an organizational development consultant for state and local home builder associations. Originally from Minnesota, Greg received his B.A. from the University of Minnesota and his M.A. in Higher Education Administration from the University of Denver. Greg resides in Washington, D.C., and is an active member of the American Society of Association Executives (ASAE), serves on the Board of Trustees for the American Council for Construction Education, and is involved with the Association for Career and Technical Education, where he serves on the workforce development task force.

**Mark Babcock, Instructor, Colorado Homebuilding Academy**

Mark has been involved in construction on and off since 1985, starting as a framer's helper and progressing to project manager for high-end home renovations. After taking a year off to become a dive instructor in Roatan, Honduras (where he met his wife), he moved from Canada to Denver to be with her. He enjoys traveling, diving, and working on cars in his spare time. Mark is very excited about being a part of the Colorado Homebuilding Academy and teaching the next generation of construction experts.

**Branka Minic, CEO, Building Talent Foundation**

Branka Minic is the CEO of Building Talent Foundation (BTF). Prior to her executive role at BTF, she was the president of Future Work Consulting, advising donors, global corporations, governments and international NGOs on the latest research, best practices, and policies for addressing youth unemployment. Branka has spent her career as an expert in the staffing industry. Her research deals with best practices to reduce youth unemployment, and specifically examines the protocols for implementing successful workplace mentoring and apprenticeship programs. She has extensive experience in labor market and skill gap analysis. In collaboration with Making Cents International, Branka led the research and authored the "Demand-Driven Framework and Toolkit," compiling the international best practices on aligning education and training systems with employers' skill needs.

**Tyler Pullen, Doctoral Student, Terner Center for Housing Innovation**

Tyler Pullen conducts research with UC Berkeley's Terner Center for Housing Innovation while pursuing his doctorate in city and regional planning. His bachelor's and master's degrees in civil and environmental engineering led him to study and research energy efficient building design, civic engagement in infrastructure delivery and operations, and ultimately industrialized and off-site construction practices. Across multiple projects and papers, he surveyed the landscape of off-site construction firms in the United States and explored how different policy and market contexts can shape the adoption of innovative construction techniques in developing economies. Tyler then spent two years teaching and working in urban planning and affordable housing analysis and advocacy in the Bay Area before beginning his studies with UC Berkeley and the Terner Center. His current work combines many of his diverse experiences and interests, exploring the potential, limitations, and barriers of industrialized construction methods to improve and expand housing production in the United States.

**Mitch Rotta, Director of New Construction, Tricor LLC**

As Director of New Construction, Mitch oversees the entire lifecycle of the project, from land acquisition through vertical construction. With a background in large commercial projects, Mitch has implemented numerous construction efficiencies into Tricor's Build-to-Rent program. BIM, alternative building materials, direct product sourcing, and in-house labor are just a few of the techniques Tricor is utilizing to help separate themselves in the build-to-rent space. This combination allows Tricor to produce the most affordable, durable, and energy efficient smart rental homes in the country. Tricor is a full turnkey construction operator for the single-family rental space, offering end-to-end construction services for large portfolio and institutional investors. Having worked on more than $1.5 billion in assets for top institutions, Tricor is widely considered the premier outsourced construction provider in this space. Tricor is the only national contractor providing exclusively built-to-spec rental product, full transparency, and a fixed-fee service.

## Summary Points and Recommendations

### RECRUITMENT AND RETENTION

Young people are not joining the trades in high numbers, and at the same time, people with skills and experience are aging out or leaving the industry. The industry is also lagging behind when it comes to diverse representation. According to the Bureau of Labor Statistics, women comprise less than 10 percent of the workforce, and only 6 percent are African-American. In addition, though Latino workers make up about 30 percent of the workforce, they are overwhelmingly found in entry-level positions (McAnaw Gallagher, 2022).

There is a need to cultivate young people to help change the prevailing mentality and help drive innovation. The younger generation embraces innovation and technology, whereas older professionals in the construction industry tend to be stuck in their ways. If someone tries to introduce an innovative product, a common response is: "I don't have time for that." This resistance to change, while understandable, must be overcome. Doing things the same old way is too expensive. Young people and those entering the industry from other professions can help inject much-needed diversity and a more innovative mindset, but industry players need to cultivate young people coming out of trade and degree programs and attract people from other fields with the promise of meaningful careers and good wages.

Here are some specific suggestions and examples for recruiting and retaining high-quality talent:

**Innovative approaches such as factory-built housing seem to attract a more diverse workforce.** There is both a physical and cultural component to this phenomenon. When the tasks are more human-

scaled, they seem more accessible to more people. A person who may not be able to picture themselves on a traditional construction site may be able to imagine working in a factory.

**Work to change the industry's image.** The construction industry is so much broader than the term implies. It is not just swinging hammers and physically building homes. For example, Tricor handles everything from land acquisition and financial underwriting of projects to site planning, product design, and integration into actual projects.

**Construction programs that teach creativity and transferable "soft" skills.** Radical innovation may also produce unemployment because people and jobs will be displaced, so industry partners have a responsibility to think forward and future-proof the workforce. This includes finding paths for "continuous learning" and growing the labor force by incentivizing the effort of learning.

**Use a "problem-centered" approach when recruiting young people.** Many millennials and Gen Zers care about doing meaningful work and solving problems such as homelessness and climate change. A career in construction can be a way to directly address the problems and opportunities presented by climate change, homelessness, and resulting socioeconomic inequalities.

**Find creative ways to increase wages.** This can be done by looking at more than just wage costs. Shaving off costs in other sectors could help offset an increase in wages. One idea is to incentivize cost cutting by offering a cash incentive to subcontractor groups who complete a job ahead of schedule. Another approach is to choose quality over quantity. Companies may be able to leverage technology to reduce the need for talent in terms of numbers of people, but the talent will need to be more sophisticated and skilled. This would enable wage increases without impacting the total cost of labor.

**Examples of successful programs.** In Colorado, Career Explorer started as a small program that introduced at-risk high school kids to construction. It has evolved to include hospitality and medicine and is now open to all interested students. The program has spread across the area. Another Colorado program introduces foster kids to pathways in construction, and it also has a contract with parolees.

PARTNERSHIPS

The industry can't drive innovation without enough skilled and talented people who are motivated to keep up with the latest techniques and technologies. Institutions, government agencies, trade unions, and other entities can play a key role in helping educate and recruit new workers as well as upskill current workers. While there are examples of all of these, there is clearly an opportunity to strengthen the number and quality of these partnerships. Here are some specific examples and suggestions:

**Create an aggregate building trades union**. Such an organization would represent an entire workforce dedicated just to homebuilding and could take advantage of what labor unions do really well: strong, embedded wealth of knowledge and experience and organizing capacity.

**Replicate the trade association model.** For example, the Illinois Masonry Institute hosts a mentoring program where master masons train young people who want to join the trades. They receive primary training and ongoing education at the Illinois Masonry Institute, then they are farmed out to job sites for actual onsite training. The trainees become certified and work their way through the trade association to eventually become master craftsmen. The trade association funds the program.

It's important to note that some trades have more continuity of opportunities than others. For example, one Colorado high school offers a one-year program that introduces students to the electrical profession. In Jefferson County, Colorado, electrical companies are hiring apprentices from these programs straight

out of high school. There is not a straightforward path in other trades such as carpentry. The residential framing trade, for example, tends to be disjointed, and companies often hire subcontractors to do the actual work. It remains to be seen whether the trade association model could work for trades including carpentry and rough framing.

**Provide government incentives and financial support.** The government could provide scholarships for individuals who are not able to pay tuition for schools, or fund individual training accounts tied to individuals, not employers.

**Utilize universities as partners.** Universities provide continuous training and revelations of new technology, especially in the digital space. This training could take a basic format such as a 2-week workshop that introduces general contractors, foreman, and laborers to digital tools.

**Example of successful programs.** Stanford University has a certification program for virtual design and construction targeted towards upper-level foreman, onsite laborers, and lower-level management. Creating a certification rather than just an online course adds value and incentive for busy people to take time out of their lives to complete the training.

**Utilize partners who aren't typically seen as part of the industry.** For example, organizations that facilitate hiring of formerly incarcerated individuals, or employment matching services for previously homeless individuals. These partners also can help the industry reach equity and representational goals.

**Find ways to scale up.** The "build to rent" model has allowed one company to test out innovative products on a larger scale as they are building dozens of homes through a single owner. This gives contractors and crews the chance to master a new process. The company is helping enact change on a meaningful scale, not just running a test pilot of a product or process with a single home.

**Develop a training and development map for the trades.** This would be a resource modeled after the offsite construction map developed by the Housing Innovation Alliance that could be available to both potential talent and employers. It would serve as a clearinghouse, linking people with education programs and opportunities.

**Engage code officials in the education process.** Nobody knows the product better than the manufacturer itself. Bringing in the manufacturing team to help pitch new products to building and code officials can instill confidence in the products. Stakeholders must be persistent and stress what the jurisdiction is potentially missing out on, especially if they are promoting sustainability and energy efficiency. The State of California is trying to take a more active role in proactively training and engaging with local officials by using local factory housing producers to make that conversation happen. Inviting code officials to join in a factory tour to learn about the assembly process and quality control while seeing how much easier it is compared to the typical onsite project can help instill confidence and ease concerns about liability.

It is important to engage local officials before they are actually needed. Tyler Pullen recommended exposing them to the process and involving them in the conversation. "[Making them] aware of what is actually taking place in the factory and inspection process at the state level has done wonders for the project teams," he said.

## UPSKILLING

Innovations will not be adopted if firms lack skilled personnel to implement them. Traditionally, the immediate employer takes on responsibility for training. Larger employers in the construction industry with more resources tend to be committed to training their workforce, but there are thousands of small

companies that lack capacity to invest in training at that level. Upskilling happens informally on job sites, not in an organized, structured way.

In addition, many workers in the industry are independent contractors or subcontractors. They may be too busy to carve out time for online classes or in-person learning, especially without clear incentives. Since online training content can be dry, it is important to keep the target demographic in mind when designing education and training materials. Engaging material may be presented differently depending on goals and experience.

How is an engaging and relevant training program created? If the industry is ready to provide organized upskilling in a complex hybrid ecosystem—who is responsible for making sure it happens?

Here are some specific examples and suggestions:

**Meet workers where they are.** Micro-learning and micro-credentialing, which delivers learning in small units, is more accessible to workers in the field, as are certifications based on product line rather than job role. Along with that, the industry should consider advocating for individual training accounts that allocate dollars to individuals. These accounts allow people to draw from them when they need to upgrade their skills, and they encourage lifelong learning.

**Invest in learning.** Training and educating in small construction companies can spark innovation; often, this equates to lower costs, allowing employers to increase wages. Mark Babcock claimed this investment will pay off. “In the long run, I am finding that innovation actually allows me to increase the wages of my people onsite,” he said.

**Retool how education is delivered.** There is a role for educational institutions that provide basic knowledge and opportunities to learn, but the industry needs other options that leverage technology to provide onsite and on-demand learning. The COVID-19 pandemic accelerated the conversion from textbooks and in-person training to web-based and virtual training. Now, it’s important to find the right combination of hybrid in-person and virtual learning and present the material in the right format to match the attention span of people on a jobsite. There is likely an ideal model that combines the technology, content, and incentives, but no one has come up with that yet.

**Take advantage of digital technology.** Bringing elements of gaming into education and training, for example, could engage younger people and help them feel like they are actually helping create the content. Virtual and augmented reality can be used to instruct in an engaging, practical way: for example, a contractor could hold a camera over a wall that’s just been framed, plumbed, or wired and point out the incorrect elements, or introduce several techniques that work.

**Incentivize training.** Leadership needs to convey the value of the training to the worker—the why—through reward or incentive. If an employee doesn’t see a path to a higher income, why would they invest resources into training? If the industry or occupation doesn’t call for additional skills, an employer or employee might not see what they get out of the investment.

**Make it pragmatic.** When introducing a new technology, convey how it can ease or quicken a process, or make the building more durable. Focusing on practical applications as opposed to academics may be useful.

**Incorporate YouTube influencers.** YouTube influencers have captured large audiences to introduce new tools and techniques. The main concern is curation: making sure the influencer is presenting best practices.

## Risk Panel and Working Group Summary

*Ensuring the value of innovation outweighs financial risk exposure.*

### Introduction

The construction industry is fraught with risk, and companies are in the business of making decisions designed to minimize risk but keep margins positive. Yet some of these decisions stifle innovation. By nature, the construction industry is conservative. Innovators fear giving away their intellectual property. Builders fear running into regulatory barriers. In addition, the litigious nature of our society creates real risk for home builders and developers—and for people who want to deploy new technology. The labor force is reluctant to step out of its comfort zone and try something new, and there is a lack of available training and inspiration at that level.

As a case in point, offsite construction offers much promise for a future of more affordable and sustainable homes, and it may be the only way production builders will be able to meet goals for carbon neutrality. But enabling offsite construction—and reducing the risks associated with bringing a new process online—requires collaboration among a host of players, from manufacturers and builders to trades such as heating, ventilation, and air-conditioning (HVAC) and plumbing. One of the biggest barriers is a reluctance to collaborate around the design of these models.

Politics also plays a role. Consensus is the enemy of progress and innovation; the industry must welcome differences of opinion and belief so that people feel safe bringing great ideas forward.

There are many strategies to mitigate risk, including increased education and knowledge about innovative products, government support for research and development, and incentives for product adoption, as well as collaboration between private companies and research institutions. How can the industry move from working in silos to fostering collaboration? How can organizations ensure that the value of innovation outweighs the exposure that could result from failure and actively mitigate risks along the way? Rewards and incentives for innovation are key. The most pressing risks for builders and developers must be considered, along with a path to who can provide solutions.

**Key Findings:**

- The success of innovations ultimately depends on individuals in the field who know how to implement them. Developing long-term relationships with the right subcontractors, designers, and vendors can help ensure innovations are disseminated and adopted.
- Adopting a decisionmaking process that includes “go/no-go” pathways can help identify viable innovations, including those that carry a ready market and add value to the homebuilding process.
- Reducing financial risk and educating homeowners can help steer them toward making decisions that improve energy efficiency and comfort as well as long-term return on investment (ROI).
- When developers and other organizations work with jurisdictions to remove zoning and land use barriers, they can deploy more energy efficient and affordable housing where it is needed most.

### Panelists

**Scott Reichensperger, Vice President of Technology Implementation, MiTek**

Scott has been with MiTek USA for more than 26 years. He is currently in charge of the company’s residential sector software direction, commercial decisions that are technical- and software-related, deploying new software products, and transitioning new customers to MiTek’s software suite. Previously, Scott served as a director of field technical support for nearly 10 years, developing an intimate knowledge of how clients leverage MiTek’s management, computer-aided design (CAD), and design software

platforms, as well as production software specifically designed to support roof truss, floor truss, and wall panel construction.

**Bill Rectanus, Vice President of Homebuilding Operations, Thrive Home Builders**

Bill is responsible for implementing Thrive's High Performance Building Initiative. A dynamic leader and manager with experience in business-to-business sales, account management, project management, and sustainability, he also oversees the construction, purchasing, and customer service departments. Bill is recognized as a dedicated self-starter, and he is skilled at managing multiple projects in tandem. He is known as an outstanding trainer who continually creates excitement and interest while effectively presenting complex information. Bill is an active member in the Denver homebuilding industry, driven by his passion for advancing energy efficiency, building science, and renewable energy. He serves on the Board of Directors for the Home Builders Association of Metro Denver.

**Anthony Grisolia, Managing Director, Innovation Programs, IBACOS**

Anthony is Managing Director of Innovation Programs, overseeing IBACOS's consulting activities and services for product and material manufacturers, including technical services and testing for existing products, development of new products and markets, and evaluation of product opportunities. Anthony also helps support production homebuilders, having evaluated hundreds of residential construction issues and performed construction quality assessments with builders in 40 different markets. He acted as principal building scientist for the construction of DIY Network's Best Built Home, and he regularly develops specifications and conducts quality assurance for green communities. In 1999, Anthony was honored with Canada's Energy Efficiency award for an energy efficient housing design. He has a master's degree in architecture with an emphasis on sustainable design from the State University of New York at Buffalo and a bachelor of building science degree from Canada's Ryerson University.

**Carolina Albano, Host, Build Perspectives Podcast**

Carolina uses her master's degree in mechanical engineering every day. She has been lucky enough to travel all over the United States and Canada for her job, interacting with trades that have specific needs based on where they are practicing, such as Texas Department of Insurance zones or seismic zones in California. Throughout her career, she's gotten to speak to installers, general contractors, architects, and designers during meetings and site visits, giving her a great view on how all the different trades and positions work together. A former technical manager for Nichiha and engineering consultant, she has played an integral role in developing go-to-market strategies and managed engineering, testing, and building code approvals and compliance for residential and commercial efforts in the United States and Canada.

**Chris Spelke, Senior Developer, Denver Housing Authority**

Chris is involved in all aspects of the development process from site acquisition, due-diligence, and financial modeling to overseeing community engagement, design, and construction and managing financial closing through project delivery. Recently, Chris orchestrated the complex financial closing of Denver Housing Authority's (DHA's) Vida at Sloan's Lake Project (a 176-unit affordable building for seniors and people with disabilities with 30,000 square feet of ground floor commercial space) that included tax increment financing (TIF), 9 percent and 4 percent low-income housing tax credit (LIHTC), and New Markets Tax Credit (NMTC) Program under a unique condo structure. Chris also supports the Real Estate Department's active construction projects and assists in planning, underwriting, and design development for various pipeline projects, including DHA's next large-scale redevelopment of Sun

Valley. Prior to his current role at DHA, Chris gained valuable experience working on two large-scale master-planned redevelopments, Aria Denver (while at Perry Rose), and South Lincoln Homes HOPE VI (when first at DHA). Chris is a graduate of the University of Colorado Leeds School of Business with degrees in finance and political science. He is a Colorado native and served as the Executive Co-Chair for ULI Colorado's Young Leaders and Colorado Housing and Finance Authority's (CHFA's) Tax Credit Advisory Committee.

## Summary Points and Recommendations

### DEVELOP A CULTURE OF INNOVATION

Playing it safe is a huge barrier to innovation. Here are some concrete suggestions for fostering a culture that embraces innovation and accepts risk as part of the process.

**Know why you're innovating.** Don't innovate just for the sake of it. Set an intention with a team. Create a plan and vision for what the future looks like. Set milestones and phases, then build in time limits and budgets for each phase.

**Plan for obstacles and failures.** Learning from obstacles helps develop future innovation.

**Model: The IBACOS Innovation Pathway.** This three-step process helps mitigate risk at each step along the pathway:

**1. Explore and discover**

- **Involving key stakeholders** (builders, manufacturers, etc.) from the initial concept is key to the evolution of innovation and minimizing risks.
- **Make sure there's a clear business value to the innovation.** Analyze both the market value of the concept or technology and the performance value. Does it cost too much? Even if it performs, it may be too expensive to fold into the industry. Finally, look at the technology's future value. Will it help projects be more sustainable or reduce their carbon footprint?
- **Use a litmus test:** If the idea cannot be killed, it may have a good chance of success.
- **Find early investors.** It can be hard to gain investment in the early stages of innovation, but the government offers grants for developing innovative ideas.

**2. Develop and demonstrate:** Physically demonstrate the technology and what it means to the builder.

- **Partner with a builder** and invite them to build a project with the technology in it.
- **Involve local building officials.** Make them aware of the technology and what it means to their inspection process and how it meets code. Code approvals can be a barrier to innovation.

**3. Startup and deliver:** This is the time to encourage builders and trades to implement the innovation—not just once, but multiple times at a community scale. Note that this may be the step with the biggest risk.

