U.S. Department of Housing and Urban Development

HUD's Past, Present, and Future Role in Accelerating U.S. Offsite Construction for Housing

A Comparative Study and Action Plan

PD&R

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HUD'S PAST, PRESENT, AND FUTURE ROLE IN ACCELERATING U.S. OFFSITE CONSTRUCTION FOR HOUSING:

A COMPARATIVE STUDY AND ACTION PLAN

PREPARED FOR

U.S. Department of Housing and Urban Development

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FOREWORD

For more than half a century, the U.S. Department of Housing and Urban Development (HUD) has worked to ensure that American families have access to safe, decent, and affordable housing. Today, as the nation faces a persistent housing shortage and rising costs, it is clear that new solutions must be pursued. These solutions must protect taxpayer dollars and foster private-sector leadership while expanding housing opportunity.

This report, *HUD's Past, Present, and Future Role in Accelerating U.S. Offsite Construction for Housing*, provides a thoughtful and thorough examination of how offsite construction can help meet these goals. Drawing lessons from our own nation's history and the experiences of peer countries, the research underscores a truth long recognized by leaders in the housing sector: industrialized building methods have the potential to improve quality and reduce costs if institutional barriers can be addressed effectively and responsibly.

The report highlights that success in offsite construction cannot be achieved by government alone. It suggests that HUD's role should focus on enabling innovation and removing outdated institutional barriers to empower the private market to innovate and grow. The Action Plan outlined in the report offers immediate, intermediate, and long-term strategies—from standardizing federal award criteria to advancing housing system certification and performance-based building codes—that are grounded in careful analysis and pragmatic. The report warns against federal overreach and actions, such as favoring one construction method over another, that could distort the private market.

Reducing the cost of housing is critical to the economic well-being of American families and communities. By applying the lessons of the past, focusing on results, and working in partnership with those closest to the work of building homes, this report highlights how HUD can help create a more resilient, market-driven housing sector that serves the nation well for generations to come.

John Gibbs
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TABLE OF CONTENTS

EXECUTIVE SUMMARY

The U.S. Department of Housing and Urban Development (HUD) has played a central role in the acceleration of offsite construction for housing in the United States. This report examines HUD's past and present role, along with peer organizations in Japan, Sweden, and the United Kingdom, and the motivations, strategies, tactics, partnerships, and effects in these contexts. The research resulted in a conceptual model for planning and implementing effective government-led action. The four relevant country case studies and resulting conceptual model inform the recommendations for a **HUD ACTION PLAN FOR ACCELERATING U.S. OFFSITE CONSTRUCTION FOR HOUSING** (Action Plan).

The researchers combined archival research on primary policy documents with in-country investigative research and knowledge exchange events held in the United States, the United Kingdom (England, Scotland), Japan, and Sweden. International delegations, including U.S. federal, state, and local government representatives, and leading industry participants attended the events. Collaborating with more than 200 domestic and international subject matter expert partners, the researchers conducted a systematic analysis of each country's goals, strategies, tactics, and outcomes relative to addressing their respective housing crises and establishing a self-sufficient offsite construction industry and supporting framework. This content was then further synthesized and instrumentalized through a series of three workshops with representatives from HUD and other federal agencies.

Key research findings from this study include:

- Accelerating offsite construction *can* rapidly increase housing supply.
- Accelerating offsite construction *can* increase housing affordability and accessibility.
- Accelerating offsite construction *can* improve overall housing quality economically.
- Regulatory reform and demand aggregation are *prerequisites* for offsite construction acceleration.
- A high-technology housing sector *and* a national innovation system ensure that an offsite construction industry can function without significant government-led action and ongoing future investment.

As HUD pointed out in 1968, "large-scale application of industrialized building systems … is not limited by technological, design or cost factors, but only by institutional constraints" (Patman, 1968). The findings of this report are not a guarantee of future success because of the complex nature of affecting institutional reform at varying scales from local jurisdictions to national programs. Rather, the findings are the best available foundation, based on case study precedent, on which to base government-led action to accelerate offsite construction.