- **Cultivate relationships.** Many manufacturers have relationships with distributors but not with the builders who implement innovations. Foster links between the intrinsic ideas team and the extrinsic team who launches it into the market. In this case, large builders have an edge because they have strong, longstanding relationships and big business accounts.

### STEPS TO SUCCESSFULLY IMPLEMENTING INNOVATION

Here are some practical suggestions, from a builder's perspective, for what it takes to actually implement an innovation at the end of the line.

"We look at three big buckets when we're trying to decide whether to move forward with some innovative product or system solution," said Bill Rectanus of Thrive Homebuilders. These are:

- **Installation.**
- **Liability and use.**
- **Maintenance.**

**Installation:**

- **Labor:** This represents one of the challenges of implementation in the field. Often an innovation comes to the builder without an attached labor force, so the builder has to help develop the labor. There are two critical ways to help avoid failure at this stage. First seek to gain buy-in and excitement from the laborers responsible for installation or implementation of an innovation. In addition, create a consistent closed-loop conversation between crew, installation partner, builder, supplier, and innovation partner.
- **Supply chain:** Consider availability and channels for the innovation, as well as where vendor partners can acquire the product or system solution.
- **Building science:** Ideally the innovation makes the process easier by reducing steps and does not create challenges by adding steps that fracture installation.

**Liability and use:** "We have to make sure that we're not increasing our risk to a level that's unmanageable or unacceptable for our business," Rectanus said. This includes making sure the risk of defect liability does not increase, whether from a building science or code compliance issue.

- **Providing warranties:** This typically falls to the vendor partner.
- **Supply chain:** Sometimes it can be easy to acquire the innovation, but when it comes down to warranty and service, getting parts and materials is a different supply chain that should be an aspect of planning.

**Maintenance.** The homeowner might live with the innovation for 5 to 20 years. Companies should have conversations with homeowners to explain benefits of the innovation but also clarify who is responsible for maintenance.

MITIGATING RISK: GENERAL SUGGESTIONS

**Find the right partners.** It is important to seek out partners whose vision and willingness to work fits well with the overall vision. As Bill Reichensperger warns, the right partners may not be the cheapest. The good news is that there are suppliers and vendors who want to contribute to building good quality homes. Innovations ultimately depend on individuals in the field who know how to implement them. Seek out partners and companies who value being attached to best practices.

**Respect timing.** Sometimes an idea is good, but the timing isn't right. It is important to understand that it can take years to bring innovations to market and for builders to adopt them. It is also important to engage with builders early on. Large projects have drawn-out timelines, but it may be too late to garner involvement midway through a project. In addition, code cycles are three years or longer.

**Use case studies.** Integrative design is going to cost more money up front, but case studies can prove how an innovative approach results in a better building—and this can help secure partners and investors.

**Build your own demonstration.** Demonstrate the technology without involving a builder if possible. Build or buy a house to retrofit with the new technology, then bring in other builders and demonstrate the value for the buyer or homeowner, allowing them to ask questions and see for themselves the value of the innovation.

**Do extensive testing in-house.** Before taking an innovation to the International Code Council (ICC), do the work to address code barriers. This requires heavy lifting upfront but shortens the timeframe for gaining code approval.

**Ensure inspectors and installers are up to speed.** An innovator may jump through all the hurdles of code compliance only to find the installers and inspectors in the field are unprepared.

**Take the time to understand the needs of the marketplace.** A lot of manufacturers are R&D focused and will spend a lot of money developing a good idea that doesn't have a real market. Take the time to quantify and objectively understand the needs of the marketplace before committing to an innovation. Similarly, understand what customers want and focus on this with marketing. Whether it is affordability, health, or sustainability, get to know what factors are driving the market.

**Court young people.** The construction industry is desperate for labor at this time, and young people can help the industry get over its aversion to risk, but the old guard needs to create a welcoming environment for younger generations. As Carolina Albano put it: "We must be willing to mentor the next generation while also allowing ourselves to be mentored by them, because they're bringing in ideas."

## Fragmentation Panel and Working Group Summary

*Driving collaboration, communication and change management throughout the value chain and the home delivery process.*

### Introduction

The homebuilding industry is extremely complex, both horizontally and vertically. It is also highly fragmented. Fragmentation in the construction industry refers to the divisions and fracturing among and within organizations that are involved in building projects. Fragmentation arises in part because of the inherent segregation between the design and construction phases of a building project, and in the use of disaggregate trades to complete a project. Each stage has its own goals and timelines, stakeholders, and professionals, and communication among them is often limited. Fragmentation can result in delays, inefficiencies, cost overruns, and mistakes. It also can inhibit innovation and the adoption of practices and technologies that would make building projects more sustainable and energy efficient.

At the moment, a crisis is building in a perfect storm prompted by labor shortage, skyrocketing material costs, and high demand. Even though innovation is occurring within the industry today, especially in the arena of modular prefabrication, fragmentation makes it difficult to disseminate innovations across the industry. It might be an issue with one or more players in the supply chain, or it can be born of the high cost of meeting regulations. Sometimes it is an aversion to risk when trying out new technologies. In other cases, it is a matter of getting information and training to the right people. Whatever the causes, the bottom line is that fewer people can access affordable, high-quality housing. Starter home prices are unattainable for many millennials and others who are finally able to enter the market. The industry needs more options including methods to streamline production and overcome regulatory barriers, incentives for sharing innovations and information, and ways to bring costs down.

**Key Findings:**

- Less litigious financing and value-added lending practices can reward innovation among homebuilders.
- Cultivating an atmosphere of support that rewards innovators and protects their intellectual property while encouraging sharing can help foster innovation. For example, a mechanism or organization that helps suppliers connect with fabricators can help them understand issues and customize products for particular markets. Such an organization also can help manufacturers develop products and launch them into those industries.
- Government can play a key role in sponsoring and incentivizing innovation, especially when government teams up with manufacturers and research institutions.
- Developers can work with municipalities and other jurisdictions to remove regulatory barriers where appropriate, incentivize development that satisfies communities' needs and desires, and educate homeowners and other community members.

### Panelists

**Andrew McCoy, Professor and Director, Virginia Center for Housing Research**

Dr. McCoy is Director of the Virginia Center for Housing Research (VCHR), Professor in the Department of Building Construction, and Associate Director of the Myers-Lawson School of Construction (MLSoC) at Virginia Tech. He currently holds the Beliveau Professorship in the Department of Building Construction, thanks to the generous support of George Clarke. He previously held the Preston and Catharine White Fellowship, thanks to their generous support. Dr. McCoy has authored more than 100 articles and has been a primary investigator on millions of dollars in funded projects, including "green"

residential construction practices, building technologies, affordable housing and safety practices in the construction supply chain. Dr. McCoy's research won the 2015 Game Changer Award for the State of Virginia and *Engineering News Record's* 2014 "Top 20 under 40" for the Mid-Atlantic. Dr. McCoy's work also won *ASCE's Journal of Architectural Engineering* "Top Paper Award 2015" and the American Real Estate Society conference's "best paper prize for the topic of Sustainable Real Estate."

**Heather Voorman, Program Manager, Housing Finance, National Association of Home Builders**

Heather is an experienced association manager and policy director with measurable advocacy outcomes in housing and community development policy. Before joining the National Association of Home Builders (NAHB), she had the opportunity to serve as the policy director for the National Association for County Community and Economic Development (NACCED) and the National Association of Local Housing Finance Agencies through SmithBucklin. There she directed government relations efforts, set legislative priorities, engaged stakeholders, and organized advocacy efforts on Capitol Hill, including budgets and appropriations, affordable housing, community development, and more. She was also a co-creator and co-host of the Holistic Housing Show, a NACCED podcast featuring leading affordable housing and community development experts. Heather is a graduate of the University of Nebraska College of Law and South Dakota State University undergrad.

**Don Jahnke, Energy Consultant, Extreme Panel Technologies**

Don Jahnke is an energy consultant at heart, working at Extreme Panel Technologies in Cottonwood, Minnesota. He started out running a plumbing and radiant heat shop in northern Wisconsin. After getting into the construction business with Structural Insulated Panels (SIPs) and Insulated Concrete Forms (ICFs) he relocated to southwest Minnesota. With a passion for energy efficiency, he became an Energy Rater for the ENERGY STAR program. At present, he works at Extreme Panel, helping to create low- and zero-energy homes with various builders across the United States. He has worked on everything from a multi-story treehouse to homes in the tens of thousands of square feet and to multistory commercial, and is always trying to figure out how to make each one a little better.

**Nolan Browne, Founder and Chairman, ADL Ventures**

Nolan is an innovation expert, entrepreneurial executive, investor, fundraiser, and board member specializing in commercialization of emerging technologies in energy, automotive, technical R&D, and innovation management. He excels at developing first-of-kind programs and products, and leading teams of high performing technical, business and political professionals. A five-time founder with 15 years of C-Suite experience in both startups and multinational corporations, Nol holds advanced economics and business degrees from MIT and Johns Hopkins.

## Summary Points and Recommendations

### REGULATORY BARRIERS AND COST

In the housing industry, there is a perception of a significant disconnect between industry and government. It is a widely held belief that regulatory barriers at the federal, state, and local levels reduce business profitability and make housing less affordable. An NAHB analysis shows that regulatory requirements alone account for 25 percent of the cost of constructing a single-family home and 30 percent of the cost of a multifamily unit. These factors make it difficult to increase the supply of affordable housing and ensure that it meets the needs of increasingly diverse households. These costs are preventing households at all income levels from finding the right home in the current market. Lack of communication between regulators and the industry often creates more pain for developers and builders;

for example, the city of Fort Collins, Colorado, in its quest for more efficient and sustainable housing, passed an ordinance requiring new builds to achieve a Home Energy Rating System (HERS) index rating of 15, which not even the most progressive builder in the state could attain.

Here are some suggestions and examples for overcoming cost and regulatory barriers to the development of affordable housing:

**Case study: Accessory dwelling units (ADUs).** In many cities that are strapped for affordable housing, local government wants to push density in the form of ADUs. Often zoning allows ADUs but the costs do not pencil out for developers and builders, in large part because of high systems development charges, especially around water and sewer connections. At the same time, many communities resist or oppose ordinances that increase density because they are afraid it will change the character of their neighborhoods, lower property values, or lead to issues with parking.

- **Education can combat NIMBYism (not in my backyard-ism).** A neighborhood may claim they don't want affordable housing because people are afraid it will drive down their property values, but they may not have a full understanding of what constitutes affordable housing. Education can weaken resistance. For example, in Minnesota, a public relations campaign is helping change perceptions of ADUs as college party houses by showing examples of different types of ADU residents, including aging family members who may need assistance.
- **ADU ordinances can be written to reflect what individual communities want and need.** For example, an ordinance can set limits on short-term rentals or requirements for exterior finish materials.
- **Municipalities can offer incentives to increase density**. The town of Blacksburg, Virginia, created a program that allows an increase in the footprint of the house or the density on the lot if the builder agrees to take on the additional costs of meeting energy efficiency specifications.

**NAHB Land Use Toolkit.** Located at the NAHB website, this resource includes information about reform efforts to reduce the impact of infrastructure fees and exclusionary zoning.

**Cost-based appraisals.** Because of the inflated cost of building materials and lumber, it is costing more to build a house than it might be appraised. Cost-based appraisals for new construction can help address this disparity.

**Financing models that reduce litigation.** Sharing the financial wins of a project with general contractors and subs is one way to validate and reward all players in its success.

COLLABORATION ACROSS AND WITHIN SECTORS

Collaboration is essential for the uptake of innovation in the housing industry. Because the industry is so complex, it can be difficult to access and share information about innovations. In addition, few builders can afford to fund their own research. Here are some resources and examples that can help foster collaboration.

**NAHB.** NAHB represents the largest national network of craftsman innovators and problem solvers dedicated to building and enriching communities. The organization operates at the local, state, and national levels. NAHB helps members connect and learn from one another. The organization represents more than 700 state and local associations and boasts more than 140,000 members. About one third of its members are home builders and remodelers; the rest work in closely related specialties, such as sales and marketing, housing, finance, and manufacturing and supplying building materials. This extensive network helps members connect and learn and innovate as a cohesive housing industry.

**NAHB International Builders Show.** This annual event is a hub for product launches, construction, demonstrations, industry thought, leader sessions, workshops, and panel discussions. The show connects people, products, and knowledge to spark innovation and progress in the housing industry.

- **The New American Home** and **New American Model** feature a variety of trending design concepts, efficient construction methods, and innovative products. Over the years, these demonstration projects have displayed technologies and design ideas that have been adopted and utilized around the world.
- **Building knowledge lessons** are 60-minute sessions that cover the most important topics in the home building industry in architecture and design, building techniques and strategies, custom building and remodeling, and multifamily housing.

**Myers-Lawson School of Construction** at Virginia Tech is a joint venture between engineering and architecture departments that offers accredited undergraduate and graduate degrees in both construction engineering and construction management. It is also the State of Virginia's interdisciplinary research center for housing research. It was established in 1989 with the core mission to improve affordability, durability, and quality of housing by creating knowledge through research. The center is a resource for policymakers, communities, non-profits, and for-profit businesses.

Historically, the organization worked with localities to examine strategies for bringing affordable housing into the local housing stock. Using publicly available data, they analyze current housing stock levels, incomes, and identify the gaps, including how some groups are crowding out other groups. They also consider the effect of regulation on cost and process. They use data to design and develop several housing-affordability indices that are used across the state.

Increasingly the center is focused on housing technology research for HUD, Department of Labor, and National Science Foundation that examines how housing technology can increase affordable housing options.

Examples:

- The center is studying how increases in efficiency and performance in mechanical system designs for low-income housing tax credit properties could reduce resources and costs.
- Researchers analyzed a large dataset of 400 units across the state to learn how behavior impacts efficiency.
- They are exploring how replacing portions of the housing production cycle with innovations could save time, money, and labor while at the same time increasing quality and durability. For example, they worked with manufacturers and policymakers on a 3D concrete-printed house in Richmond, Virginia.

**Supporting innovators.** ADL Ventures works with fabricators, suppliers, general contractors, and developers—everyone in the supply chain of industrialized construction. Many fabricators have developed great ideas for their own use. ADL Ventures applies a rigorous evaluation methodology to identify which of these ideas have potential for real traction, then works to monetize innovation, helping to get industry-improving ideas to market and making sure that the people who have the ideas get paid for them. ADL helps the fabricators who assemble products find pathways to markets by using a quantitative method to assess where there are opportunities and unmet needs. There are three main pathways:

- Creation of a new start-up company.

- Matching the fabricator with a major industrial partner so the fabricator receives licensing revenues.
- Consortium licensing model through **Advanced Building Construction (ABC) consortium.**

**ABC Collaborative.** A federally sponsored U.S. Department of Energy (DOE) program for innovation in industrialized construction helps industries share best practices and knowledge across the entire industry.

From the ABC website (2022): "Advanced Building Construction employs industrialized construction and innovative building technologies with a focus on energy efficiency, reduced greenhouse gas emissions, streamlined project delivery, and high-quality yet cost-effective building techniques and materials. The ABC Collaborative brings together forward-looking people and organizations to modernize the construction industry and advance the buildings sector. Through five core competencies, the Collaborative is paving the way for high-performance, low-carbon new construction and building retrofits."

MODULAR CONSTRUCTION

One of the obstacles to bringing more affordable housing online is the cost of onsite building. Building small is not necessarily less expensive than building big. At the same time, the number of skilled building professionals is on the decline. One possible solution would be modular or factory construction, which offers opportunities to streamline the homebuilding process, reduce labor costs, and make lower cost homes that are more accessible to more people. There are many obstacles to industrialized construction: getting different suppliers along the chain on board, making sure there are enough trained installers in the field to apply the technologies, variation in local codes and ordinances, and variation in lot size and characteristics—just to name a few. Some in the Fragmentation Panel are more optimistic about this scenario than others. Some feel that we will be able to industrialize and modularize portions of the process, but that there will always be onsite and custom components to homebuilding.

Here are some of the technologies and ideas that are moving industrialized and modular construction forward and helping to reduce costs, materials, and labor:

**Panels and pods.** Panelized wall systems, predesigned and prebuilt mechanical rooms, and kitchen pods enable multi-family projects that are still technically site-built, but they take a fraction of the time because some of the most complex components are prefabricated.

**SIPs.** Extreme Panel is continually working to advance the most efficient and sustainable product possible. This process of constant innovation impacts the types of materials used and the installation methods, which in turn impacts supply chains and installers in the field. The product can reduce labor costs and material use; for example, it significantly reduces the amount of framing for a site-built home.

**Guiding innovation in manufacturing for new markets.** Building materials manufacturers see that the industrialized construction industry could be a new market. But they're often trying to sell a portfolio of products that are made for onsite, not offsite, construction. ADL Ventures helps suppliers connect with the fabricators to understand the issues so they can customize their products. They also work with materials manufacturers to develop products and launch them into those industries (see also ABC collaborative).

## Behavioral Factors and Biases Panel and Working Group Summary

*Breaking ingrained habits, changing perspectives, and paving the way for innovation within the industry, with local government and consumers.*

### Introduction

Human behavior is a key element that can both foster and inhibit innovation. Challenges associated with human behavior are seen at every level and every step in the design/build process: whether seeking project approvals from counties and municipalities, getting buy-in from neighbors, convincing a homeowner to embrace more sustainable choices, or working within the culture of a company or firm. It is easy to keep doing things the same old way. Innovation requires breaking out of the box, trying new things, and bringing stakeholders along in the process.

Understanding behavior and the many factors that influence it is key to driving innovation and change. Governments can drive behavior by creating policies and incentives. Technology can drive behavior by providing customers with feedback on their energy usage. Architecture and construction firms can drive behavior by modeling best practices and educating clients. Understanding the importance of cost-to-end users can help craft policies and incentives that put high-efficiency choices on equal footing with conventional code-compliant practices.

**Key Findings:**

- Government plays a special role in nudging the private sector by creating policies, processes, and incentives around affordability, resilience, and energy efficiency. The federal government needs to reevaluate its guidance and incentives regarding the homebuilding industry.
- Inviting municipalities and communities into the process early on is critical to removing barriers and facilitating projects that will benefit all.
- Taking time to identify the true barriers to adoption for homeowners is key to removing them. Architects and builders can influence homeowners' choices by careful presentation of those choices.
- Fostering a culture of learning within firms—which includes allowing for mistakes—can encourage innovation and "outside the box" thinking.

## Panelists

**Tripp Shealy, Associate Professor, Virginia Tech**

In both teaching and research on sustainability, Tripp applies concepts from behavioral science, neuroscience, and data science to help inform design and delivery for more sustainable outcomes. This research investigates engineering decisionmaking at the system, behavioral, and cognitive levels to encourage less carbon intensive and more user-centered infrastructure system solutions. Tripp's approach to research bridges data science and cognitive psychology with engineering for sustainability.

**Mackenzie Aron, VP of Investor Relations, Taylor Morrison**

In August 2020, Mackenzie joined the Taylor Morrison team as their VP of Investor Relations. A Chartered Financial Analyst, she was a vice president with Zelman & Associates for more than 8 years. Mackenzie holds a master's degree in finance from the University of Florida's Warrington College of Business Administration.

**Christopher Fox, VP of Architecture and Building Science, Van Metre Homes**

Christopher is Vice President of Architecture & Building Science for the Van Metre New Homes Architecture Team and has been with the company since 2005, helping them transition from predominantly site-built housing incorporating roof trusses to a fully componentized solution. He is now experimenting with modular and cartridge-based construction. Christopher focuses on the overall building structure, mechanical, electrical, plumbing, efficiencies, and comfort of the single-family townhomes and condominiums designed and built by Van Metre. The Van Metre Architecture Team designs and permits all projects in-house with a team of 11 architects. Chris is licensed to practice Architecture in Maryland, Virginia, and West Virginia and is a member of American Institute of Architects (AIA) and National Council of Architectural Registration Boards (NCARB). He has received two degrees in architecture from Catholic University of America in Washington, D.C., and has practiced architecture professionally for 23 years in the Boston and Washington, D.C., areas.