The following recommended actions are organized across three timescale goals and strategies:

Immediate Timescale Strategy: STANDARD AWARD CRITERIA

- **Goal**: The immediate goal is to increase housing supply rapidly by accelerating offsite construction capacity through **demand aggregation**.
- **Strategy**: The strategy to accomplish the immediate goal is a *whole-of-government* **standard award criteria** for federal programs coordinated with existing and expanded

federal funding that affect offsite construction for housing as a means of demand aggregation.

Intermediate Timescale Strategy: HOUSING SYSTEM CERTIFICATION

- **Goal:** The intermediate goal is to cost-effectively streamline building regulations to expand the overall supply, variety, and performance of housing.
- **Strategy:** The strategy for accomplishing the intermediate goal is to develop and implement a performance-based, federally sanctioned **housing system certification program** for offsite housing construction.

Long-Term Timescale Strategy: PERFORMANCE-BASED BUILDING CODE

- **Goal:** The long-term goal is to create a national innovation system and a high-technology housing sector to sustain housing supply into the future.
- **Strategy:** The strategy to accomplish the long-term goal is to develop and implement a **performance-based building code** as a means for further increasing and maintaining a high-quality housing supply and fostering a functional national innovation system and high-technology housing sector.

The researchers recommend that HUD enact the immediate, intermediate, and long-term timescale strategies concurrently. The recommended actionable strategies, as evidenced in the research, have compounding effects to realize the goals of developing rapid housing supply and affordability. Standard award criteria as a means of demand aggregation should be applied to housing system certification. Likewise, housing system certification is intended to work in concert with a performance-based code as parallel regulatory reform action.

The Offsite Action Plan calls for the intentional and persistent leadership of HUD in developing standard award criteria, housing system certification, and a performance-based code framework to foster a national innovation system and high-technology housing sector. HUD leadership in offsite construction can only be realized with strategic industrialized housing partnerships with federal, state, and local government, nongovernmental entities, industry, academia, and international corollary organizations. These strategic partnerships offer the best possible opportunity for leveraging offsite construction rapidly to increase housing supply, affordability, resilience, and building performance across the United States in the long term.

INTRODUCTION

This report is a **HUD ACTION PLAN FOR ACCELERATING U.S. OFFSITE CONSTRUCTION FOR HOUSING** (Action Plan). The Action Plan recommendations are based on a systematic comparative study of HUD's past and present roles, along with peer organizations in Japan, Sweden, and the United Kingdom in accelerating offsite construction for housing. Through this comparison, the researchers developed a conceptual model for planning and implementing effective government-led action.

The need for an Action Plan was identified through the researchers' ongoing collaborations with offsite construction organizations internationally.[1] The genesis of the research effort started in 2016 with a project for the Modular Building Institute (MBI), culminating with a report titled the ***5 IN 5 MODULAR GROWTH INITIATIVE: RESEARCH, ROADMAP, RECOMMENDATIONS*** (Smith and Rupnik, 2018). The research concluded that the conventional construction industry was challenged with: (1) internal barriers, including the low capacity, competency, and capability (3Cs) of the offsite manufacturing base, and (2) external factors such as the lack of value chain and dearth of regulatory harmonization and standards that limited offsite construction uptake and evolution.

During the project with MBI, a study of international contexts of the United Kingdom, Japan, and Sweden revealed that strategic government-led action had, in fact, eliminated barriers to the growth of offsite construction. Researchers discovered that these more mature offsite construction markets had been influenced by policy proposals and business models that HUD had supported in the 1960s but had not had the opportunity to fully develop.

Building on this work, the researchers from MOD X Advisory LLC (MOD X), together with the National Institute of Building Sciences (NIBS), HUD, and industry representatives, collaborated on a subsequent report titled ***OFFSITE CONSTRUCTION FOR HOUSING: RESEARCH ROADMAP*** (Smith et al., 2022). The roadmap documented key knowledge gaps and research needs to address and overcome the barriers and challenges to accelerating and scaling offsite construction in the United States. The roadmap also supports HUD aligning its offsite construction for housing programs and partnerships. Published in 2023, the seminal report serves as an industrywide roadmap that the offsite construction industry, government, academia, and related nonprofits can follow to progress offsite construction for housing. Utilizing an industry consensus process, the following six topical areas emerged, listed in order of priority:

- Research Topic 1: Regulatory Framework
- Research Topic 2: Standards and System Performance
- Research Topic 3: Capital, Finance, and Insurance
- Research Topic 4: Project Delivery and Contracts
- Research Topic 5: Labor and Workforce Training and Management
- Research Topic 6: Business Models and Economic Performance

The MBI Growth Initiative and the Research Roadmap reports identified the need for government action, with a strong emphasis on regulatory policy reform, to accelerate offsite construction as a rapid housing supply tactic. By extension, the researchers proposed this project

[1] Sequential studies by MOD X and the National Institute of Building Sciences identified the need for government-led action to encourage a harmonized regulatory and standards environment in which innovation, including offsite construction, can thrive.

to assess and identify recommendations for the role of HUD in leading a coalition of government, industry, academic, and nongovernmental partners to accelerate offsite construction for housing.

The research was conducted during a 2-year period (2022–24) and organized into three phases of work utilizing mixed research methods. In Phase 1, the researchers conducted a comprehensive analysis of the intentions, costs, and effects of *Operation Breakthrough*, a HUD offsite housing program from the 1960s and 1970s. The researchers accomplished the analysis by reviewing archival reports and government publications related to the program. Furthermore, the researchers conducted interviews with key participants of more recent offsite construction programs and initiatives in the United States.[2]

In Phase 2, the researchers performed several comparative case studies of offsite construction programs and initiatives in highly developed markets to identify and analyze key public, private, and nongovernmental actions that accelerated offsite housing in each country.[3] They gathered the data through interviews and reports that international offsite construction companies and public entities provided. The researchers facilitated in-country participatory and knowledge exchange events in the United States, the United Kingdom (England, Scotland), Japan, and Sweden, joined by international delegations that included representatives from U.S. federal, state, and local governments, industry, academia, and related nonprofit entities (Yin, 1994). Collaborating with more than 200 domestic and international leading subject matter experts, the researchers conducted a systematic analysis of the goals, strategies, tactics, and outcomes of each country's actions that accelerated offsite housing relative to addressing their respective housing crises and establishing a self-sufficient offsite construction industry and supporting framework.[4]

Phase 3 consisted of a series of action research workshops with HUD and domestic and international partners to peer review the preliminary findings and resulting proposal (Brydon-Miller et al., 2003; Corbin and Strauss, 2014).[5] The research resulted in a conceptual model for accelerating offsite construction evolution in the United States and a related Action Plan with recommendations submitted to HUD leadership that are included in this report.

PART A – ACTION PLAN FOR ACCELERATING U.S. OFFSITE CONSTRUCTION FOR HOUSING outlines the conceptual model for accelerating offsite construction for housing through effective government-led actions. Definitions of the key terms utilized in this report are included in this section. The section also includes an excerpt of the Action Plan recommendations submitted to HUD through an internal report, organized around three actions and related time scales:

- Immediate Timescale Strategy: Standard Award Criteria
- Intermediate Timescale Strategy: Housing System Certification

[2] The researchers utilized archival analyses or literature reviews from the archives of HUD and international corollary organizations and qualitative interviews of key knowledge brokers in the offsite construction domain in the United States.
[3] The researchers generated case studies of offsite construction in international contexts through triangulating archival literature, original reports and presentations by international research partners, in-person interviews, and in-country observations. The purpose of the case studies was explanatory, descriptive, and exploratory because the research was qualitative and required comparative evaluation to develop a conceptual model and recommend actions.
[4] A summary list of the domestic and international knowledge partners and contributions is included in the Appendix.
[5] The researchers employed action research, an ethnographic tactic, when participating with international partners and HUD to identify, promote, and evaluate challenges and potential solutions for action. More specifically, the researchers consciously used a grounded theory method because the aim was to develop a conceptual model and action plan based on international case studies that relied on credible, applicable, and transferable findings.

- Long-Term Timescale Strategy: Performance-Based Building Code

Each section defines the action, presents arguments demonstrating action need, and explains how each action works in practice based on related in-country case studies.

PART B – CASE STUDIES IN EFFECTIVE GOVERNMENT-LED ACTION TO ACCELERATE OFFSITE CONSTRUCTION FOR HOUSING provides overviews of the detailed in-country case studies delivered to HUD during the project duration. The U.S. case study focuses on HUD's most effective offsite construction program, Operation Breakthrough, and the Housing and Urban Development Act of 1968, the Housing and Community Development Act of 1974, the establishment of state industrialized building programs, HUD's Manufactured Housing Program, and the establishment of the National Institute of Building Sciences (NIBS). The Japan case study focuses on the country's housing system certification program developed by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Building Center Japan (BCJ), the Japan Housing Finance Agency (JHF), and the Japan Prefabricated Construction Suppliers and Manufacturers Association. The Sweden case study analyzes the Million Homes Program and the ongoing work of Boverket (the National Board of Housing, Building, and Planning) and the country's pioneering adoption of a performance-based building code. The UK case study focuses on the introduction of the modern methods of construction (MMC) framework and two key organizations, Homes England and Built Environment-Smarter Transformation (BE-ST) in Scotland. The section includes key lessons learned from each country and comparative conclusions regarding successful offsite construction acceleration actions. These lessons, in turn, informed the conceptual model and Action Plan in Part A.

PART A – ACTION PLAN FOR ACCELERATING U.S. OFFSITE CONSTRUCTION FOR HOUSING

A.1 KEY RESEARCH FINDINGS

Part B of this report includes summaries of the research conducted on the U.S. and three international government-led offsite acceleration programs. The summaries informed the development of the following conceptual model, which in turn helped guide the development of the Action Plan recommendations.

1.1 CONCEPTUAL MODEL FOR ACCELERATING OFFSITE CONSTRUCTION FOR HOUSING

The Action Plan report utilizes a conceptual model structured around key terms and concepts. As such, it facilitates the comparison of the four different cultural, social, and political contexts (United States, United Kingdom, Japan, and Sweden) and establishes links between these country case studies and the proposed Action Plan. The first three terms explain the industry-related concepts of industrialized construction (IC), offsite construction, and industrialized housing delivery. The last two terms explain the goal of successful government-led acceleration efforts and the creation of a high-technology housing sector (HTHS) and a national innovation system (NIS) as its framework. Each is succinctly defined with synonymous terms utilized in the United States and the other contexts listed and sourced, followed by a list of common characteristics that expand the concept of the term.

Terms and Concepts

Industrialized Construction: A form of construction that utilizes processes and technologies typical of industrial manufacturing.

Synonymous Terms: Industrialized building,[6] systems building,[7] rationalized building,[8] modern methods of construction,[9] advanced building construction.[10]

Common Characteristics: Industrialization can be applied to onsite and offsite construction. Industrialized construction (IC) can refer to forms of construction that occur entirely on site but utilize technologies and practices more commonly used in manufacturing industries. Alternatively, IC can refer to forms of construction for which significant portions of construction activity occur off site. IC uses manufacturing principles of organized labor, data management, serial production, and economies of scale and scope. Although currently no national housing sector exists in which offsite construction has the majority market share, IC has become the dominant form of housing construction in Japan and Sweden and is on a trajectory to take the majority market share throughout the developed world. Industrialized offsite construction companies are the innovators and early adopters of IC practices, which are then adopted by the early and late majority.

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[6] The term *industrialized building* most closely resembles IC, which HUD widely used in the 1960s and 1970s. It is still often used in overseas contexts.

[7] The term *systems building* refers to building that utilizes some degree of a predetermined system and was widely used in the 1970s. The National Association of Home Builders (NAHB) still references the term.

[8] *Rationalized building*, like systems building, refers first and foremost to the design approach that utilizes rationalized elements, unit plans, and building and neighborhood layouts.

[9] *Modern methods of construction (MMC)* is a relatively new term similar in meaning to IC and widely used in the UK, Ireland, Australia, and New Zealand.

[10] *Advanced building construction* is virtually synonymous with modern methods of construction and IC and is used by the U.S. Department of Energy (DOE).

Offsite Construction: A form of industrialized construction for which a significant portion of onsite construction activities move off site to a controlled environment (i.e., factory).

Synonymous Terms: Prefabrication,[11] factory-built,[12] offsite manufacture,[13] premanufactured,[14] modular[15] (Bertram et al., 2019; Smith, 2019; Smith and Quale, 2017).