**John Guilliams, Partner and Director of Design, KGA Studio Architects**

John Guilliams has been designing innovative and successful homes and communities for over 30 years. He is a Partner and Director of Design at KGA Studio Architects in Colorado, where he leads the firm's award-winning Community and Production Design Studio. Having worked for some of Colorado's most reputable design firms specializing in multi-family, land planning, and residential architecture, John combines his vast experience and technical knowledge with a team approach in order to serve his long-standing client base. John is a member of the Urban Land Institute and a board member of the NAHB's Design Committee and Sustainability Green Home Building Subcommittee.

**Gregory Heller, Senior VP, Philadelphia Housing Development Corporation**

Gregory Heller currently holds several roles as Senior VP at Philadelphia Housing Development Corporation, Executive Director of the Philadelphia Redevelopment Authority, and Executive Director of the newly created Philadelphia Accelerator Fund. Previously he consulted for financial institutions, developers, and other clients across the United States relating to socially responsible real estate development and worked on the ground in community development in Philadelphia. In 2015, he presented a talk at TEDx Philadelphia on how to set up social impact real estate. Gregory is the author of "Ed Bacon: Planning, Politics, and the Building of Modern Philadelphia," a biography of the city's former planning director and a narrative of midcentury urban development.

## Summary Points and Recommendations

### AGENCIES, UTILITIES, AND OTHER STAKEHOLDERS

Firms understandably complain about how the many requirements, including zoning restrictions and fire ratings, have increased the cost of buildings. Often multiple departments at a county or municipality have various requirements to be satisfied. Agencies are overwhelmed, especially in the wake of the COVID-19 pandemic. Many are trying to wade through the backlog of permits and are understaffed, but municipalities and other entities also can be allies. Government plays a special role in nudging the private sector by creating policies, processes, and incentives around affordability, resilience, and energy efficiency. How can builders and architects work with and communicate the benefits of innovation to municipalities so they allow innovative practices to be adopted? Here are some specific suggestions and examples.

**Involve stakeholders early in the process.** It is critical to get agencies on board as soon as possible, especially when doing something different. This helps project teams understand the friction points at an early stage. Informal conversations early in the process, even before the pre-application meeting, can help identify challenges. Taking the time to bring all the stakeholders together upfront saves a lot of time in the end. Encourage communication by holding a meeting where everybody is invited. Often project goals and the city's goals are aligned. Open, transparent communication can open up opportunities.

> **Example:** The City of Los Angeles is receptive to innovation because one of their goals is to provide more housing for more people. The city created subsidies for certain types of projects that were aligned with their goals.

**Host site visits and tours to show positive examples of projects.** Showing stakeholders (city council or board of trustees, for example) examples of affordable housing developments and/or developments which have incorporated sustainable technologies that look just as good if not better than market rate developments can increase buy-in, especially when these projects are in their backyards.

**Create a roadmap that other jurisdictions can follow.** Example: Tripp Shealy described a strategy in Virginia for streamlining approvals at the county level: "We had a long meeting and came up with a roadmap of what the local authorities are going to review versus what our third party is going to review for the state of Virginia," he explained. "And that made it a lot easier for the next county, because we actually showed up at the meeting and said, let us present this to you since it was already agreed on by this county." Having a roadmap helped facilitate getting the second and third counties on board more quickly.

**Have common goals.** Example: Boulder County formed the regional housing partnership in 2017. Every jurisdiction agreed to certain goals which sought to increase affordable housing by 12 percent by 2035. This initial buy-in was crucial; even if personnel changed, the goals and objectives remained consistent.

**Heed the lessons of the pandemic.** Government can lead, but it often takes a crisis to spark change. For example, some municipalities changed zoning during the COVID-19 pandemic to create car-free zones that are friendlier to pedestrians and bicycles. Denver implemented a patio program that temporarily lifted zoning restrictions so that restaurants and small businesses had more options for outdoor seating. The pandemic forced municipalities to rethink how they served these businesses. Communities enjoy these changes and are not likely to want to revert back, so the trick will be how to work with municipalities to make these programs permanent.

### COMMUNITIES AND NEIGHBORHOODS

NIMBYism (not-in-my-backyard-ism) is real. Communities sometimes resist projects, especially if they fear the project will change their neighborhood for the worse. Here are examples of how to work with communities to help facilitate projects that will benefit all.

**Invite them into the process.** Just as with municipalities, involving the community upfront is critical for removing barriers. Justin Whitefield recommended hands-on design charettes, which gives stakeholders a say in the initial design of a project and helps them feel heard. For example, during one of these charettes he might show community members photos of homes from their neighborhood and have them choose the styles they like best, then use the results to guide the design of the new project.

**Help people connect with the future more vividly.** As a case in point, Tripp Shealy described an exercise during which some people were shown pictures of resilient design features for a renovation of a San Diego airport, while others were not. Those who viewed the images were willing to spend more tax money than people who were not.

**Turn a challenge into an asset.** Here again, identifying the friction points can help you address them early on. For example, in one project, a required drainage pond located in front of the proposed homes was perceived as an eyesore. The project team convinced the community that they would turn the pond into an asset for the entire neighborhood.

**Develop creative solutions for affordable housing**. For example, as Gregory Heller explained, Philadelphia has a profound housing affordability challenge. One in every four people lives under the federal poverty line. The supply of housing that is affordable is constrained and diminishing year by year. At the same time, federal funding for affordable housing has been in steep decline. Heller's agency has been working on data-informed solutions with the private sector, including home builders. The approach is to identify specific market gaps and come up with viable subsidy solutions with private sector partners that require the lightest touch possible from government.

HOMEOWNERS AND CUSTOMERS

Customers and homeowners often resist innovative and/or sustainable options because of the higher upfront cost. Sometimes the customer simply does not understand the benefits. At other times firms do not do a good enough job understanding what is most important to their clients. Here are some suggestions and examples for encouraging long-term thinking and more sustainable choice making.

**Remove barriers to entry.** In a compelling example, Gregory Heller described an urgent challenge: How to retrofit row houses in Philadelphia to be more energy efficient and weatherized, and to remediate home health hazards. Moderate-income homeowners who applied for home repair loans were denied by commercial banks at a rate of 75 percent. Heller helped put into place a program called Restore Repair Renew. "We set the underwriting terms, private banks originate the loans, and then we buy them from the bank and pay the bank to service it, leaving the bank with no risk," Heller explained. After 2 years, 60 percent of program applicants were approved, compared with the 75 percent denial rate from the private sector. They also had no defaults and a lower delinquency rate than private market loans.

**Identify the real barrier.** Example: A UK energy savings program installs spray foam insulation in attics at no or low cost, but participation was lower than expected. A behavioral study performed by the Nudge Unit determined that people did not participate in the program because they had too much stuff in their attics and did not want to have to clean them out to take advantage of the program. In response, they changed the marketing to free attic cleaning instead of energy savings.

**Take advantage of "choice architecture."** How we present options to people influences outcomes, said Tripp Shealy. Similarly, in design, how we present information impacts behavior. For example, the design of the Bullitt Center in Seattle includes a staircase that is highlighted in the front of the building, while the elevators are in the back. The design encourages people to choose to use the stairs, which helps reduce energy use and benefits health. Just as design influences how people interact with a space, architecture works the same way. How we design the choices influences the outcomes.

**Understand what the home buyer is looking for.** COVID-19 has accelerated the adoption of some new technologies and shifted customer priorities. Potential homeowners are much more willing to make many important decisions online. For example, Van Metre launched a program called BYO: Build Your Own House. Customers work with an online sales representative to choose options. In return, the customer receives plans and elevation, and the firm is able to estimate cost based on those choices.

**Know your market.** Understand the target demographic. Hold community meetings. Partner with the municipality to overcome regulatory hurdles. John Guilliams of KGA Studio Architects illustrated how this can work by citing a new development near a university in Louisville, Colorado. Recognizing that the market was not nuclear families but graduate students and professors, KGA abandoned the typical home in favor of a mixed-use product. The development consists of 12 single-family detached homes and two- and three-story townhomes with a mixture of one- and two-car garages. Downsizing the townhomes and garages lowered the price point and enabled single parents and graduate students to live close to the university. "Finding out what municipalities and communities are looking for is really the way to get a successful project started," Guilliams said.

COMPANIES

Every company has its own culture. Overcoming "status quo bias" and group think are significant challenges that hamper innovation, yet it is possible to change group behavior, and there are companies that make a habit out of so-called failing forward. Here are some specific suggestions and examples.

**Overcoming "status quo bias" by moving the goalposts**. This was demonstrated using a rating system called Envision. Typically, the system works by awarding points for every measure above the industry standard. As an experiment, the system was changed so that the threshold level was net-zero. People lost points for every measure that did not meet the standard. They were more motivated not to lose points than to gain points. Simply changing the point structure can impact motivation.

**Change the defaults.** Showing people what is possible can encourage them to set loftier goals. Tripp Shealy provided another example using the Envision rating system. Engineers were instructed to evaluate their own projects, but they also were given a case study of a high-performance project. This increased what they thought was possible for their projects by 20 percent. "Leveraging these success stories significantly shifted what they thought was possible for their project," Shealy said.

**Resist "group think" in the decisionmaking process.** Do not allow big decisions to be made at a single meeting. Instead, present ideas at the initial meeting, then encourage people to conduct follow-up research before the group reconvenes.

**Foster a culture of learning.** A culture of learning and allowing for mistakes can foster big changes and "outside the box" thinking. For example, Van Metre has committed to a research and development budget that ultimately led to a shift to modular or offsite constructed housing. The firm has its own lumberyard, and this led to an experiment with panelized wall construction. Next, they started building floor trusses and stairs offsite in their factory. Then they added a door shop. Now they have their own

freight/transportation division. Ultimately, they are exploring building entire houses offsite. They built the Powerhouse, which Christopher Fox called a big box module, but there were some issues with it, so they tried a new approach using a concept called "cartridges" or smaller modules that fit together to complete a whole house. They built a single townhouse out of 11 cartridges that were all inserted on the site in one day. All of this is possible because of the culture of learning cultivated within the company.

## General Observations—2005 to Today

The following key points were present in the 2005 study that are still unresolved today:

### Education

- Any innovator hoping to be successful must convince production builders, developers, large-scale owners, subcontractors, and building code officials to try the innovation—and make its case powerfully and succinctly. These are the key decisionmakers innovation programs need to influence.
- Subcontractors who embrace an innovation can be allies in convincing a builder to try it. Given their extensive use among builders of all sizes, subcontractors are also key decisionmakers for innovation.
- Existing education channels are insufficient to meet the current needs of the construction industry, let alone support new innovations. There is a shortage of young workers entering the field, since most young people do not currently perceive the construction industry as an attractive line of work.
- Because the job of successfully educating so many decisionmakers is so involved, large and sophisticated organizations have a distinct advantage in bringing innovations to market. Such companies tend to focus on incremental innovations that are less risky and extend an existing market. Large groups, such as trade associations, can act like a big company in supporting innovations that are related to the mission of the association.

### Fragmentation

- Industry fragmentation was not a panel topic in 2005, because the study believed fragmentation was an issue easily solved by more communication. In 2021, there was a clear focus on industry fragmentation being a highly complex issue at the root of many issues related to the adoption of innovation. Fragmentation as a barrier came up in every single panel and is worth taking seriously.

### Risk

- The lack of experienced installers—typically subcontractors—exacerbates the risk of innovation adoption. There is a critical shortage of qualified labor.
- To guard against the risk of unintended consequences, all builders must implement changes at the local level. Accordingly, staffing business units are built around producing 250–500 houses per year. However, large builders are not confined to incremental change; many large manufacturers and builders are in fact considering structural changes in the process.
- Building industry safeguards help prevent the widespread adoption of bad ideas. However, builders are wary of assuming additional marginal risk with new innovations since they already assume substantial risk in this highly competitive market.

### Behavioral

- Consumers must also be made more aware of innovations so that they can become viable options in the marketplace.

- Energy efficiency does not ensure market penetration for an innovation.

Fundamentally, although significant technical and market progress has been made to reduce barriers to the adoption of innovation, many of the same barriers to innovation still exist more than 15 years after the 2005 study.

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# Appendix A: Literature Review

**Topic: Education**

Reference: Barbosa, Filipe, Jonathan Woetzel, Jan Mischke, Maria Joao Ribeirnho, Mukund Sridhar, Matthew Parsons, Nick Bertram, and Stephanie Brown. 2017. "Reinventing Construction: A Route to Higher Productivity." McKinsey & Company. McKinsey Global Institute. www.mckinsey.com/business-functions/operations/our-insights/reinventing-construction-through-a-productivity-revolution.

Reviewer: JVB

| 1. Scope and content of the reference |
|---|
| Construction productivity has always lagged behind other more industrialized industries and produces less than half per capita. Educating an industry from the top down is suggested by this report. Forces that may eliminate barriers are: rising requirements and demand in terms of volume; cost and quality; larger-scale players; more transparent markets, new disruptive entrants; more readily available new technologies, materials, and processes; and cost of labor increases with restrictions on migrant workers. A way more barriers may be eliminated: small guys being replaced by mega-builders. Global supply chains are increasing. Distribution systems are being digitized. Better customer-intelligence gathering. Lean principles and aggressive automation. The low labor productivity of the construction industry is an important issue. The smaller the trade the less productive they are. Industrializing the labor force could double productivity. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| If seven areas could be improved upon, productivity could be boosted 50 to 60 percent. Reshape regulation; rewire the contractual framework to reshape industry dynamics; rethink design and engineering processes; improve procurement and supply-chain management; improve onsite execution; infuse digital technology, new materials, and advanced automation; and reskill the workforce. Governments are slowly getting involved in the conversation of low productivity. The study identified 10 causes of low productivity and market failures. Among those is a low-skilled workforce, poor project management, and inadequate design processes. More productive trades are being outbid by cheaper informal labor. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| There is poor project management and execution; insufficient skills; inadequate design processes; and underinvestment in skills development, research and development, and innovation. Educating not only the workforce in a continual way, but a top-down re-education of the industry is needed, and it will garner a 50 to 60 percent increase in productivity. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |

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|---|
| Not a consumer base paper. Owners should be the main beneficiaries of a move to a more productive model but tend to be risk-adverse and inexperienced consumers. They need productive builders they can trust to provide choices, quality, and low prices at a large scale. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Support was through public collected data and a vast body of knowledge held by McKinsey Global. A global thinktank company. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| A holistic approach from design and engineering to use of new technology to supply chain reliability to site execution can improve productivity by 50 to 60 percent and reduce waste and onsite activities dramatically. Saving a lot of energy in the process. Technology was not limited to assembly, but also the production of light-weight low-energy products. So, technology and energy walked hand in hand. The unskilled, non-nimble labor force (engineers and carpenters, etc.) was seen as a large barrier (of the 10 mentioned) to instituting the radially disruptive conclusions included in this paper. The goal is to bring more volume, less time, less cost, and more quality to a complicated problem. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Education**

Reference: Chachere, John Marvin, and John Riker Haymaker. 2011. “Framework for Measuring the Rationale Clarity of AEC Design Decisions.” *Journal of Architectural Engineering* 17 (3): 86–96. https://ascelibrary.org/doi/10.1061/%28ASCE%29AE.1943-5568.0000036.

Reviewer: MC

| 1. Scope and content of the reference |
| --- |
| The reference focuses on the rationale behind design decisionmaking. Establishing a Design Decision Rationale (DDR) is a critical component of design throughout each of the design phases. The reference claims that "supporting every design decision are reasons that collectively form a design rationale." Since the rationale informs many, if not most, of the decisions made throughout a project, it is crucial to develop means to determine the clarity of the rationale or Rationale Clarity Framework (RCF). |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| A "point of departure," as labeled by the reference, or barrier relates to the lack of standardized rationale. Each decision is made based on a different set of rationale. An architecture, engineering, and construction design practice without a clear rationale yields a fragmented and confused design. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Behavioral Factors and Biases: Architectural design poses significant challenges "due to broad social participation." Developing a design rationale to support the utility function of all involved parties is difficult. From a manager or designers’ perspective, it may be instinctual to create an even level of satisfaction amongst entities but "one must sacrifice total group welfare" in order to do so. A design decision model in which all stakeholders' preferences are synthesized "into a single view of social welfare" is a more successful approach.<br><br>Education: Adopting theoretical methodology will inevitably present barriers to any organization, especially a methodology as esoteric as decision/design rationale. The training process alone would be painstaking. Many design decisions are subjective in their rationale and some "are too complex for individuals and organizations to address with absolute clarity." Since there is not always a clear-cut solution, it is critical that organizations that choose to adopt DDR implement systemic education for their new employees. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |

| |
|---|
| A DDR analysis should clarify which groups of people will be affected by the design. These groups of people are consumers, or stakeholders as the reference refers to them. Stakeholder groups typical of building projects include residents, maintenance staff, faculty, students, and neighbors. Since a DDR is meant to organize and describe the investigated options and alternatives, it is critical that these alternatives are judged on the metric of how they affect stakeholders (consumers). |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Judging from the information presented in the reference, the DDR is still highly theoretical. Aside from a brief nod to explorations by Chachere (2008), the reference provides no sufficient experiential data that is more than mere observation. While the figures presented are clear and make logical sense, there is no concrete data supporting the success of the DDR/RCF. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference focuses on non-energy components of innovation, although energy aspects may be a primary driver of the design decision rationale. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Education**

Reference: Gilbert, Stanley W. 2012. "Characterization of the U.S. Construction Labor Supply." Special Publication, National Institute of Standards and Technology (NIST), Gaithersburg, M. www.nist.gov/publications/characterization-us-construction-labor-supply.
Reviewer: RJ

| 1. Scope and content of the reference |
|---|
| This study characterizes the construction labor pool and carries out preliminary work toward an estimation of the supply and demand for construction labor. Specifically, it evaluates the composition of the construction labor force by race, age, educational attainment, union membership, and employer type, and how that composition is changing over time. It also identifies which industries are most closely related to construction, and estimates labor flows over time by race, place of birth, and age. Finally, the report makes a preliminary evaluation of how skills have changed in the construction labor force overtime and how the skill level of the construction labor force changes with changing wages. This study characterizes the construction labor supply, and in particular characterizes how it is changing over time. This is a preliminary step toward estimating the supply and demand for construction labor, which is itself part of an effort to understand changes in construction labor productivity. The variables that were analyzed were chosen based on three main considerations. First, variables were selected based on data availability. Second, some variables were chosen because they have been previously identified as potentially being associated with the changes in construction productivity. Third, some variables are included because they may represent categories of workers that may respond differently to price signals in the construction labor market. Four basic questions are answered in this study. First, the supply pool from which construction labor is drawn is identified. Second, composition of the work force is characterized, and how it changes over time. Third, net labor flows by age are estimated for several different groups within the construction labor force. Fourth, some specific issues related to skilled labor within the construction labor force are evaluated. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| This report analyzes the entire labor force for the construction industry (including construction workers, skilled tradesmen, office staff, management, etc.). In particular, this report provides details on the methodology used to obtain the results, and a detailed discussion of what can be concluded from the data. Despite its importance to the economy, construction seems to be undergoing a long-term decline in productivity. Data for this study are taken from the Current Population Survey (CPS) from 1994 to 2010. The CPS data used to generate this report is not detailed enough to distinguish skilled craft workers in construction from general laborers. This work needs to be done for different segments of the construction market. This study is intended as a preliminary step toward understanding the changes in construction labor productivity. Since many of the factors believed to influence the changes in construction productivity are related to changes in the construction labor supply, this study characterizes construction labor supply, and in particular characterizes how it is changing over time. There are four sections to the report: 1) provides a measure of how closely related construction is to other industries, and how large the labor flows are between other industries and construction with an attending theory, model, and results; 2) provides a detailed discussion of the characteristics of the construction labor pool with an attending theory, model, and results; 3) evaluates the nature and magnitude of labor flows in and out of construction by worker characteristic with attending methodology, models, and results; and 4) concludes by discussing implications of the results, and suggesting directions for future research. Note that tables, graphs, and figures are included with the results of each section/model. |

| 3. How the reference helps define one or more of the four relevant categories of barriers |
| --- |
| The main finding is that construction draws from a pool of industries that are low- to medium-skilled and not necessarily closely related to construction like retail trade and food-service. The construction market is seasonal. About 10 percent of the construction labor force is female. Union membership is declining at a rate of about 2.5 percent per year. Over the long term, private employment and self-employment in construction are increasing as a proportion of total employment. As privately employed non-union members get older, many of them move into self-employment. The decline in union membership appears to be primarily due to younger cohorts choosing not to join unions rather than to existing members dropping out. More recent cohorts appear to be less likely to be self-employed. Susceptibility to the business cycle decreases with age. Hispanic men are entering construction at an increasing rate compared to White or African-American men. Hispanic men are more susceptible to the business cycle than African-American men. The likelihood of a man without a high school education being in construction has increased at a faster rate than the likelihood for a man with a high school education. The number of people in construction with a high school education still outnumbers those without one. The greater the level of education, the less susceptible a person is to the business cycle. The bulk of entrants to the work force are younger than 25. In most years, young people entering the industry outnumber older people leaving it. The bulk of the inflow of White men to construction over the long term occurs before the age of 21. The bulk of the inflow of African-American men to construction over the long term occurs before the age of 24. The bulk of the inflow of U.S.-born Hispanic men to construction over the long term occurs before the age of 25. A shortage of skilled workers is exacerbated by a 30-year decline in real construction wages relative to workers in other industries. There are relatively few “highly skilled” construction workers because such people can earn more in other industries. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers. |
| As discussed earlier, there is a perception that the construction industry has difficulty attracting and retaining skilled workers, and as a result faces a shortage of skilled workers. It appears that the workforce is aging, and that few young people are entering the industry. Training programs for skilled craft workers were traditionally funded and administered through unions, and open-shop training programs have tended to be rare. Since unions have been in a long-term decline, it is not clear where new skilled craft workers will come from. The resulting difficulty staffing projects results in increased costs and schedule delays. This problem is exacerbated by a 30-year decline in real construction wages relative to workers in other industries. The reference does not infer homebuyers as participating in making decisions in terms of the characterization of labor outlined in the article. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

| |
|---|
| If construction costs (including delay costs) have increased, why haven't wages? To begin answering this question, two questions are addressed. First, to what extent can a decline in skills be discerned in the data? Second, how does labor supply adjust to changes in wage? Skills: To determine whether the educational level of construction workers is changing over time, an index of educational level was constructed and graphed versus age for four different years and that preliminary result provides some support for the idea that there is a decline in skill level among the construction labor force. Labor supply and wage: The issue of shortages of skilled labor immediately raises questions regarding the nature of supply and demand for construction labor. Preliminary efforts to model supply and demand failed. It seems reasonable to assume that skill will correlate with age, education, and years in service. There is no convenient proxy for years in service, age and education, though, do correlate with wage. A model was developed resulting in the following: Since construction seems to gain less in productivity terms from skill and ability than other industries, the growing skills premium in the modern economy induces people with relatively high skill and ability to seek employment elsewhere. Future directions: Characterization at the regional/local level. This report characterized labor supply at the national scale for the most part. Construction is primarily a local market and there will be aspects of the market that will be obscured by looking at it nationally. Estimation of supply and demand: Estimating supply and demand functions for construction labor would help. That turns out to be surprisingly difficult due to the high correlation between wages and employment. Labor unions: Some of the concern about productivity in construction centers on a perceived shortage of skilled labor. That seems to be linked to the decline in union membership. Wage trends for skilled craft workers versus general construction labor: The data above, derived from the CPS, is not detailed enough to distinguish skilled craft workers in construction from general laborers. Labor flows by educational level: Expanding the analysis of labor flows to address educational levels would provide additional insight into long-term changes in educational levels in people entering construction. Analysis by market segment: Eventually, this work needs to be done for different segments of the construction market. Housing is such a large portion of the market that the results above are likely dominated by that segment of the market. But other segments will likely be different. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Not applicable. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| There are numerous tables and charts reflecting the results of modeling analysis as noted above. Too many to highlight here, so look into the report itself for further information. |

**Topic: Education**

Reference: Koebel, C. Theodore. 2008. "Innovation in Homebuilding and the Future of Housing." *Journal of the American Planning Association* 74 (1): 45–58. www.tandfonline.com/doi/full/10.1080/01944360701768991?needAccess=true.

Reviewer: BM

| 1. Scope and content of the reference |
|---|
| This article explains challenges involved in innovation in homebuilding, as well as providing planners with strategies to influence innovation in the industry. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The structure of the homebuilding industry has recently shifted toward greater concentration of production in larger regional and national firms. These firms have the capital and human resources to promote innovation and are trying to establish regional and national brand identities that transcend local markets. As fewer firms control a larger share of housing production, these larger firms become increasingly important in the successful diffusion of innovation. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The research literature on innovation identifies several factors influencing diffusion. Whether a firm adopts a new technology will depend on its organizational structure (size, resources, and complexity); organizational culture (business strategy, presence of innovation champions, perceived value of innovation); human resources; sources of information and influence on innovation; as well as the characteristics of its industry (including concentration); and the technical and economic attributes of the innovation. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Larger production builders have the resources to invest in research and to evaluate new products and processes as natural extensions of their value and process engineering. They can use information technology systems to integrate design, costing, engineering, purchasing, building and marketing their product by bundling innovation with brand identity, national marketing campaigns, and customer service. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| In order to examine the joint impacts of several variables on building technology innovation among homebuilders, a multivariate regression analysis using a weighted index of innovation for each survey respondent as the dependent variable. |

| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
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| Most builders, including large production builders, have limited opportunities to test innovative products or processes. Production builders are particularly reluctant to engage in tests that disrupt their normal production process. Individual states or consortia of states with similar climatic, hazard, and site conditions could establish testing programs through universities and public-private partnerships to improve simulation, modeling, and full-scale testing of innovations in homebuilding. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| Despite uncertainties, trends suggest that housing production over the next 50 years will likely be very different than during the previous 50. The impacts of industry consolidation are likely to be substantial. As the capacity and pressures for innovation in housing increase, planners may be able to increase the pace at which innovations are adopted and diffused, leading to increased efficiency, decreased costs, and improved sustainability. |

**Topic: Education**

Reference: Nahmens, Isabelina, and Laura H. Ikuma. 2011. "Effects of Lean Construction on Sustainability of Modular Homebuilding." *Journal of Architectural Engineering* 18 (2). https://ascelibrary.org/doi/abs/10.1061/(ASCE)AE.1943-5568.0000054.

Reviewer: MKC

| 1. Scope and content of the reference |
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| The reference discusses the importance of lean construction methods in social, environmental, and economic dimensions. The dimensional impacts of this methodology are respectively: improved working conditions, waste reduction, and improved efficiency/productivity. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The Safety and Lean Integrated Kaizen (SLIK) method is an evolved form of the traditional kaizen which can be defined as an "event" or intervention used to diagnose, in the case of this reference, productivity, waste, and safety issues related to modular homebuilding processes. SLIK promotes a five-step process in order to effectively identify problems, implement process improvements, refine said improvements and presenting results, "celebrate success, and plan next event" (or kaizen). |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The reference states some studies ascertained skill level and decision authority to be unfavorable byproducts of lean method adoption. The reference also mentions risk in regard to the adoption of the lean methodology. Some potential risks include wrist, shoulder, and back posture due to an increase in work pace due to higher productivity. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Construction companies have a responsibility to address issues of sustainability to "meet the needs of the present without compromising the ability of future generations to meet their own needs". By simply choosing to confront the barriers of the three categories of sustainability, using kaizen/SLIK strategies, the builder is engaging in an innovative approach to combat waste, lack of workplace safety and an efficiency deficiency. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| Three case studies were performed; each of which focused on a different sustainability category in relation to modular homes at the manufacturing phase of the life cycle. The studies implemented the SLIK method in an attempt to achieve increased sustainable outcomes. To do so, per the SLIK method, researchers diagnosed problems, implemented potential solutions, and analyzed the findings. In all three studies, lean was observed to have had a positive effect on waste reduction (environmental), safety (social) and man-hour reduction (economic) and were deemed a successful kaizen.While the studies are compelling and might have proven statistically significant, there is no evidence that suggests that the same results will be achieve if performed again. "Replicating this study in other modular home manufacturers would serve to potentially validate the current results." |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| National Association of Homebuilders' green building guidelines considers modular construction methods to be rated highest in the material category of their rating system. Modular construction has a direct impact on the reduction of waste; therefore qualifying it as an environmentally sustainable product of lean methodology. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Education, Fragmentation**

Reference: Pinkse, Jonatan, and Marcel Dommisse. 2009. "Overcoming Barriers to Sustainability: An Explanation of Residential Builders' Reluctance to Adopt Clean Technologies." *Business Strategy and the Environment* 18 (8): 515–527. https://onlinelibrary.wiley.com/doi/abs/10.1002/bse.615.

Reviewer: DW

| 1. Scope and content of the reference |
|---|
| The reference attempts to identify the reasons that construction firms do not employ cost-effective, off-the-shelf clean technologies to reduce the carbon footprint in the construction of residential homes. The focus is on replacing gas-fired boilers with solar boilers or heat pumps. Four construction firms were chosen for case studies. The firms varied in size. Two were members of the Projectgroep Duurzame Energie Projectontwikkeling Woningbouw (PGDEPW), or Sustainable Energy Project Group, an industry group that supports the adoption of green technologies. The other two firms were not. The reference describes the analytical framework, research methodology, and findings and concludes with discussion of said findings. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| It is proposed that the adoption of clean energy efficient technologies depends on the ability of the contractor to develop dynamic capabilities for this purpose. Enabling a firm to adapt, integrate, and reconfigure its organizational competencies and resources to maintain a fit with a changing business environment. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The study findings indicate that firms that do not employ green technologies lack the personnel in the organization with knowledge to implement these technologies, and further, that companies that actively engage in the pursuit of information about these technologies are more likely to implement them. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Though the market is shifting from a supply-driven to a consumer-oriented market, the end users have little effect on the adoption of innovation, in large part because a very small percentage of residential projects in the Netherlands are private commissions and because consumer preference concerns items such as location and number of bedrooms with energy-efficient technologies being a low priority. Construction firms and external stakeholders in projects are the primary drivers. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| A description of the methodology and survey used for the case studies is provided though very little actual data is provided. |

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| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Energy usage and carbon footprint are the primary focus of the reference with very little mention on non-energy innovation. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Education**

Reference: Tomkiewicz, Heidi S. 2011. "Barriers to Implementation of Sustainable Construction Practices in the Homebuilding Industry: A Case Study of Rochester, NY." DigitalCommons@University of Nebraska - Lincoln. University of Nebraska - Lincoln. https://digitalcommons.unl.edu/archthesis/121/.

Reviewer: CLG

| 1. Scope and content of the reference |
|---|
| The scope of this reference attempts to define sustainability (ecology, economy, and society) and investigates why implementation of sustainability has not been as successful in residential housing more clearly. The first section focuses on the definition of sustainability, and the second section defines the barriers. The third section evaluates the consumer/residential builder's mindset in Rochester, New York, to fill some of the information gaps explained in the first two sections. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Not applicable. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Through the literature market perceptions, information gaps, infrastructure issues, and implementation issues were defined as the biggest barriers. More specifically the survey results state that the largest barrier from the view of the homebuilder was the lack of affirmed respect and understanding of sustainability. The significant areas for improvement were in education of green certifications and professional development seminars. Home builders seem unclear on environmental practices of sustainable land development and their methods have changed minimally in the past two decades. Home builders were more aware of energy efficiency and more confident in the implementation. Home builders had low levels of confidence in substituting new materials and preferred materials that they had firsthand knowledge of. Homeowners have taken initiatives in reducing waste, but the residential construction industry has not. While home builders stated they understood the importance of the health benefits inside a home, very rarely were methods implemented/tested. In conclusion, the main barrier was educational failure. The most significant finding is that energy efficiency was the focus for many builders although a more holistic approach to sustainability is the goal. The most telling data is that 87 percent of builders surveyed disagreed that residential housing negatively impacts the environment, which points to major systemic failure in sustainable development education. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| In the literature, builders create barriers by having a short-term investment that focuses on profit, homebuyers create barriers by lack of education on the importance of sustainability in the residential market. In the survey results the significant areas for improvement were in education of green certifications and professional development seminars. Home builders seem unclear on environmental practices of sustainable land development and their importance. The importance to the homebuyer is also lacking. |

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| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Reference cites important literature including "Overcoming Barriers to Innovation in the Home Building Industry" (Building Technology Inc., 2005). Experiential data is supplied using a survey for home builders in the area of Rochester, New York. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference focuses on sustainability and emphasizes the lack of clarity in the term. It is noted that energy efficiency is more commonly understood and practiced by consumers. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Fragmentation**

Reference: Gambatese, John A., and Matthew Hallowell. 2011. "Enabling and Measuring Innovation in the Construction Industry." *Construction Management and Economics* 29 (6): 553–567. https://doi.org/10.1080/01446193.2011.570357.

Reviewer: BM

| 1. Scope and content of the reference |
|---|
| Understanding the innovation process, how innovation can be enhanced and how it can be measured are key steps to managing and enhancing innovation. This understanding can enhance innovation through better communication among project team members, integration of the design and construction disciplines, more efficient designs, development of unique ways of completing work and sharing of the lessons learned. The end result of innovation will be projects that successfully meet and exceed cost, quality, schedule, and safety goals. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Owner influence, presence of an innovation champion, lessons learned/knowledge management, upper management support, research and development, organizational climate, and organizational structure. How organizations create and establish a climate directly impacts the integration of innovation into the culture therefore can inhibit innovation or lead to innovation. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Establishes a means and method to evaluate leading indicators of innovation. One aim of the study was to validate existing knowledge of factors within and among organizations at the project level that enable and impede innovation and determine additional factors if possible. Enablers of innovation were found to include: support from upper management, good communication within the firm, and the overlap of design and construction phases that is common within integrated project delivery methods. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The process of innovation involves different components and activities to generate new ideas and bring them to reality. The article identifies that innovation in the construction industry requires three components: *idea generation*, *opportunity,* and *diffusion*. Each component is important to the innovation process and all three components must exist in order for innovation to occur and thrive. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

Both quantitative and qualitative analyses of the case study results were conducted. For open ended questions in which the case study respondents provided a narrative response, the researchers reviewed the responses and recorded trends based on the frequency of response. This was done to identify key concepts and terms and to develop an understanding of the similarities and dissimilarities between the techniques used on the projects.

6. How the reference differentiates energy and non-energy aspects of technology or system innovation

For the primary indicators (extent of change on the project, number of new ideas implemented, amount of new training and education, and extent of diffusion), a scale of 1 to 10 was used with 1 indicating none and 10 indicating significant/extreme. All of the projects selected for the study were built within the previous 5 years.

7. Potentially important references not previously cited

The study also aimed at identifying leading and lagging indicators that can be used to measure innovation potential and success, respectively. Those project-level leading indicators that were found to have a strong positive relationship to innovation on the project were: owner/client influence, presence of an innovation champion, presence of lessons learned/knowledge management system, upper management support for innovation, and extent to which research and development is supported. These leading indicators add to those previously identified by Dikmen et al. (2005). The inclusion of lessons learned/knowledge management as a leading indicator supports similar findings by Chinowsky et al. (2007) and Chinowsky and Carillo (2007).

8. Additional comments or summaries of other important information

The three propositions tested by the case studies were all supported to some degree. Proposition one (owners serve a pivotal role in the innovative capacity of a project), was confirmed with extremely strong evidence from the case studies. The second proposition (project delivery and contracting methods that encourage phase overlap contribute greatly to innovation) was moderately supported. The case studies revealed that organizational attributes that contribute to culture and structure had a greater influence on innovation success than project-specific factors such as phase overlap. However, the authors recommend further investigation of project delivery and contracting methods in regard to their connection to innovation. While the present study found only moderate support for innovation, these methods can be structured to promote the integration of design and construction expertise on a project and communication among the team members. Such integration aids in creating a multi-functional team, establishing a collaborative environment, and enabling an intentional, innovation-seeking plan on a project. These methods also support the mutual sharing of knowledge and benefits which are shown to have a positive impact on innovation (Bosch-Sijtsema and Postma, 2009). Finally, the third proposition (leading indicators can be identified and correlated with innovation success) was strongly supported by the quantitative and qualitative analyses of the case study data. In addition to the findings associated with the propositions, there were collateral findings related to specific organizational characteristics that affect innovation (for example, upper management support and formal recognition of innovation) that confirmed literature such as Wolfe (1994), Hausman (2005) and Lee et al. (2005). The case study analysis did not indicate the extent to which innovation brokers are a leading indicator. However, further work associated with innovation brokers as suggested by Winch and Courtney (2007) is recommended to study their impact and involvement at the project level.

**Topic: Fragmentation, Education**

Reference: Lovell, Heather. 2008. “Discourse and Innovation Journeys: The Case of Low Energy Housing in the UK.” *Technology Analysis & Strategic Management* 20 (5):613–632. www.tandfonline.com/doi/abs/10.1080/09537320802292883.

Reviewer: DW

| 1. Scope and content of the reference |
|---|
| The reference investigates the importance and the role of discourse in innovation journeys. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Discourse coalition theory and discursive framing as they apply to the innovation journey. Use of discourse framing by discourse coalitions is a critical influence on innovation journeys. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Fragmentation: The references studies the use of discourse as a means to simplify a complex problem involving a large group of actors with broad, though often overlapping, goals. Prior to the nineties, low energy housing was dominated by a single close-knit network of people with shared ideals and social values. In the nineties, stakeholders became a much broader and looser group of multiple networks united by a shared language. Education: It is noted that the use of discourse–if misleading–can have long term negative effects, especially if applied to something more technical, such as energy saving technology, since problems that arise must be addressed effectively for the technology to function properly. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The focus of the reference is on how discourse effects policy decisions within larger groups, primarily government agencies, and how it is used in turn to "sell" the idea (in this case, energy efficient housing) to the general public. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Research methodology is well documented and includes two case studies and over 50 interviews. While little empirical data is presented, many of the conclusions are backed up with examples that reinforce what could otherwise be anecdotal conclusions. References to specific political speeches and policy documents are available. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |

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| While the reference concerns the adoption of energy efficient technologies in the UK, it deals with it through the lens of social science (discourse theory), and little of the focus is on the technology itself. It is noted however, that technical issues such as energy saving technology are better served if discourse does not mislead the audience into thinking that no issues exist with innovative technologies, when that is not the case. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Fragmentation**

Reference: McCoy, Andrew P., Walid Thabet, and Ralph Badinelli. 2008. "Towards Establishing a Domain Specific Commercialization Model for Innovation in Residential Construction." *Construction Innovation* 8 (2): 137–155. www.emerald.com/insight/content/doi/10.1108/14714170810867050/full/html.