Common Characteristics: Offsite construction is often categorized by the scale of the key structural elements transported from the factory to the construction site. These elements include one-dimensional structural elements (usually called a kit of parts), two-dimensional structural elements (often called panelized), and three-dimensional structural elements. Offsite construction can also be distinguished based on the degree of enhancement to a structural element achieved in a factory setting, ranging from a purely structural component to components that also include utilities, insulation, and interior/exterior finishes. Offsite construction can refer to "building under a roof," essentially the shift of conventional building practices from the construction site to a factory, or it can refer to the application of manufacturing practices and technologies to produce building components, which this report refers to as *industrialized offsite construction*.

Capacity, Competency, and Capability (3Cs): Like other manufacturing-intensive production processes, offsite construction can be measured through the 3Cs. *Capacity* is associated with the potential of offsite manufacturers to meet market demands given the available time, quantity, and volume of management resources. *Competency* measures how well an offsite construction company can apply knowledge, skills, and attributes to achieve the performance requirements of an evolving industry and housing sector that demands increasing technical and logistical complexity of product and process delivery. Competence also involves workforce training and development to achieve the performance requirements of the enterprise. *Capability* is the competence and capacity of an offsite manufacturer to achieve and sustain housing delivery (*Capacity* + *Competency* = *Capability*).

Industrialized Housing Delivery (IHD): IHD is a form of integrated project delivery (IPD) optimized for applying industrialized offsite construction to housing delivery. IHD integrates the planning, offsite manufacturing, and onsite assembly of housing into a coordinated set of activities.

Synonymous Terms: Industrialized house-building,[16] prefabricated houses,[17] industrialized housing,[18] turnkey.[19]

Common Characteristics: IHD is distinct from common modes of project delivery that rely on the design-bid-build process. In traditional project delivery, design and engineering professionals design a project with only a general sense of how it will be produced and how much it will cost, usually in the form of a "bid set." Builders bid on that set whether they utilize onsite or offsite

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[11] *Prefabrication* is the most-used term to describe offsite construction for much of the 20th century.
[12] *Factory-built* is the most-used term in U.S. housing policy, but industry or academia no longer use it widely.
[13] *Offsite* manufacture is a nearly synonymous term used in the UK to highlight the fact that offsite construction is inherently different from construction and closer to manufacture.
[14] *Premanufactured* is a nearly synonymous term also used in the UK.
[15] *Modular* is a term that often refers to all IC and offsite construction. The term sometimes refers only to volumetric modular or permanent modular.
[16] *Industrialized house-building* is a commonly used term in Sweden.
[17] The term *prefabricated house* is commonly used in Japan and continental Europe, including Sweden.
[18] *Industrialized housing* is a term that was commonly used in the United States during the 1960s and 1970s.
[19] *Turnkey* is a commonly used term worldwide.

construction techniques. The project set and cost estimates are revised before the project is built. The IPD approach emerged as an alternative to design-bid-build for which all the parties involved in a project communicate from the outset of the planning process to the end of the build. IPD can help make conventional construction more efficient and improve the outcomes of offsite and onsite construction in the form of IHD. Without IHD, offsite construction can often be more costly than conventional construction.

Like offsite construction, IHD requires long-term planning and investment. The IHD approach has generated the best results by fully applying manufacturing industry design and management processes by a **vertically integrated company** offering a turnkey housing product. These design and management processes include the modularization of a given product and the creation of a product platform that can manage the physical and procedural modules of a product to balance standardization and customization in creating value for the end user. The IHD approach can also be **practiced by integrated teams** consisting of design and engineering professionals, offsite manufacturers, onsite builders, and project integrators if early coordination occurs on a project basis and, ideally, the relationship extends across multiple projects.

The IHD approach can also be used by companies that combine offsite production and onsite construction but do not offer a complete turnkey product. In this mode, external design and engineering teams establish a clear set of parameters to prepare a project. This approach allows partner designers to practice **design for manufacturing and assembly (DfMA)** without compromising the cost and schedule of a given project. This approach is common in mid- and highrise multi-unit housing.