Reviewer: CLG

| 1. Scope and content of the reference |
|---|
| This reference presents the development of a commercialization model specific to the residential construction industry using previous innovation/commercialization models and data. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The literature develops a new commercialization model for the diffusion of innovation in the residential construction industry. This is important because innovation models focus on diffusion/adoption theory whereas commercialization models are based on theories of business. Previous commercialization models were evaluated including Rourke (1999) and Goldsmith, (2003) but none were specific to the complexities of the residential construction industry. Many concepts were consistent with the generic industry models including the reiterative loop concept that allows for review phases. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Fragmentation: Commercialization models used for other industries do not apply to residential construction very well. Site variability causes one-off situations, site conditions require unique solutions, there exists isolation of knowledge learned on site, the site is end of supply chain and knowledge does not generally flow upstream, and research and development confusion can resist knowledge transfer. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Financial benefits are passed on to homebuyer, so the builder is less likely to make the change. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| The reference develops the model using case study literature and tests their model with input from construction industry experts interviews (example case study). |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference defines innovation diffusion as historically focusing on behavioral/social science aspects rather than business management. |
| 7. Potentially important references not previously cited |

Koebel, C. T. and A. P. McCoy. 2006. "Beyond First Mover Advantage: The Characteristics, Risks, and Advantages of Second Mover Adoption in the Home Building Industry." Paper presented at the American Real Estate and Urban Economics Association Meeting, Washington, DC, May.

8. Additional comments or summaries of other important information

No additional comments.

**Topic: Fragmentation**

Reference: McCoy, Andrew P., Yong H. Ahn, and Annie R. Pearce. 2012. "Towards Establishing Diffusion Barriers for Innovative Green Building Products: A Survey of SIPS Builders." *Journal of Green Building* 7 (2): 153–176. https://meridian.allenpress.com/jgb/article/7/2/153/116428/TOWARDS-ESTABLISHING-DIFFUSION-BARRIERS-FOR.

Reviewer: BM

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| 1. Scope and content of the reference |
| Paper explores approach of diffusion barriers for Structural Insulated Panels (SIPS) in the residential construction market. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Several builders separately identified "lack of consumer demand," which could be interpreted differently than resistance, as a reason for not trying SIPS. Data seems to indicate that builders perceive consumer uncertainty, either through a market "pull" or market resistance, as a large barrier to the adoption of SIPS. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Fragmentation is identified in the article as follows: "Compatibility was also addressed in the literature by Slaughter (1993) as a barrier to adoption due to the need for congruency between manufactured products and industry habits. Interestingly, this barrier seems not to have been reduced by SIPS manufacturers, at least according to builders, a key stakeholder in the supply chain. Further, builders tend to increasingly identify it as a barrier after continual use." |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| A comprehensive picture of barriers and accelerators to innovative green building products will ultimately shorten the diffusion period for environmentally friendly building products and help reduce the massive ecological footprint of the residential construction industry. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Survey respondents provided meaningful feedback on their choices to adopt or not adopt SIPS and were candid in their reasoning through the free response sections of the survey. Specific barriers that exerted the largest effect on adoption were supporting innovation, relative advantage, and risks, while the barriers that exerted the smallest effect on adoption were regulatory resistance, trade resistance, and trialability. Timing of commitment also scored relatively low on the diffusion factors chart, indicating a lack of concern by builders over when the SIPS product is adopted during the home production process. Product manufacturer/suppliers and builders can learn from these perceived barriers (or lack thereof) to inform the SIPS commercialization process and increase diffusion across the industry. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Study has established a framework for evaluating the role of innovative product attributes in the adoption decisions of a specific stakeholder group and has shown that barriers (or accelerators) of innovative products can be identified and quantified. Applying this study methodology to other green and non-green products will allow the comparison of attributes across products. fits comparison will allow conclusions to be drawn as to whether innovative green building products demonstrate different barriers to adoption than other products, or if they are basically perceived as the same by builders. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Fragmentation**

Reference: Moore, Mike, Steve Shrader, Sam Bowles, Newport Partners LLC, and Davidsonville, MD. 2010. *Introducing Innovation into the Home Building Industry.* Prepared for U.S. Department of Housing and Urban Development (HUD), Office of Policy Research and Development. www.huduser.gov/Publications/PDF/hsg_innovation.pdf.

Reviewer: DW

| 1. Scope and content of the reference |
|---|
| Discussion of the obstacles that face innovators in the homebuilding industry. Obstacles related to the size of the market, number of players, and complex relationships between manufacturers and end users in the residential construction market. Discussion of potential approaches to marketing innovation in the homebuilding market. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The industry is slow to adopt new technologies and the further a technology departs from familiar and lowest first cost the more challenging adoption becomes. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The reference is focused on fragmentation and the complexities of the homebuilding market. Cultural aspects are touched upon as well. Innovation that deviates from the norm is not easily adopted and building code officials are often reticent about adopting innovation even if the codes allow it. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The reference is largely focused on the relationship between the manufacturer and the innovator with a focus on how to market an innovation either to a manufacturer with a license agreement or marketing to the building sector through direct manufacture. Little time is spent on the decisionmaking process of the homebuyer. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| An excellent case study ID presented: Purfect Glaze is a hurricane rated glazing compound created by National Starch and Chemical Company, a large chemical company with annual sales of over $3.5 billion. Though a massive player in the chemical industry, they had no contacts or experience in this particular market segment. It avoided the costs and risks of startup manufacturing by teaming up with an established manufacturer of glass sealant products, TruSeal Technologies. TruSeal pays royalties to National Starch and makes profit off the manufacturing of the product. There is also data presented on several federal and non-profit grant programs designed to help encourage innovation. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Energy is mentioned only as it relates to what the authors term "Code-Plus" programs such as Leadership in Energy & Environmental Design (LEED) and ENERGY STAR that focus on energy and provide a platform for innovative products. |
| 7. Potentially important references not previously cited |
| None. |
| 8. Additional comments or summaries of other important information |
| None. |

**Topic: Fragmentation**
Reference: Pauly, Justin Talbott. 2005. Innovation and the Big Builders: Barriers to Integrating Sustainable Design and Construction Practices into the Production Homebuilding Industry: The Case of Pulte Homes. Master's Thesis. Massachusetts Institute of Technology. https://dspace.mit.edu/handle/1721.1/33276.
Reviewer: JVB

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| 1. Scope and content of the reference |
| Case study of Pulte Homes. One division of builder uses incremental product and process based on technologies. Another uses radical/systemic innovations through component manufacturing processes. Study also looks at building code and other governmental interventions. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Systemic innovations happen through mega builders. Incremental innovations happen through large and small builders. Two types of sustaining and disruptive means to innovation. Sustainable uses proven materials and methods in a better way. Disruptive innovation is more radical and only used by mega builders at large scale. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Fragmentation: The many and diverse forces in the homebuilding industry that hampers innovation, quality and performance of homes is a huge challenge even for the mega builders who attempt to go vertical in their organizations. The small company just tries to get the quality right but accepts innovations more readily due to size. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| What drives the consumer? Cost, then guilt. If given a choice, the consumer usually doesn't pick energy efficiency over aesthetics. A good sales team that believes in and really understands a high performing home can sway customers, even at more cost. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| This was a case study that relied first on literature reviews then interviews by a single mega builder that uses two differing methods to try to innovate. Conclusions included:1) government should focus on the small- to medium-sized builders. 2) If government to continue to work with mega builders they need to go after the heads of companies. 3) Innovations and new technologies need to address lack of skilled labor and beneficial to the trades. 4) Partnering with product and material suppliers is a key component. Government should help pay for the innovation process. 5) Large production builders need to integrate design and engineering systems. 6) Cross-industry dialogue needs to be established between the building industry and more sophisticated Industries. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| It seems government (codes) drives the energy issues. Builders first try for quality to eliminate warranty call-backs, then profitability. Energy is a lower priority for builders, unless it separates the builder as better and creates more sales. Mortgage lending rates that favor ENERGY STAR homes is not used often. Consumers go for style and size first and don't look for energy efficiencies. When given a list of options they will look at energy saving options and even pay more for them if there is a relatively short payback. |
| 7. Potentially important references not previously cited |
| None. |
| 8. Additional comments or summaries of other important information |
| A good look at manufactured versus stick-built homes. |

**Topic: Fragmentation**
Reference: Sesana, Marta Maria, and Graziano Salvalai. 2018. "A Review on Building Renovation Passport: Potentialities and Barriers on Current Initiatives." *Energy and Buildings* 173 (15): 195–205. www.sciencedirect.com/science/article/abs/pii/S0378778818302937.
Reviewer: RJ

| 1. Scope and content of the reference |
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| Building passports (BPs) could play a valuable role in boosting the availability of information to a wide range of market participants. Better information flows are a necessary part of improving the quality assurance system for buildings and the construction industry market overall. The aim of the paper is first to set a Building Renovation Passport (BRP) definition and to explore the potential role of a voluntary scheme across EU as a key tool to help overcome this information imbalance by providing all market stakeholders, including financing institutions, providers of mortgage credit, investors, and insurers with access to key building-related documentation and information to properly assess the many factors impacting the overall quality of buildings. Buildings account for 40 percent of total energy consumption and around 75 percent of them are energy inefficient. Energy efficiency in buildings suffers from underinvestment and numerous barriers. Whereas buildings are regularly maintained or improved, energy saving investments are often disregarded because they face competition for scarce capital, a lack of trustworthy information, lack of skilled workers or doubts on the possible benefits. Lack of information and transparency increases risk and undermines investor confidence. The paper has been structured as follows: section one sets the scene of the energy efficiency goals, regulations, and respective directive on the building sector identifying challenges, barriers, and instruments; section two explores the concept of BP introducing definitions and experiences within EU and an initiative in Australia; section three focuses on BP for existing buildings with the aim to increase understanding on BRP definition, initiatives, and research related to the renovation roadmap; section four provides a comparison of three ongoing applications of the BRP in EU Member States (Belgium, Germany, and France) highlighting weaknesses and strengths of each one; section five outlines a series of recommendations for the introduction of BRPs across the EU. Section headings are as follows: 1. Introduction; 2. Building Passport concept overview: genesis, definitions, and structure; 3. Building Renovation Passport: a focus on existing buildings; 4. Overview on three European BRP running experiences; 5. Conclusions. Tables are as follows: Table 1 - BP definitions overview; Table 2 - Basic model components of the BP Schleswig Holstein; Table 3 - Description of contents for Birth and Health certificate of buildings as introduced by Virta et al.; Table 4 - Summary of the BRP comparison in Belgium, Germany, and France. Figures are as follows: Fig. 1 - BRP structure (elaboration of the authors from Building Performance Institute Europe [BPIE] study). A large Bibliography is included at the end of the report. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The Principal Agent Theory deals with the design of contracts, especially with respect to asymmetric information, which can have effects before as well as after closing a building project contract. A Building Information System (BIS) is tailored for new development, and difficult to implement for existing buildings, for which the problem of information asymmetry is the most severe. Building Health and Hygiene Index (BHHI) is used to evaluate the health performance of multi-story residential buildings; Ho and Yau took one step further and developed another index named the Building Safety and Conditions Index (BSCI) for evaluating a building's safety performance. Energy Performance Certificates (EPCs) could be an appropriate tool to provide information in a meaningful and comprehensible way. However, they are not designed to provide tailor-made and understandable information about renovation potentials. Within the ZEBRA2020 European research, 35 recommendations based on project outcomes and related research have been derived for EU Member States divided in six different categories: legislative and regulatory, economic, communication, quality of action, new business models, and social measures. A BRP has been moreover defined, within the BPIE report, as "a document–in electronic or paper format–outlining a long-term (up to 15 or 20 years) step-by-step renovation roadmap for specific buildings, |

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| resulting from an onsite energy audit fulfilling specific quality criteria and indicators established during the design phase and in dialogue with building owners." Individual Building Renovation Roadmap (iBRoad)– the renovation roadmap is like a home-improvement plan, which considers the occupant's needs and specific situations (for example, age, financial situation, composition of the household, etc.) and avoids the risk of locked-in future renovation solutions due to a lack of foresight. The ALliance for Deep RENovation in buildings (ALDREN) objectives are to achieve higher renovation rates and better renovation quality by overcoming market barriers and preparing the ground for investment. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| BPs are increasingly being considered as an important source of information for valuation experts, financiers, and insurers but also to improve information for owner occupiers about the quality of their house. Despite the promise of attractive returns on investment, the lack of confidence in energy savings and the often-prohibitive costs of conducting due diligence create a substantial barrier to investors and building owners taking action. Most of this information, however, are not collated in one place and a systematic approach of organizing and managing this information is currently largely missing. None of the information is being handed down from the beginning to the end of the supply chain. The main lessons learned from the Australian experience is that a large amount of information is normally generated for an individual dwelling over its lifetime, but the various actors are not able to capture the full benefits of their investment in these data. The actors involved in different building phase design and construction need to be educated to respect the information needs of other stakeholders/target groups. A construction project is characterized by a high number of project participants and a multitude of contract relations. The concept of BPs is continuing to evolve in tasks, content, and scope. The BP, however, is only one of the possible tools to support information management and exchange between different target groups and actors within construction and real estate sectors. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Text of the report lacks any clear cut guidelines as to how to increase participation in BPs. References for customer participation as follows: Building Passport (Germany); ImmoPass (Germany); Gëbaudepass (Germany); Building folder - Hausakte (Germany); Building Passport (Finland); Concept of Building File - CoBF (Netherlands); As-Built File - Oplever- dossier (Netherlands); Libro del Edificio (Spain); Fascicolo del fabbricato (Italy); Home information pack - HIP (England and Wales UK); Building Logbook (Cornwall UK); Building Logbook (UK). |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| European models of BRP running experiences as follows: Flanders in Belgium, France, and Germany. All of them have the same main aspects and goal: to improve the overall building stock energy efficiency and all targeted to residential buildings. BRPs in Flanders (Belgium) are being developed as the so called "Woningpas" or Dwelling ID. The passport goes way beyond the notion of energy consumption or the EPC. It contains all information about the building in a logbook. Furthermore, it is meant to provide tailored renovation advice for the building owner and an expanded energy certification for tenants and potential buyers, called EPC+. The graphic design is of major importance in providing an appealing and clear layout with adequate visualizations etc. can be very stimulating for the normal private owner to be engaged in and providing the average private house owner with an easy-to-use tool to keep track of his property. In Germany, a newly developed program, Individueller Sanierungsfahrplan (iSFP) was launched at the national level in 2017 aiming to provide long-term guidance on deep renovation to the building owner. The iSFP is part of the National Energy Efficiency Programme and of the "Federal Efficiency Strategy for Buildings" (ESG). The iSFP is based on two site visits and on proper dialogue between the owner of the building and an energy auditor and is performed in a face-to-face approach considering the opinion, needs, and possibilities of the owners to achieve a reasonable result avoiding excessive costs. The energy auditors' handbook clarifies that two documents are included for the owner: an overview page of all measures to be taken along the road and a well-explained technical report containing the more detailed documentation on the renovation works, their costs, effects, and impact. Contrary to the initiative in |

Flanders (Woningpas) the German building renovation roadmap does not foresee the introduction of a digital logbook associated with the renovation roadmap. In France, Building Renovation Passports are being developed in the form of the so-called 'Passeport éfficacité énergétique' (abbreviated P2E) as part of the energy efficiency action plan for France. Identical to other examples, the BP has set a long-term vision targeting in this case at transforming the whole French building stock to Low Energy Building standards by 2050. It starts with a certified audit, leading eventually to a complete renovation scenario in concordance with the owner's needs and possibilities.

6. How the reference differentiates energy and non-energy aspects of technology or system innovation

Referencing the "Conclusions and recommendations for developing a BP," long-term perspective needed; how timing and sequencing of actions are developed; customer engagement consideration of the individual renovation context; attractiveness and motivation; automation and dynamism of the process instead of a static tool, energy transition. Engaging customers and considering their specific situation to ensure the advice they receive is personalized, reliable, low risk and provides both a long-term perspective and suggestions about the right timing and sequencing of action, will contribute to drive the EU towards a clean energy transition and promote a better involvement of consumers.

7. Potentially important references not previously cited

Not applicable.

8. Additional comments or summaries of other important information

BRP Structure as follows:

*M.M. Sesana, G. Salvalai / Energy & Buildings 173 (2018) 195–205*

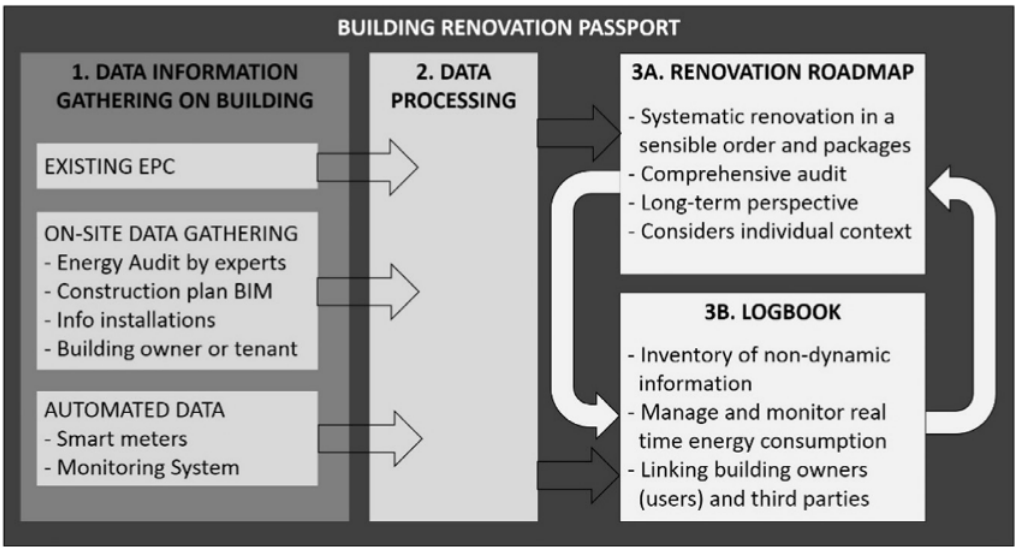


**Fig. 1.** BRP structure (Rielaboration of the authors from BPIE study).

**Topic: Fragmentation**

Reference: Smyth, H., Razmdoost, K. and Mills, G.R.W. 2019. "Service Innovation Through Linking Design, Construction, and Asset Management." *Built Environment Project and Asset Management* 9 (1): 80–86. https://doi.org/10.1108/BEPAM-03-2019-136.

Reviewer: MKC

| 1. Scope and content of the reference |
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| The reference provides commentary on the theoretical approach of providing innovation and value maximization. This approach is focused around the importance of the user experience through integrating value "co-creators." While the strategy that has hitherto been adopted, project and asset management, poses benefits on a tangible level, what is paramount is the manner in which these tangibility's are leveraged to create the best possible outcome for the user. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Contrary to marketing and business development "service design tries to deliver in an optimal way as possible and innovation progresses the way in which this is achieved." In theory, service-dominant logic (SDL) places an emphasis on innovative arrangement as opposed to buying outputs. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Fragmentation of the industry: The service design approach emphasizes "a long-term service and innovation exchange of specialized knowledge, skills and capabilities, rather than goods." SDL discredits short-term thinking where "construction and infrastructure firms focus on maximizing profits through ... fixing on tangible outputs and isolating themselves from users and operators to minimize the cost of delivering a unique process and solution." Therefore, the theory is in opposition to fragmentation of entities and interactions. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Builders create barriers by placing less importance on the long-term user experience and focusing on the short-term project and asset management. Even though a plethora of companies have embraced the service design approach, many have remained loyal to the provision of goods. Methods of determining user experience should be implemented post-construction after tenants/users have had sufficient opportunity to test out the finished product. The homebuyer plays a critical role in making decisions and is considered a co-creator of value by providing the builders with empirical evidence on the value of the built environment. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| Aside from the multitude of external sources indicated at the end of the references, the guest editorial provides several relevant paper summaries that define some of the empirical evidence backing the service design approach. This article also explicitly states that "the lack of empirical work had hitherto been lacking; however, more is required to explore and examine across multiple roles." In other words, the service design ideology is still very much theoretical and will require more studies to become an empirically corroborated practice. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The theories presented in the article are predominantly non-energy aspects of technology and innovation. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| Commentary on #6: The article claims that "assets, although tangible, are valuable for their intangibility and experience in use." In the specific case of environmental impacts, the converse of this claim may be true. For example, the guest editorial makes a reference to the environmental needs brought about by the impact of climate change on the planet. In this case, one should begin with the intangibility of the normative outcome (what should be or ought to be) of ultimate environmental implications. After this analysis, the "systems integrator," or designer/contractor, can move forward with asset management or material selection to yield the most valued outcome possible. |

**Topic: Risk**

Reference: Abbot, Carl, KS Jeong, and Stephen Allen. 2006. "The Economic Motivation for Innovation in Small Construction Companies." *Construction Innovation* 6 (3): 187–196. https://doi.org/10.1108/14714170610710686.

Reviewer: MKC

| 1. Scope and content of the reference |
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| Innovation is hypothesized to have a direct relationship with the long-term economic success of businesses. Adoption of new methodologies is understandably daunting for a business that has previously thrived with a project-based model. The reference discusses the university's relationship to increase innovation in the construction industry by addressing two topics: 1) the benefits and risks of innovation and 2) what is the motivation for a business to adopt innovation. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Clark and Staunton define the "integrated nature of innovation activity" using three categories: 1) incremental innovation, 2) entrenching innovation, and 3) altering innovations. Entrenching innovations build upon the existing capabilities by organizing the building blocks in a manner different that before. In contrast, an altering innovation is aimed at reshaping the entire organization requiring an overhaul of equipment, raw materials, and knowledge. Due to the radical nature of altering innovations, most organizations engage in incremental innovation. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| University studies play a critical role in cultivating innovation by providing valuable insight for increasingly successful future collaboration between the education sector and construction companies. The reference uses data from an existing case-study to demonstrate this. Establishing a "knowledge supply-chain" through "interorganizational networks based on depth, quality and diversity are the most important source of new knowledge." |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| "A suitable strategy is more likely to emerge from small beginnings." The reference suggests that the more developed a company the less likely it is to adopt innovation activities. A company that promotes a "business as usual" mindset typically does not have the internal expertise necessary to make substantial changes in the name of innovation. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| The reference uses Amara, a London based company, to support their conclusions. Amara's growth is attributed to their collaboration with academia and willingness to innovate. In the early stages of Amara's growth, they were responding to economic drivers, which is considered survival per Sexton and Barrett's hierarchy of motivational needs. Through implementation of an innovation methodology Amara was able to shift from the survival stage to the development stage (Sexton and Barret). In this final stage of the motivational needs model, the company can innovate to create competitive advantage as opposed to simply being reactionary. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Not applicable. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |

**Topic: Risk**

Reference: Burgess, Gemma, Michael Jones, and Kathryn Muir. 2018. "BIM in the UK House Building Industry: Opportunities and Barriers to Adoption." University of Cambridge. https://www.researchgate.net/publication/331993150_BIM_in_the_UK_house_building_industry_opportunities_and_barriers_to_adoption.

Reviewer: RJ

| 1. Scope and content of the reference |
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| The aim of the study was to explore the use of Building Information Modelling (BIM) in the UK house building industry and to consider opportunities and barriers to its wider uptake/use. The study included a review of existing evidence and literature listed in an appendix. Telephone interviews were conducted with practitioners from the industry about the use of BIM. A round-table discussion was held with key stakeholders in the house building industry. What benefits could BIM offer the housing industry and what are the barriers to the adoption of BIM in the housing industry? |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Innovation (from the abstract): The adoption of BIM has been recognized within the housing industry and includes reducing construction costs and time efficiencies, fewer design clashes and costly reworking on site, greater accuracy in design and build, and fewer defects in new homes. Some of the benefits: reduction of design errors, reducing conflicts/design clashes, construction of sustainable buildings/using materials that could decrease environmental impacts, and efficiency improvements for maintenance and operation companies. UK building industry is working toward Level 3 BIM or open BIM versus the current Level 2 BIM where models are not necessarily shared. Barriers: the uptake of BIM is slow requiring considerable investment of time and resources in addition to skill shortages. In 2013, the National House-Building Council (NHBC) surveyed 18 major house builders in the UK to assess their levels of awareness and understanding of BIM (NHBC, 2013). They found that only 11 percent of the major house builders were currently engaged in BIM. Twenty-five percent had not heard of BIM, and the majority (64 percent) had investigated it but could see no obvious application or benefit to their business in using it. Those house builders that did use BIM used it in only limited ways. The UK house building market is more concentrated than that of the USA: the top 20 house building firms in the USA built 153,000 homes (12 percent of the total market) in 2015, while the top 20 firms in the UK built an average of 75,000 homes, or 69 percent, of a market less than one tenth the size. A consequence of the effect of the financial crisis in forcing a change in the output mix of house builders has been the loss of skills and expertise in apartment block construction, and a parallel reduction both in repetition and in the need for more complex documentation of the project. Quality control across multiple sites and multiple small subcontractors present major problems. Limited uptake of BIM and digital technology affects quality control on site which contribute to building defects, warranty claims and customer dissatisfaction |
| 3. How the reference helps define one or more of the four relevant categories of barriers |

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| In terms of risk: Construction 2025, the UK government's 2025 industrial strategy, identified five main barriers that prevent innovation in the construction sector:<br>1.The nature of construction procurement frequently restricts collaboration between client and supply chain, particularly at an early enough stage to fully explore options for innovation.<br>2.Companies are not confident that innovation will be commercially rewarding, with particular concerns about levels of demand for innovative products and services.<br>3.Companies that do want to innovate find that the necessary finance is too expensive and/or difficult to access, that the approach to risk and insurance of works deters innovation and that some of the government support available to the industry is not sufficiently visible.<br>4.There is a failure to capture learning from successful innovations and take this forward to future projects.<br>5.Collaboration between industry, academia and research organizations is patchy, which limits effective knowledge transfer (HM Government, 2013). Barriers to the adoption of BIM: business barriers, technical barriers, and human or organizational barriers. Business and legal barriers include a lack of standards; a lack of clarity on roles and responsibilities; a lack of clients/market demands; ambiguity in data ownership and legal risks; and high investment cost and low incentives. Technical barriers include interoperability and lack of a BIM library/dataset. Human or organizational barriers include a resistance to changing current practices; a lack of knowledge and skills; and a lack of initiative and training. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Builders: Lack of scale: BIM was perceived as beneficial for large scale projects, but not smaller scale. Standardization: A key advantage of BIM was allowing for broader standardization. While the larger house builders would be able to achieve this, small- and medium-sized home builders are more likely to be dealing with fragmented and irregular areas with a need for greater variations in design. Difficulty in ensuring that the final built home conformed exactly to the computer-aided design (CAD) or BIM models. Slow progress in creating BIM objects for domestic building materials and products: manufacturers aiming their products at the residential market had done the least to create new information models and BIM data for their products. Subcontractors: Downstream, there is little, if any, sharing of information using BIM, and few, if any subcontractors have BIM, or any interest in acquiring it. Owners: Lack of fourth state for BIM: Want the ability to hand BIM data and models over to owners at the end of construction. Architects: The clearest difference between the architect and the house builder is that the architect uses BIM on all their projects, whatever their size. They can use BIM most successfully where they are involved in a project from start to finish. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| A number of case studies were reported as follows: Modern Methods of Construction: Case studies: Berkeley Homes–Berkeley Homes, London's biggest house builder, has committed 20 percent of their output to factory-built homes. Berkeley Homes has now been given planning permission to build a modular homes factory in Ebbsfleet, which will produce up to 1,000 properties a year. Legal and General–Legal and General invested £55m in a 580,000 sq. ft. offsite factory in Leeds in 2016, the largest offsite housebuilding factory in Europe. They anticipate that they will install their first factory-built modular homes in mid-2018. Persimmon–Persimmon's "Space4" business operates an offsite manufacturing plant producing timber frames, highly insulated wall panels and roof cassettes, but they have stopped short of producing entire homes off site. Separate case studies: The architect: See text in item 4 above under "architect." Case study: The volume house builder: A volume house builder first started developing the use of BIM in 2012. In describing their experience, they said: "It has been a long, hard slog." They found it to be a very time-consuming process. Working towards the adoption of BIM took a whole team out of the design office to work on developing the first models. A lack of staff skills and shortages of staff have been a problem. Case study: The cross-industry trade body: The fundamental issue that the trade body raised with introducing BIM was the difficulty of getting the supply chain to produce documentation that is not only BIM compliant but also contains the data needed by house builders. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Not applicable. |
| 7. Potentially important references not previously cited |
| None. |
| 8. Additional comments or summaries of other important information |
| From the roundtable discussion: Offsite, modular construction offers potential in terms of increasing productivity, increasing standardization, and avoiding inefficiencies and mistakes in onsite construction. But these methods of construction still have a long way to go in terms of utilizing robotics and of moving beyond simply being indoor building sites. More standardization of housing is needed for the benefits of modular construction to be realized. The overall conclusion was that technology is already available, house builders just need to utilize it, but the take up of BIM is inhibited by issues around skills, awareness, resources, and willingness to change. |

**Topic: Risk**

Reference: Cole, Pam, and Theresa Gilbride. 2015. "Overcoming Codes and Standards Barriers to Innovations in Building Energy Efficiency." *Home Energy Magazine*. www.homeenergy.org/show/article/nav/water/id/2022.

Reviewer: DW

| 1. Scope and content of the reference |
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| A discussion of how building codes and standards put in place by Authorities Having Jurisdiction (AHJs)–while often motivating builders to increase the energy efficiency of new homes–often lag behind technical advances in products and construction techniques becoming barriers to innovation themselves. The reference presents five approaches to work through the barriers to innovation caused by cades and standards. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The problem is stated as the difficulty that local codes and standards have in keeping up with innovations in the construction industry. No specific theoretical models are proposed. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Risk: While not stated specifically, it can be inferred that AHJs weigh managing risk with innovation; often opting for mitigating risk.<br><br>Education: Contractors and other building professionals are the target market for the reference and it is geared towards educating the professionals who use codes on methods for getting innovation written into codes. It also alludes to the idea that educating code officials is one pathway to removing the code barrier to innovation. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Code officials are the decisionmakers for code related barriers to innovation. Building and design professionals are the decisionmakers when it comes to attempting to remove those barriers. This idea is apparent in the target audience, which is building professionals who either have a need (or may have a need in the future) to get building and code officials to allow new and innovative practices and products. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| There is no research or hypothesis to support, as the reference is not an academic reference. There are brief case studies and guidelines providing guidance towards either getting innovative practices approved through existing codes, or getting codes updated to reflect more innovative practices. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Energy is dealt with primarily in the context of how energy codes are utilized by AHJ's. Energy and other technologies are not necessarily differentiated, though the Department of Energy is referenced numerous times. |

| 7. Potentially important references not previously cited |
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| The reference is a website for an industry organization and has no bibliography attached. There are however relevant links to other websites located throughout the reference. |
| 8. Additional comments or summaries of other important information |
| The reference is not an academic reference but rather an industry website. As such, it does not site specific research. It does, however, provide practical information. |

**Topic: Risk**

Reference: D'Oca, Simona, Annarita Ferrante, Clara Ferrer, Roberta Pernetti, Anna Gralka, Rizal Sebastian, and Peter Op't Veld. 2018. "Technical, Financial, and Social Barriers and Challenges in Deep Building Renovation: Integration of Lessons Learned from the H2020 Cluster Projects." *Buildings* 8 (12). www.mdpi.com/2075-5309/8/12/174.

Reviewer: JVB

| 1. Scope and content of the reference |
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| Study of four government/local home renovation projects resulted in a team of experts working for the common good. Lessons learned include the financial, social, and technical tools used and their success and what short comings still exist to convince homeowners (large and small) from endeavoring to do expensive deep home renovations. Trust, cost, logistics and technical tools were discussed. Teams explored extensively prefabricated and mixed-component options in a semi-real setting and their findings. One finding was the cost was still prohibitive even if the construction itself had significant direct savings. Taking the production to a mass scale while still lending flexibility was a main challenge. A whole way of valuing and thinking of housing needs to be undertaken. There doesn't seem to be a magic bullet solution. The paper suggests a very fragmented and traditional way of thinking and doing home renovations. And most times the traditional way is the least expensive, but is hurt by inconsistencies and skill of labor, which results in call-backs. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| A multi-cultural shift will be required to spur on mass renovations to a better energy model for the EU. From the education of the user and empathy from the designer/builder, to better communication of goals from the beginning, to tweaking the technology to work better and talk to each other, to banking practices that value better homes (not just based on floor area), to government intervention and support of innovation studies to be shared to all. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Risk: The homeowner has a few major motivation factors they go to when considering a deep home renovation: cost/pay-back time, trust they are getting value, trust that it is going to predictably work, will government allow the necessary construction, getting over the funding issues of banks lending practices, funding incentives from government or elsewhere, and moving manufacturing into mass production with flexibility and how volume is there. |
| 4. How the reference better defines the extent to which developers and builders participate in making decisions or creating barriers. |

For this paper the focus was on the homeowner's risk and how they can be guided/educated, by a trusting entity, on these very complex projects. All the decisions that must be made and the time and money it takes to motivate owners. Then how to educate the renovator to give the correct information to an owner to help them make important decisions, while having some level of assurance it will all work. It was acknowledged that risk is on all parties. What is the reward? Will the government simply say do it or else, then what?

5. How the reference supports the conclusions with reliable and sufficient experiential data

Other studies support the methodology and conclusions of this study. This paper dealt with a real time set of projects in England as a test of systems and process. The conclusions were based on real costs and real homeowners, yet government funded partially.

6. How the reference differentiates energy and non-energy aspects of technology or system innovation

The whole of the four projects were undertaken in answer to the EU net zero goal by 2050. Existing home stock renovations are usually one-off projects for contractors/designers. So, energy was the center of the study, but seismic issues were also a major consideration. The product technology was not necessarily new (there was a reluctance by the homeowner to use something not tried and true), but the processes used from project beginning to end was attempting to be creative and flexible, with systems bundled in ways to move components into a mass production, repetitive, modular atmosphere. For example, prefabricated wall systems had solar and heating equipment built and delivered to the site together.

7. Potentially important references not previously cited

Most sources supported different parts of the study but was not a paper built on previous case studies. No references that would add value.

8. Additional comments or summaries of other important information

This paper was a summary of panelists conclusions of the barriers and some answers to a systemic problem of renovating a non-consistent building type (consistent in that they all were heavy energy users and not built to withstand seismic loading activity. It was a good look at how these types of projects need careful, technically sound methods of construction that a homeowner can see the value in pursuing. Then, how is that accomplished with the technology and systems we have or that we need to be improved upon: BIM versus manufacturing platforms, bank funding practices, design integration, etc. Education, social acceptance, and money were key in getting this done.

**Topic: Risk**

Reference: Knaap, Gerritt, Stuart Meck, Terry Moore, and Robert Parker. 2008. "Zoning as a Barrier to Multifamily Housing Development." Prepared for HUD, Office of Policy Research and Development. www.huduser.gov/Publications/pdf/zoning_MultifmlyDev.pdf.

Reviewer: JVB

| 1. Scope and content of the reference |
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| This was a Geographic Information System (GIS) data, interview and reference study on the effects of zoning on the development of multifamily and other higher density housing in the United States. Six metro areas in various parts of the country were examined for land availability, relative property values, and the growth rates of the area, as well as local regional and statewide land regulations in place or not. The goal was to see if zoning regulation (land use regulation) affected multifamily housing trends. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Using good GIS data and the means to analyze it (considering the many factors that affect the creation of more dense housing) may give us tools to quickly analyze a local or regional areas trends for growth, income, and where more and what type of housing is needed. This could be a great tool for governments and research groups (and maybe someday developers) to utilize to manage and spur housing growth where needed. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Risk: With all the many, varying variables that decisionmakers have to make when deciding how to create more and better, appropriate housing in all cities, how can we wisely hurdle the zoning and land-use barriers in place that prevent it from happening? Zoning is just one of the barriers, but it has been widely researched that if land is available, whether the area has high or low income, high or low zoning densities, more will be built within that zoning constraint. This seems to be mostly a political, social, and governance set of issues. How local governments deal with land planning, infrastructure deficiencies, and land prices remain to be seen. |
| 4. How the reference better defines the extent to which developers and builders participate in making decisions or creating barriers. |
| Developers usually take the easy road. If a municipality has no multifamily zoned land, is reluctant to re-zone land for higher density, or has so many regulations associated with land use (like traffic and infrastructure use fees) the less likely a developer will even venture in that direction. If an investor incentive is there, developers will follow. Not many are interested in "affordable" housing due to the lack of monetary incentive. Builders and developers are regularly on planning boards and do have influence, but this study did not focus on this. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

| |
|---|
| Other studies did reinforce the theories and study methods of this paper. Much of the data was compiled using other research. The conclusions were "grey" as to the overall effect of zoning on land development (more on land availability that was zoned for multifamily projects). The research used GIS data, which varied in usefulness. The lessons learned were direct from that use and a conclusion was it was very good information depending on whose data you were using, but there was an inconsistency across the board. There was not much doubt that zoning was a definite barrier, but the extent was always local. Regional and state comprehensive land use plans that local governments had to adopt had definite effects. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Energy was not a focus of this study. It was not mentioned as this was focused study on land appropriation. |
| 7. Potentially important references not previously cited |
| Bonham, J. Blaine, Jr., Gerri Spilka, and Darl Rastorfer. 2002. “Old Cities/Green Cities: Communities Transform Unmanaged Land.” In *Four Supreme Court Land-Use Decisions of 2005: Separating Fact from Fiction.* American Planning Association. |
| 8. Additional comments or summaries of other important information |
| The interviews used in this paper were from a good range of knowledgeable persons that deal with zoning issues daily: academia, planning, building, developing, and government. Those that affected zoning and those that had to deal with zoning. |

**Topic: Risk**

Reference: McCoy, Andrew P., C. Theodore Koebel, Andrew R. Sanderford, Christopher T. Franck, and Matthew J. Keefe. 2015. "Adoption of High-Performance Housing Technologies Among U.S. Homebuilding Firms, 2000 Through 2010." *Cityscape* 17 (2). https://vtechworks.lib.vt.edu/handle/10919/80399.