IHD is difficult to practice in contexts in which the **regulatory framework** assumes design-bid-build. In most countries where offsite construction is either new or has not gained significant market share, the regulatory framework, project and labor contracts, financing, insurance, professional and workforce training, and existing business models all assume a de facto design-bid-build project delivery model, deeming IPD and especially IHD difficult to implement. Conversely, in those countries where those barriers have been overcome and the sector has grown, IHD, industrialized construction, and offsite construction are viewed as synonymous. By eliminating a bias toward design-bid-build, regulatory frameworks have also supported an increase in IPD among conventional builders.

Just as offsite construction companies more generally act as innovators and early adopters in the broader shift to industrialized construction, IHD companies and teams act as innovators and early adopters for offsite construction. In turn, IHD may never become the dominant form of production or project delivery, but as it gains significant market share (10–20 percent of total housing market share and perhaps more in certain building types), it leads to a greater adoption of IPD among early and late majority adopters.

High-Technology Housing Sector (HTHS): HTHS is a subsector of the construction industry focused on delivering housing using approaches and technologies comparable with other high-technology sectors of the economy.[20]

[20] The term *high-technology housing sector* was used in preparation for the HUD's Operation Breakthrough and denoted the ultimate goal of the program was not only to respond to the immediate housing crisis and to increase the use of offsite construction, but also to encourage the creation of a sector that would adapt the same technologies and processes that had made many other sectors of the U.S. economy so effective, including automotive, aerospace, information technology, and food production. A similar goal was restated in the 1990s.

Common Characteristics: Every context studied in this report with a sustained high market share of IHD-based offsite construction does so within a functional HTHS. HTHS requires a **national innovation system** (defined below) as a framework. HTHSs can respond to new societal goals for housing without sustained government action, either in the form of increased demand aggregation or regulatory reform. These societal goals can include the rapid increase of housing supply for increased access and affordability and can lead to a variety of other goals, ranging from resilience to natural disasters, increased quality and performance, improved occupant health, aging in place, and barrier-free accessibility.

HTHSs more easily accommodate knowledge and personnel transfers from other high-technology sectors of the economy. HTHS directly benefits and is essential to the scaling of IHD-based offsite construction companies. Moreover, this type of sector can improve the outcomes of all housing production and delivery approaches. HTHSs are characterized by a mix of industrialized construction approaches, ranging from fully integrated IHD-based offsite construction to onsite builders who utilize prefabricated structural components and some form of IPD appropriate to their market and broader context. IHD-based offsite construction companies tend to play a key role in pioneering the transition from a more conventional housing sector to HTHS. During this transition, the pioneers, innovators, and early adopters focus on a particular subsector of the housing market, gaining major market share in the process. As the sector and supporting NIS framework develop around these pioneers, aspects of their approach are adopted by early majority and later majority companies.

National Innovation System: NIS is a network of institutions in public and private sectors whose activities and interactions initiate, import, and diffuse new technologies (Carayannis and Campbell, 2009; Freeman, 1987; Rogers, 1962, 2010).[21]

Common Characteristics: Every context studied in preparation for the report that has an HTHS also has NIS that serves as a framework for that sector. NIS frameworks for housing require government-led action and support to become established. They offer returns on that public investment by assisting HTHSs in addressing societal problems related to housing without the need for major government-led regulatory reforms or significant financial investment. NIS frameworks include the *quadruple helix* of innovation actors: government at the national, regional, and local levels, nongovernmental organizations, academia, and industry. NIS frameworks for housing ensure that building regulations balance the need for life safety with an openness to sustained innovation around housing from any of the four innovation actors composing the quadruple helix. NIS frameworks for housing tend to coincide with performance-based approaches to building and building product regulations.

1.2 EFFECTIVE GOVERNMENT ACTION FOR ACCELERATING OFFSITE CONSTRUCTION FOR HOUSING

The analysis of the four contexts included in the report through the conceptual model previously described was also structured around a series of questions developed with HUD during the

[21] *National innovation systems (NIS)* is a concept developed by policy scholars in the 1980s and 1990s. The quadruple helix of innovation is an oft-cited component of NIS.

course of the collaboration. The questions focused on what constitutes effective government action for accelerating offsite construction for housing. The aim of this research is as follows:

How effective are government-led acceleration actions of offsite construction in supporting the rapid increase of housing supply?