Reviewer: RJ

| 1. Scope and content of the reference |
| --- |
| This article describes foundational processes of a larger project examining U.S. home builders' choices to adopt innovative housing technologies that improve the environmental performance of new single-family homes. This article focuses on home builder choices by analyzing a summary of innovation adoption literature and that literature's relationship to homebuilding. The researchers then describe analytical approaches for studying home builders' choices and markets at a core based statistical area level, the data and statistical methodologies used in the study, and the policy implications for promoting energy efficiency in housing. Future work will draw on the foundation presented in this article to specify versions of the generic model outlined and report results using improved quantitative analyses. This work (and article) sits at a convergence where builders are characterized as slow to adopt innovation and researchers who have not regularly experimented with advancing variations of innovation diffusion models within residential building construction. Whereas homebuilding innovation has traditionally experienced slower rates of adoption, some green building technologies exhibit accelerated adoption patterns. Little empirical work exists that measures and analyzes such phenomena, which is the subject of this work. The work focuses on the home builder as the central actor and will set the stage for a series of different empirical analyses of builders' adoption of energy efficient (EE) green building technology innovations by moving beyond a traditional focus to analyze a broader array of factors including public policy, climate, and market area characteristics that could help explain builders' high-performance technology adoption patterns. The article is outlined as follows: 1) Introduction; 2) Literature Summary; 3) The Adoption Decision; 4) Attributes of the Adopter; 5) Attributes of the Product, Supply Chain, and Communication Networks; 6) Attributes of the Market; 7) Energy Prices; 8) Time; 9) Conceptual Model; 10) Data and Proposed Analytical Techniques; 11) Clusters of Dependent Variables; 12) Potential Statistical Modeling Techniques; 13) Independent Variables; 14) Regression Modeling; 15) Discussion; and 16) Acknowledgments, Authors, and References. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |

In this article, the authors address the following research questions: 1) What external parameters are likely to be associated with builders' decisions to adopt high-performance housing technology alternatives across time and into recent years, and 2) Do external parameters surrounding this change support a general shift toward environmental performance as a central component of diffusion in the homebuilding industry? In answering, they describe an array of data that will inform diffusion modeling and enable others to refine industry models and draw empirical conclusions about builders' innovation adoption choices. Their description of the data and the generic conceptual model further proposes 1) methods for measuring adoption patterns of high-performance technologies, 2) a comparison of the sample with independent measures of the builder population, 3) regression analysis tools, and 4) the potential significance of the preliminary model for diffusion of technology in general. The article links the diffusion of innovation among home builders to broader concepts of sustainability and highlights several implications for federal policymakers. In the context of the literature summarized and the conceptual model in the report, the research team assembled a large dataset describing U.S. homebuilding product use from 1996 to 2010. The measures of product use in the dataset come from the Builder Practices Survey (BPS), an annual survey conducted by the NAHB Innovation Research Labs. The BPS is designed to capture builders' product use patterns of new residential construction projects annually across nearly 1,100 product types and more than 40 clusters of products. The BPS data do not contain any information about the characteristics of the firm beyond the city and county of the respondent's address and summary measures of the number, size, building type, and price of the housing units built during the previous year. The data are nonlongitudinal because respondents cannot be linked over time. After being merged with exogenous market characteristic variables sourced by the research team, the dataset is the largest of its kind and unique in its integration of industry, market, and public policy measures. The team assembled County Business Pattern (CBP) data from 2003 to 2010 by year and compared those data with BPS respondent data, based on single-family and multifamily builders by state. The original goal of the research was to discover patterns of use in energy efficient technologies among builder firms, which was later expanded to high-performance products as explained in the article. The research team initially needed to organize BPS variables into clusters of products that affect performance in a home, focusing on energy-efficiency as part of performance.

3. How the reference helps define one or more of the four relevant categories of barriers

The authors' focus in this article is the general cluster of technology critical to performance. They use, as an example, the high efficiency windows cluster that includes insulated glass (IG) in three product types, all of which can be used by builders as choices not mutually exclusive between homes: double-pane, Argon; double pane, Argon low-E; and triple-pane windows. The model used is for the choice between the high-efficiency cluster and double pane no Argon. In the aggregate the authors are modeling the rapid replacement of the low-efficiency alternative by high efficiency windows (HEWs) option, in exhibit 3 (see additional comments section below). The logistic regression model described in the report for analyzing use of HEW reflects the dichotomous choice framework. Given the structure of the BPS dataset and its nonlongitudinal nature, the authors consider the adoption decision to be a dichotomous choice to adopt or not adopt the high-performance technology over its traditional economic substitutes.

4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers

After more than 100 years of innovation research, scholars can show that adoption and diffusion of innovation are critical forces that build competitive advantage, disrupt existing markets, and create new markets and until recently scholars of innovation have not focused a great deal on construction. Few diffusion-of-innovation modeling techniques have been applied in the commercial construction literature. Measurement of the attributes of the potential buyer is also important—though the literature is opaque on precise attributes that play significant roles. Basing decisions on the literature summarized in sections of the article, the authors propose the conceptual model in exhibit 1 (see additional comments section below) as a graphic representation of the adoption decision. In the center is a builder with a dichotomous choice to adopt or not adopt a high-performance housing technology. Although U.S. housing has historically been marked by its lack of change, innovative building technologies have recently diverged from previous adoption and diffusion patterns. In place of previous path dependency, the construction industry is demonstrating a widening awareness and likely use of innovative practices and technologies. Little empirical evidence measures and analyzes the choice of building products, which is a shortcoming addressed in this project. After reviewing the adoption, diffusion, technology, construction, real estate, and statistics literature, the authors identified an array of factors that are likely to be associated with builders' adoption decisions around high-performance technologies. In addition, the authors analysis on initial plots of the data, they estimate that the construction industry is moving increasingly toward the adoption of high-performance technologies within new homes.

5. How the reference supports the conclusions with reliable and sufficient experiential data

The innovation-decision process surrounding the use of technologies in housing (and why) clearly influences energy consumption, a rippling effect toward future resource consumption. It is also clear that energy efficiency in housing can influence financial sustainability for multiple stakeholders along the supply chain—residents, developers, owners, and operators, to name a few. Government plays a strong role in supporting green building causes—incentives, cost relief, regulations, and promotion. From a policy perspective, energy efficiency in housing could benefit residents through reduced overall housing costs and monthly savings that provide a cushion against unforeseen economic shocks. Green building using a third-party, verified process could also serve housing stakeholders as a risk mitigation tool into the future (healthy homes, durability, and long-term value).

6. How the reference differentiates energy and non-energy aspects of technology or system innovation

The model used is for the choice between the high-efficiency cluster and double pane no Argon. In the aggregate the authors are modeling the rapid replacement of the low-efficiency alternative by HEWs option, exhibit 3 (see additional comments section below).

7. Potentially important references not previously cited

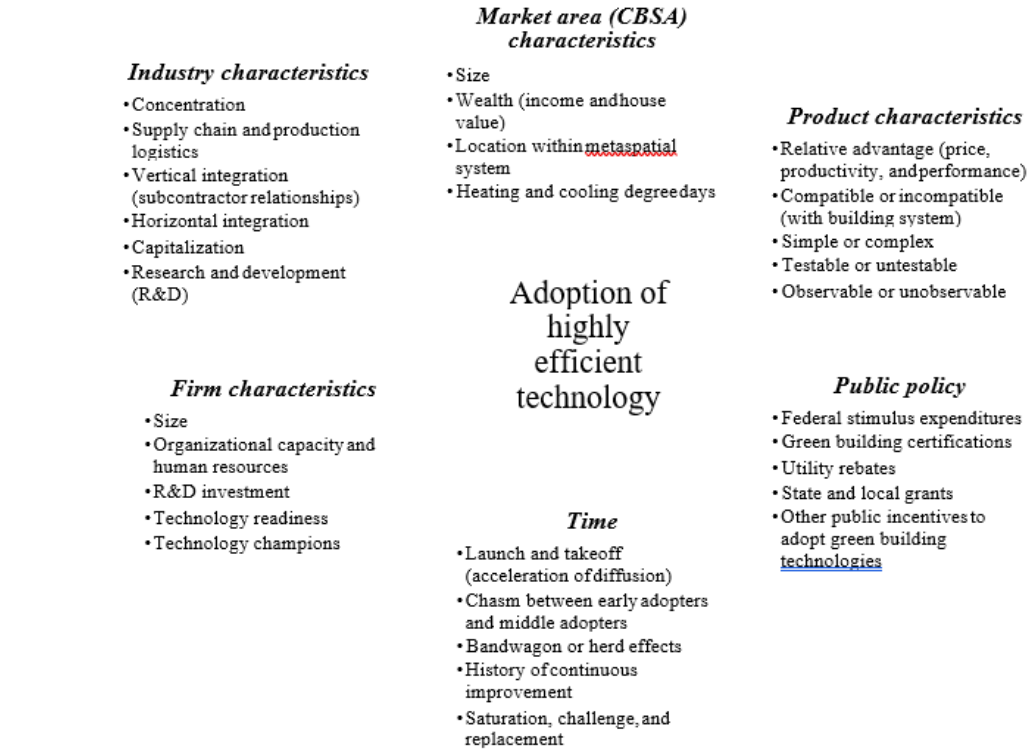
Not applicable.

8. Additional comments or summaries of other important information

**Modeling Exhibits Below:**

## Exhibit 1

The Conceptual Model and Variables




*CBSA = Core Based Statistical Area.*

**Topic: Risk**

Reference: McCoy, Andrew P., Walid Thabet, and Ralph Badinelli. 2011. "Defining a Commercialisation Model for Residential Construction Innovation: Industry Case Studies." *Construction Innovation* 11 (1): 114–133. https://doi.org/10.1108/14714171111104664.

Reviewer: CLG

| 1. Scope and content of the reference |
|---|
| Discuss the issues with failed commercialization and provides validations for a successful model using research from 15 case studies. Focuses on the business plan and the critical commercialization steps that are essential to mitigating the risk of failure. While the steps outlined are crucial, the sequence in which they are completed can be customized to the specific innovation although the initial steps are the most essential in identifying an innovation's success. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| This is a further validated domain-specific commercialization model for the residential construction industry. The reference identifies key steps that reduce adoption failures. The use of models by innovation manufacturers increases the probability for success. Investigates the role of product champions as an important influential impact that ensure every step of the model is completed. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Residential construction in the United States particularly has a high rate of uncertainty with innovation adoption, therefore the primary barrier for innovation manufacturers is risk. This risk is mitigated by the techniques shown in the commercialization model that provides steps to increase the probability of successful adoption. Code compliance and product liability that is unique to construction products is additional risk that needs to be effectively addressed early on in development. Common barriers defined by interviews: poor knowledge of the market by product developers, poor supply chain and distribution coordination, poor regulatory knowledge, poorly trained personnel, and poor sales management. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The interviews define how consumers create barriers including: poor client and end-user relationship, poor education, and poor installation by end-user. However, these types of barriers should be mitigated by the manufacturer. The case studies showed that interview responses gave low importance to SCM which is interesting due to the importance of developers/builders and inspectors role in deciding whether a product proceeded to the next stakeholder in the supply chain. Commercialization steps within the area of SCM can be a risky and expensive investment since builders are typically reluctant participants. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| This reference continues the work in the reference "" and applies 15 more case studies in order to further validate the commercialization model for the residential construction industry. They cite references that state case-study methodology is the best approach to investigating and validating this type of model. The 15 case studies vary widely in order to get a wide range of demographics. |

| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
|---|
| The reference does not differentiate. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Risk**

Reference: Na, Lim Jay, George Ofori, and Moonseo Park. 2006. "Stimulating Construction Innovation in Singapore through the National System of Innovation." *Journal of Construction Engineering and Management* 132 (10). https://ascelibrary.org/doi/abs/10.1061/%28ASCE%290733-9364%282006%29132%3A10%281069%29.

Reviewer: JVB

| 1. Scope and content of the reference |
|---|
| Article examines the development of Singapore's national system of innovation, a government source of research partnering with local contractors. The main actors are made up of local contractors, suppliers, national research institutions, government, and foreign contractors. The role of the National System of Innovation (NSI) is to bring these entities together and create a forum for innovation. There is not motivation, as the general contractors (GCs) see it, to innovate due to the risk and return model of today's construction. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The suggestion is that a National Systemic Model of assisting the varied parties to do research and development to everyone's benefit but maintain one's individuality and competitive edge, by sharing the risk involved in research and development for everyone. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| There is a systemic issue with the construction industry in Singapore that contributes less and less each year toward the National GNP. Profit is the motivator to any innovation, or the lack thereof. Creating a national center for innovation research is how Singapore is going to help eliminate the risk of new innovation, no matter what it is. |
| 4. How the reference better defines the extent to which developers and builders participate in making decisions or creating barriers. |
| Decisions are based on cost/profit first, then quality second. That is the sum total of the decision making. The research and development is only a barrier due to cost and not processes. Firms that have best controlled quality for large projects are winning the battle. Intellectual property is not valued like it is in the United States and foreign contractors are forced to share their knowledge. Singapore GCs use that to learn rather than do their own inventing. This is not a sustainable way to survive long term. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Many other studies are referenced to support theories and findings, but all are from 2004 and earlier and are not necessarily relevant today. This is not a case study in that no interviews were done. National statistics were used to shore up assumptions. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Energy was not mentioned in this study. |
| 7. Potentially important references not previously cited |

| |
|---|
| Most sources were from 2004 and before. |
| 8. Additional comments or summaries of other important information |
| Study makes a compelling argument that the construction industry for local builders will die without the ability to get into their organizations the proper research and development and education to compete in the future. The small contractor was not a part of this study, nor how information on new products will trickle down to them, even though the research and development generated by government funding (which is a shared cost with suppliers and builders) would eventually be public information. Foreign contractors are seen as more sophisticated than local contractors. Their intellectual knowledge is not always shared unless forced by government. |

**Topic: Behavioral**

Reference: Barlow, James, and Ritsuko Ozaki. 2005. "Building Mass Customised Housing Through Innovation in the Production System: Lessons from Japan." *Environment and Planning A* 37: 9–20. doi:10.1068/a3579.

Reviewer: MKC

| 1. Scope and content of the reference |
|---|
| The reference provides background on the beginnings of the customized homebuilding surge in Japan spawning the 1960s. In summary, the synthesis of social, economic, political, and geographical conditions have led to the customization approach. Customized homebuilding is broken down into two categories: industrialized national or local craft housebuilders. The resource delves into the advantages and disadvantages of small local business and mass customized housing suppliers. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Local embeddedness is the theory that suggests smaller housebuilders are in a better position for spatial organization. Smaller local homebuilders have a connection with their community that allows them to increase their "after-care service" without having to implement complex consumer interface. The continuing relationship between homebuilders and consumers is considered part of the initial sale. Follow up visits from the homebuilder can occur up to 20 years post-occupancy in order to capture the experience of the user. While mass customized housing suppliers have created in-depth customer-interfaces and production systems, the approach is more costly than smaller home builders "after-care service" research and development. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The reference focuses on what went right in the examples of the Japanese Housing industry rather than focusing on the barriers. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The Japanese mass customized housebuilding practice offers a multitude of choices to the consumer regardless of their price-point. "Japan's mass customized housing suppliers offer choice across their entire product range and not simply those at the upper end of the market." While the UK offers around 30 standard floor plans without any customizability, Japanese mass customized housing suppliers offer 300 design permutations that can be adjusted to the customer's preferences. The customer chooses from various house models, floor plans, structural materials, cladding materials, interior fixtures, and design concept. |

| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| --- |
| The literature offers myriad citations referencing the need for homebuilding customization. The sources also reflect the pros and cons of local homebuilders versus mass customized housing suppliers. Being that this reference is from January 2005, it would behoove one to study more recent literature on the need for customizability in Japan (and potentially the rest of the world). Does Japan still place as much emphasis on home customization as it once did? |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference does not differentiate. |
| 7. Potentially important references not previously cited |
| No additional references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Behavioral**

Reference: Dainty, Andrew R. J., and Alistair G. F. Gibb. 2012. "Establishing and Weighting Decision Criteria for Building System Selection in Housing Construction." *Journal of Construction Engineering and Management* 138 (11): 1239–1250. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000543.

Reviewer: JVB

| 1. Scope and content of the reference |
|---|
| Case study: Examines the reasons large builders may go to factory-built homes versus stick-built using cost, time, quality, sustainability, procurement, and process as key factors. Cost always won. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The main barrier to using factory-built housing was company leadership and values of each organization interviewed. They all had differing values, but cost and time usually won at every company. Few, but some, builders see sustainability and energy use as important company cultural items. Client satisfaction was also a motivator, but not dwelled upon in this study. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The client/leadership is the most likely source to push innovation, so educating clients to use value-based decision making and find ways to measure that value. The mentality of large builders to seek radical change is not changing rapidly in this building industry which is similar to the United States other than the density at which land is being developed. |
| 4. How the reference better defines the extent to which developers and builders participate in making decisions or creating barriers. |
| Most decisionmaking is at the corporate leadership level, of course. Builders want the certainty of price. Time was second, quality was third, sustainability and procurement alternately were fourth and fifth, process was sixth and way down the line of values were health and safety as well as government regulation, which are both required and not seen as "values" that drive decisions. The study attempted to create a valuing tool (customized by company) to make value decisions when choosing a structural system delivery. There was a lack of incorporating innovative sustainable technology into corporate strategy. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Other studies support the methodology and conclusions of this study. As well this study points out deficiencies in previous studies that it tries to fill. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Sustainability was the direct subject of this study but suggests sustainability (in the environmental context) s not high on the priority list of values, unless it is imposed by outside forces to be a requirement. |
| 7. Potentially important references not previously cited |

| |
|---|
| Most sources were from the UK and were of similar studies. |
| 8. Additional comments or summaries of other important information |
| This study was based mostly on interviews with large builders who could afford to undertake factory-built delivery of homes and apartments. No correlation to the small builder or remodeler were offered. Cost and time, as well as quality (call backs,) were sighted as the motivation behind most decisions of builder/developers. |

**Topic: Behavioral**

Reference: Engström, Susanne. 2020. *Managing Information to Unblock Supplier-Led Innovation in Construction: Barriers to Client Decision-Making on Industrialized Building in Sweden*. PhD diss., Luleå University of Technology. http://urn.kb.se/resolve?urn=urn:nbn:se:ltu:diva-17324.

Reviewer: DW

| 1. Scope and content of the reference |
|---|
| The reference is a doctoral thesis undertaken to understand the role of the construction client as decision maker in supply-led innovation. The study was done for the "Timber Structures" group at Luleå University of Technology. Industry focus is on the timber structure industry in Sweden, specifically what is termed "industrialized construction," and defined as examples of contemporary innovation in that industry. The ability of the Swedish construction client (primarily stakeholders of multi-family projects and schools, as opposed to individual consumers) to manage, communicate, and interpret information was the primary focus of research six separate papers describing the background, research, and conclusions of the research are referenced in the body of the thesis and appended to it. Ultimately, the goal of the research is to determine how to unblock supply-led innovation. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The stated theoretical framework for the research utilizes three information management perspectives: A decision theory perspective on managing information, an organizational information processing theory perspective, and a communication process perspective on managing information. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Behavioral: Several behavioral barriers are identified in the reference. Long term versus short term gain and status quo bias when there are several alternatives are examples. Managing communication is a major component and the ambiguity or "equivocality" caused by poor communication is a major driver of innovation barriers.<br><br>Risk: Behavioral issues are the focus, but perceived risk is also addressed in the reference. Equivocality or ambiguity in communication results in a perceived higher risk. Clients prefer known problems to potential new ones. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |

Three lessons related to client decision making were described in the research.
First: "The building clients (as a group of actors) did not emerge as an apparent force for change towards industrialized building, even though their evaluation of industrialized building characteristics was generally positive."
Second: "The information and understanding required (according to respondents for both client and contractor) for supporting clients' decisions on whether or not to enforce market power towards industrialized building did not seem to be readily available (again, according to respondents for both client and contractor)."
Third: "It was unclear how building clients evaluate the different options that are offered by an industrialized building process, compared to what may be lost when abandoning the traditional building process, not least with respect to the needs of end users and the value given to them. It remained unclear what actual impact different “wants” expressed by clients had on their buying decision."

5. How the reference supports the conclusions with reliable and sufficient experiential data

Summarized within–and appended to the reference–are six papers that outline the background, theory, methodology, and conclusions of the research.
Paper I: Competitive impact of industrialized building: In search for explanations to the current state.
Paper II: Construction clients’ ability to manage uncertainty and equivocality.
Paper III: Clients as drivers of innovation: Lessons from industrialized construction in Sweden.
Paper IV: Sustaining Inertia? Construction clients’ decisionmaking and information-processing approach to industrialized-building innovations.
Paper V: Towards improving client-contractor communication in industrialized building.
Paper VI: Barriers to client-contractor communication: Implementing a process innovation in a building project in Sweden.