Government-led offsite construction acceleration action can rapidly increase housing supply by helping scale the capacity, competency, and capability (3Cs) of the existing offsite construction industry while encouraging new companies to enter the industry and better outcomes from traditional onsite construction.

Can government-led offsite construction acceleration actions rapidly increase housing supply to address a housing affordability crisis on immediate and intermediate bases, and can these actions create a self-sufficient offsite construction housing industry and supporting framework to address future national housing requirements without ongoing government intervention?

Although responding immediately to the current housing crisis is crucial, ensuring that major government-led action plans are implemented and committed to intermediate and long-term actions is equally important. The long-term goal of creating a self-sufficient HTHS and supporting NIS for housing to address future national housing requirements without ongoing government intervention will also reinforce the efficacy of immediate and intermediate actions.

What are the most effective government-led actions for accelerating offsite construction to rapidly increase housing and establish a self-sufficient offsite construction housing industry and supporting framework that can effectively and economically address future societal goals?

A combination of **(1) regulatory reform** and **(2) demand aggregation** has proven effective at accelerating offsite construction. Harmonizing regulations across as large a market area as possible and shifting away from prescriptive toward performance-based specifications has demonstrated to be the most effective strategy. Housing system certification has also proven to be an effective intermediary action. The amount of direct funding and project funding incentivizing the use of offsite construction is less effective than clear societal goals coordinated over maximal programs utilizing the most consistent award criteria possible.

Regulatory Reform Action: The frameworks that regulate the construction and occupation of housing in the United States and overseas evolved alongside the sectors during more than a century. This historical development has led these frameworks to unintentionally prescribe the conventions of onsite construction onto offsite construction. Those regulatory frameworks, in turn, inform other institutional frameworks regarding labor, contracts, financing, and insurance. Like conventional construction, these regulatory frameworks are also highly localized and varied and, as such, present a barrier to offsite construction. The logic of onsite construction regulates offsite construction, which is concurrently expected to outperform conventional construction.

In the context of which offsite construction has accelerated and scaled, direct government action has been essential in implementing and refining effective long-term policy reform. In Sweden and Japan, this process is essentially completed with a regulatory framework that places offsite and onsite construction on equal footing. This regulatory transition is underway in the United Kingdom, Australia, New Zealand, the European Union (EU), and several other countries. In the United States, various regulatory reforms that HUD or other governmental or nongovernmental

entities directly initiated have improved the situation significantly, but additional reforms are required to move the industry forward.

Based on the international case studies included in this report, effective regulatory reform has occurred via two often-related policy initiatives, including the (1) harmonization of building code and land use regulations over a substantial market area, and (2) transition from prescriptive-based to performance-based specifications. The following paragraphs describe both initiatives.

1. **Harmonization of building code and land use regulations over a substantial market area.**

Harmonization of building code and land use regulation over a large market area eliminates arbitrary differences in specification and can improve the efficacy of conventional construction methods, but often severely restrains the acceleration and scaling of offsite construction. Harmonization of building code can occur through the preemption of a national regulation over local regulations (e.g., Japan in 1950, Sweden in 1960, and the United States in 1976 via the HUD Code), or it can occur through the introduction of model regulation incentivized for adoption by local governments (e.g., Eurocode in the EU since 2010 and International Residential Code since 2000 that was developed by the International Code Council).[22] In Sweden and Japan, comparable harmonization of land use codes nationally during the early postwar period has also had a positive effect on offsite construction for housing and on housing supply more broadly.

2. **Transition from prescriptive-based to performance-based specifications.**

In addition to the harmonization of regulation, the shift of building codes from a prescriptive-based to a performance-based form of specification has proven to be highly effective at accelerating offsite construction and improving the outcomes of onsite construction.[23] The full transition from prescriptive- to performance-based building codes takes time to achieve. In all four contexts studied, an intermediary step was first implemented to pave the way for this broader transformation. Most European countries transitioned to a performance-based specification system for building products during the postwar period, directly affecting offsite construction and overall housing supply. The United States was the first country to experiment with a full building-scale housing system certification program that HUD conducted in collaboration with the National Bureau of Standards, renamed the National Institute of Standards and Technology (NIST) in 1988, between 1969 and 1973. Although that program was not continued as planned, it nonetheless directly affected HUD's Manufactured Housing Program and the HUD Code. Japan's government and industry closely followed the development of this program and implemented its version of housing system certification in 1973. That program functions to this day, with one in three housing units utilizing this form of regulatory reform.