6. How the reference differentiates energy and non-energy aspects of technology or system innovation

Very little time is spent on energy related issues.

7. Potentially important references not previously cited

No additional references.

8. Additional comments or summaries of other important information

As a doctoral thesis, the reference is highly detailed and highly academic, written largely for its very specific research group and academia but addressing very real market driven forces in the construction industry.

**Topic: Behavioral**

Reference: Fischer, Corinna. 2008. "Feedback on Household Electricity Consumption: A Tool for Saving Energy?" *Energy Efficiency* 1 (1): 79–104. https://doi.org/10.1007/s12053-008-9009-7.

Reviewer: CLG

| 1. Scope and content of the reference |
|---|
| Electricity consumption is intangible to consumers and conservation starts with choosing innovative products. Feedback is a psychological behavioral tool and an innovation within products that can be used to change energy consumption behavior in consumers. Specific feedback includes costs and environmental impacts. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| In this reference a psychological model is presented that explains why feedback works. Environmental psychology develops models that show relevant behavior and ways to successfully change behavior that is detrimental to the environment. While many aspects of feedback are shown, the medium and mode of presentation is where feedback can be an innovation itself. In the study electronic and written feedback was used with the internet playing a big role in electronic feedback which provides flexibility and interactiveness. However, a unique approach was to install the feedback at the appliance itself. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The reference helps define one aspect of behavioral economics which is the importance of feedback. When people cannot see the tangible results/feedback quickly they do not value the actions or products. The example used in this reference is electricity consumption. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The reference defines how consumers are less likely to make changes to behavior when they do not see tangible results/feedback. While the reference is specific to electricity consumption it touches on the broader implications of behavioral economics and choices towards innovations that do not have tangible, timely, and frequent feedback. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| The reference uses five review studies and 21 original papers to support their conclusions. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference focuses on energy consumption and the environmental psychology that can alter behavior. |
| 7. Potentially important references not previously cited |
| None. |

| 8. Additional comments or summaries of other important information |
| --- |
| While this reference does not specifically focus on innovation it does point to the behavioral economics theory that feedback is important to change behavior. Therefore, feedback could be used to promote innovations whether incorporating feedback into the design of the product or on a more holistic level showing how innovations can improve the feedback in a home. |

**Topic: Behavioral**

Reference: Heinstein, Patrick, Christophe Ballif, and Laure-Emmanuelle Perret-Aebi. 2013. "Building Integrated Photovoltaics (BIPV): Review, Potentials, Barriers and Myths." *Green* 3 (2): 125–156. https://doi.org/10.1515/green-2013-0020.

Reviewer: CLG

| 1. Scope and content of the reference |
|---|
| A review of the types of technologies, potentials, comparisons to Building Applied Photovoltaics, (BAPV), barriers, and myths to Building Integrated Photovoltaics (BIPV). |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Diffusion of this innovation is inhibited by "both a considerable lack of awareness and a persistent resistance among stakeholders." The stakeholders include almost every stakeholder in the theoretical model that is needed for diffusion including architect, contractor, developer, and homeowner. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The reference helps define the behavioral barrier because it shows how the innovation was blocked in various ways including: mythically perceived as expensive and prestigious (despite a favorable effect on overall costs), psychological worries about warranties from homeowners, the technology has been declared "dead" by the media and competing industries (primarily the oil and gas industry in the United States), architect objections to the aesthetics, skilled installers seen as unwanted competition to contractors, waiting for better technology, and irrational behavior in consumers unless utilizing localized diffusion techniques.<br>Costs and lack of skilled installers also posed as barriers.<br>Best strategies for overcoming these barriers were state incentives, localized diffusion ("keeping up with the Joneses"/imitative instinct mentality for homeowners), legality/code enforcement, and technological advances that appeal aesthetically. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The reference adequately defines how builders and designers object to this innovation due to cost, aesthetics, and competition in the market. Ultimately, the homeowner participates in creating barriers due to myths about the product, worries about warranties, irrational behavior in decision making, and influence from the media and the oil and gas industry. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| The reference is supported by experimental data including multiple citations that use surveys. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference focuses on energy aspects of technology specifically solar energy. |
| 7. Potentially important references not previously cited |

| |
|---|
| No important references. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

**Topic: Behavioral**

Reference: Koebel, C. Theodore, Andrew P. McCoy, Andrew R. Sanderford, Christopher T. Franck, and Matthew J. Keefe. 2015. "Diffusion of Green Building Technologies in New Housing Construction." *Energy and Buildings* 97: 175–185. https://doi.org/10.1016/j.enbuild.2015.03.037.

Reviewer: RJ

| 1. Scope and content of the reference |
| --- |
| The authors analyze the selection of high efficiency windows by builders of new housing units in the United States from 2000 to 2010. They note that windows are among the five most important technologies impacting energy use in structures. Focusing on windows provides insights into the decisions that result in energy efficient houses and the factors affecting those decisions, which can be muted or completely missed when looking at building ratings or other aggregated estimates. The study analyzes a large data set for the continental United States, applying the Least Absolute Shrinkage and Selection Operator (LASSO) model selection and cross validation of the training set model with a randomly selected validation data set. The authors findings strongly support the importance of climate and energy costs in decisions on energy efficient housing, with important but smaller effects for public policies and incentives. They also find that taxing and insurance policies that increase the overall costs of construction can have negative impacts on the diffusion of energy efficient products. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Green building technology selection model utilizing the application of the LASSO model selection and cross validation of the training set model with a randomly selected validation data set. LASSO is a form of continuous variable selection that operates by imposing a constraint on the sum of the magnitude of regression coefficients. Use of the model allows for green building model analysis. Due to the importance of residential energy consumption, the authors model the decision of builders to use specific energy efficient products, in this case high efficiency windows. Cross validating the LASSO training model coefficients on the validation set produced a virtually identical concordance statistic and attests to the robustness of the model results. Digital technologies such as Building Information Models are rapidly expanding the potential of decision models and analysis in construction. A general model proposed for green building technology adoption is shown in the figure attached below in section 8 and includes seven multi-dimensional arrays identified in diffusion and adoption theory and in previous research, grouped into the seven multi-dimensional categories of product, market area, climate, time, firm, industry, and public policy. One of the distinct features of the authors research is its specification of a specific building product as the dependent (selection) variable. For this paper, the authors analyze the decision to use specific window technologies in new housing construction. This paper defines high efficiency windows (HEW) as double-paned argon-filled, double-paned argon-filled low-E and triple-paned windows, and are treated here as equivalent products. A table outlines the variables used to develop the model indicating on the vertical axis the following: time, product, firm, industry, public policy, market area, and climate. The horizontal axis indicates: variable category (listing the vertical axis variables), variable, definition, source, and unit of observation. For future research, adding more characteristics of the firms making decisions would potentially be fruitful in pushing the model's concordance. |

| 3. How the reference helps define one or more of the four relevant categories of barriers |
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| The compatibility dimension of the product reflects the importance of network effects in building construction. New products that are compatible with other products (windows have to be compatible with framing and siding materials and installation) will be more readily adopted than products that require changes in other materials and processes. Laboratory testing, modeling and simulations rarely substitute for field testing, hence the importance of field demonstrations in construction to minimize the risks of trial and error. Construction products that are not easy to test and verify in the field, or with less certain laboratory testing, face greater obstacles in adoption. Public policy can have accelerating or impeding effects on innovation adoption. Market area characteristics have also been suggested as important for innovation diffusion. Areas with larger populations, higher incomes, education, and growth might have greater demand-pull for innovation in residential construction. Innovation diffusion relies on awareness and knowledge about innovations, and is often described as a process similar to contagion. Diffusion researchers have focused on the communications networks that influence innovation adoption–proximity within these networks increases exposure. Highly restrictive land use regulations can increase land and building costs, which would potentially lead to lower levels of innovation adoption. Climate is readily measured and should have important effects on the adoption of green building technologies. Price is a key component of relative advantage and can act as an impediment to adoption during the early stages of diffusion which are not included in the time period of this study. Builders clearly do not select products in isolation from local climatic conditions or market conditions. They also do not select products as singular decisions but as part of a bundle of products. The authors specification of a single product dependent variable provides clarity about window selection but does not address the more complex question of product bundling. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| In high performance home construction, where tightness of construction (air leakage) and efficiency of walls are critical (resisting heat transfer), the performance of high efficiency window (HEW) units becomes a key factor in ensuring efficiency for the building's envelope (builder) and operation (homeowner), which can in turn influence long-term durability and value. It is not surprising that builders make different product selections in response to differences in climate—they sensibly build to the local climate. Builders (and ultimately consumers) also appear to be very sensitive to energy costs in their product decisions. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| Some public policies could have negative effects on construction innovation, particularly by increasing the relative cost of construction in the jurisdiction through taxes and regulations. The assumed expectation is that builders of larger, more expensive homes would be more likely to select higher energy efficient products. Another potentially important distinction is between firms that include multi-unit housing in their production portfolios and those that build only single-family detached or attached units. Multi-unit properties are more likely to be rental housing where it becomes more difficult to capitalize energy efficiency in rents or to otherwise capture the savings in operating costs associated with energy efficiency investments. Supply chain has been suggested as an impediment to diffusion of innovation in building products, although the impact of suppliers could be potentially more important in the early stages of diffusion, depending on the origination of the product and category of project for a home builder. Focusing on HEW technology use, the authors findings strongly indicate that climate does indeed matter for innovation in energy efficiency in housing; colder climates with higher heating degree days are associated with much higher diffusion of energy efficient windows but warmer climates with higher cooling degree days had no association with window selection. Although not targeted to energy efficiency, taxing and insurance policies that increase the overall costs of construction can have negative impacts on the diffusion of energy efficient products. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Heating degree days had the largest impact on HEW selection. The second largest effect is the cost of energy, high electricity prices (and colder climates) are clearly a major driver of HEW use. State and local energy grants had the third largest effect. State-wide mandatory energy codes for residential construction had marginally significant effects. Year has the fourth largest effect. This could very well reflect bandwagon effects as HEW became more and more dominant in the market. The largest negative effect is the impact of building multi-family housing structures, which reduces the probability of HEW selection. |
| 7. Potentially important references not previously cited |
| Not applicable. |
| 8. Additional comments or summaries of other important information |

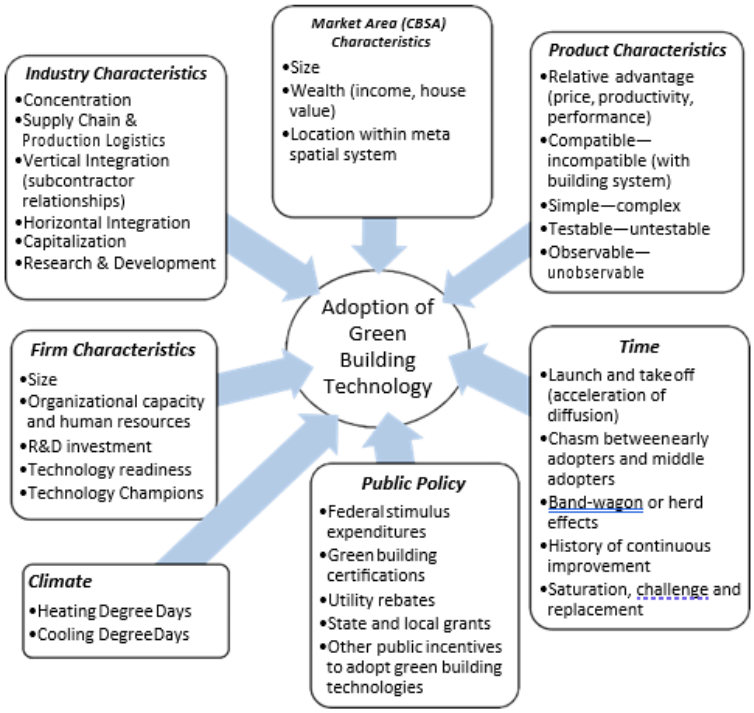


**Fig. 1.** General model of green building technology adoption.

**Topic: Behavioral**

Reference: Loosemore, Martin and Justin Richard. 2015. "Valuing Innovation in Construction and Infrastructure: Getting Clients Past a Lowest Price Mentality." *Engineering, Construction and Architectural Management* 22 (1): 38–53. https://doi.org/10.1108/ECAM-02-2014-0031.

Reviewer: JVB

| 1. Scope and content of the reference |
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| Article examines motivations of clients to demand innovation over lowest price approach to projects as a means to find value and recognizing that the lowest price is not always the greatest "value." Clients want the certainty of price; cost is the main driver of decisionmaking. Procurement choices emerged as a major constraint on innovations. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Innovation starts at the top of firms. Innovative firms need to find "open minded" clients. Focus on the time it takes to innovate; collaborate along many lines to find innovations that work; integrate of an innovative environment; and perform risk management. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| The client/leadership is the most likely source to push innovation, so educating clients to value innovation and find ways to measure that value. |
| 4. How the reference better defines the extent to which clients (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| Clients want the certainty of price. Procurement choices emerged as a major constraint on innovations. Create a market and innovation will follow. Builders must have permission to innovate from the leaders. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| Other studies support the conclusions of this study. However, most conclusions were taken from 46 variable professional interviews. Interviews were consistently supportive of the theory. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| Suggests technology has the ability to help measure the values of innovation and performance to show long term advantages. There may be more training needed to give the managers of this technology the skills to run it. |
| 7. Potentially important references not previously cited |
| Blayse, A. M., and Karen Manley. 2004. “Key Influences on Construction Innovators.” *Construction Innovation* 4 (3). |
| 8. Additional comments or summaries of other important information |

The innovation-driven builder is rare and usually a mega builder with the resources to make systemic changes in their companies. Owner/occupiers more readily see innovation as a value. Price usually rules the day for decisionmakers. Introduce innovations before beginning a design project. Use performance-based specifications.

**Topic: Behavioral, Risk**

Reference: Maslen, Sarah, Jan Hayes, Janice Wong, Christina Scott-Young. 2020. “Individual Liability and the Development of Defensive Engineering in Professional Practice.” *Journal of Civil Engineering Education* 146 (4). https://doi.org/10.1061/(ASCE)EI.2643-9115.0000023.

Reviewer: JVB

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| 1. Scope and content of the reference |
| Article examines engineering practice and methods to avoid personal litigation, and how it has spawned "defensive" rather than "creative" engineering practices. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| Litigation is seen as a barrier to creative or innovative engineering, and the need to foster ethics and environmental practice in our education system as well as social and ethical classes. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| It defines the engineering risks, rather than the building risks in our litigious society. It does not direct its attention specifically to affordable or better housing. A generalization could be made that this defensive design keeps us between the rails and does not foster creative solutions to housing in general. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| If the elimination of risk can be defined as staying with tried and true ways of building, then liability within our court system is a real barrier to innovation. No one will want to be "first." |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |
| This was a survey of engineers’ thoughts on the matter. Then the medical profession was used to simulate the problem in the engineering profession as it is well documented, but for engineering it was not well documented: only the correlations between the two professions was examined. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| It does not, other than suggesting that social and ethical impacts of engineering are important for good decisionmaking, yet heightens the prospects of litigation. |
| 7. Potentially important references not previously cited |
| None. |
| 8. Additional comments or summaries of other important information |

Other articles point out that creative, inclusive design is essential to innovation. This article points to the designers and their sound decisionmaking to make better products versus the litigation that keeps new designs and thoughts out of the bigger conversation.

**Topic: Behavioral, Education**

Reference: McWhirter, Nathan, and Tripp Shealy. 2017. "Teaching Engineering Students About Cognitive Barriers During Design: A Case Study Approach Using the Envision Rating System for Sustainable Infrastructure." Paper presented at *International Conference on Sustainable Infrastructure 2017*. https://doi.org/10.1061/9780784481202.040.

Reviewer: CLG

| 1. Scope and content of the reference |
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| The reference discusses how design students can overcome cognitive biases and barriers during design decision making using a certification program, specifically the envision rating system which focuses on civil engineering. The behavioral barriers taught to the engineering students include choice overload, bounded rationality, status quo bias (upstream institutional bias), satisficing, precommitment (Ariely and Wertenbroch, 2002), choice architecture (Johnson et al., 2012), and nudging (Thaler and Sunstein, 2008), etc. The results attempt to educate students about the interrelatedness of engineering design and behavioral decision science. The results found that students were effectively able to connect behavioral barriers to the case studies and implement the envision rating system to overcome the barriers. |
| 2. Any theoretical model of innovation and/or barrier operation to consider based on work |
| The barrier investigated in this reference is cognitive biases during the design decision making process. |
| 3. How the reference helps define one or more of the four relevant categories of barriers |
| Behavioral decision science (psychology, behavioral economics, and decisionmaking) has long been overlooked in engineering and design but is very relevant in regard to cognitive biases, assessment of risk, impact of sustainability, and poor decision making. The behavioral barriers taught to the engineering students include choice overload, bounded rationality, status quo bias (upstream institutional bias), satisficing, precommitment (Ariely and Wertenbroch, 2002), choice architecture (Johnson et al., 2012), and nudging (Thaler and Sunstein, 2008), etc. but were not explained in detail within the reference. The focus of the reference was on how educating students on cognitive biases can help them overcome that barrier during the design decisionmaking process. |
| 4. How the reference better defines the extent to which consumers (builders at one level, and, ultimately, homebuyers) participate in making decisions or creating barriers |
| The references focus on the influence of designers in making decisions and creating cognitive barriers, however, it is touched upon how multiple stakeholders including the builder and end-user increase many of the cognitive barriers. The cognitive barriers that increase are choice overload and satisficing, however, accounting for multiple stakeholders may reduce bounded rationality. |
| 5. How the reference supports the conclusions with reliable and sufficient experiential data |

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| The reference applies the conclusions to two case studies. One focuses on incorporating stakeholder design requirements and the other focuses on engineering challenges and upstream institutional barriers to innovations. Engineering case studies were used because they utilize real-world scenarios and role-playing activities which prepares engineering students for future decisions in the field. Class modules are used to create a bridge between behavioral science and engineering. |
| 6. How the reference differentiates energy and non-energy aspects of technology or system innovation |
| The reference addressed energy as one aspect of a holistic approach using the envision rating system. |
| 7. Potentially important references not previously cited |
| American Psychological Association. 2010. Psychology as a Core Science, Technology, Engineering, and Mathematics (STEM) Discipline, Washington, DC. http://www.apa.org/pubs/info/reports/stem-report.pdf.<br>Ariely, D., and K. Wertenbroch. 2002. "Procrastination, Deadlines, and Performance: Self-Control by Precommitment." *Psychological Science* 13 (3): 219–224.<br>Beamish, T. D., and N. W. Biggart. 2012. "The Role of Social Heuristics in Project-Centred Production Networks: Insights from the Commercial Construction Industry." *Engineering Project Organization Journal* 2 (1–2), 57–70.<br>Huntzinger, D. N., M. J. Hutchins, J. S. Gierke, and J. W. Sutherland. 2007. "Enabling Sustainable Thinking in Undergraduate Engineering Education. *International Journal of Engineering Education* 23 (2): 218–230.<br>Johnson, E. J., S. B. Shu, B. G. C. Dellaert, C. Fox, D. G. Goldstein, G. Häubl, R. P. Larrick, J. W. Payne, E. Peters, D. Schkade, B. Wansink, and E. U. Weber. 2012. "Beyond Nudges: Tools of a Choice Architecture." *Marketing Letters* 23 (2): 487–504.<br>Van Buiten, M., and A. Hartmann. 2013. "Public-Private Partnerships: Cognitive Biases in the Field." Proc., Engineering Project Organization Conference, Devil's Thumb Ranch, CO. |
| 8. Additional comments or summaries of other important information |
| No additional comments. |

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