***Demand Aggregation Action*:** Comparable with other capital-intensive, manufacturing-based sectors, offsite construction and especially industrialized housing delivery require a steady pipeline to amortize requisite investments. Housing demand highly varies in terms of specifications and oscillates in demand along with macroeconomic variables. Demand

[22] Sweden provides a unique country case study that first transformed its own preemptive national building code from a prescriptive-based to a performance-based code in 1995 before incentivizing it to modify the national code to the supranational Eurocode in 2010.

[23] A more detailed discussion of performance codes is included in the case studies of the U.S., Japan, and Sweden contexts in Part B of the report.

aggregation in offsite construction acceleration can be defined as some form of government support, including incentives, subsidies, and/or project contracts, to create a more consolidated and stable production pipeline for the offsite construction sector.

Demand aggregation for offsite construction can be direct or indirect and typically occurs via three distinct forms, including:

1. Direct demand created by the procurement of offsite construction for government-financed projects.
2. Indirect demand created by government-coordinated procurement of offsite construction by other entities.
3. Indirect demand created by coordinated **award criteria** for government-financed projects and subsidies.

Demand aggregation results in substantial impacts on offsite construction for the housing sector, including:

1. Effective cost amortization to support capital-intensive innovation investments in research and development (R&D), including technology, intellectual property, automation, and critical labor resources.
2. Consistent and predictable product specifications that attenuate mass customization and transitory oscillations in demand that exist in a highly fragmented housing market sensitive to long-term economic variables.
3. Signals that offsite construction is at least as high quality, if not more so, as conventional construction to consumers, end users, and financial and insurance sectors.

- **Interplay Between Regulatory Reform and Demand Aggregation**

In all four contexts studied for the report, the interplay of government-led regulatory reform and demand aggregation proved decisive in the acceleration and scaling of offsite construction for housing. This interplay provides an immediate increase in housing supply and creates a functionally stable and self-sufficient HTHS and NIS to ensure that housing supply and quality are maintained in the long term. **Regulatory reform without demand aggregation** eliminated many of the barriers to the acceleration and scaling of offsite construction, but increased supply often materialized slowly to address the immediate needs of a given context. **Demand aggregation without regulatory reform** did provide an immediate increase in housing supply but would often create an offsite construction industry that was particularly sensitive to fluctuations in demand and highly dependent on government programs and subsidies. Within this context, rapid supply increase also resulted in a lower-quality product leading to a long-term market stigmatization of offsite construction.

- **Long-Term Goals, Intermediate Programs, and Immediate Actions**

In all four contexts studied, a combination of long-term, intermediate, and short-term goals and actions were effective at accelerating offsite construction. The subsequent Action Plan and supporting country case studies all follow the same general guiding principles.

A.2 ACTION PLAN RECOMMENDATIONS

Long-Term Strategy With Immediate and Intermediate Effects

The Action Plan identifies immediate, intermediate, and long-term timescale strategies for realizing the goal of accelerating offsite construction to increase housing supply rapidly, improve the quality and performance of housing, and ultimately create an HTHS and NIS:

- Immediate Timescale Strategy: Standard Award Criteria
- Intermediate Timescale Strategy: Housing System Certification
- Long-Term Timescale Strategy: Performance-Based Building Code

The immediate, intermediate, and long-term timescales indicate the duration a strategy is likely to take to achieve desired goals. The researchers recommend that HUD commence work concurrently on all three timescale strategies, with standard award criteria having the potential for immediate impact, housing system certification requiring more time to develop and take effect, and performance-based regulations for construction requiring the longest period to achieve. The research indicates that these three strategies have compounding effects on actualizing the goals of developing a rapid and affordable housing supply. For instance, standard award criteria will introduce guidelines that will ultimately progress toward a federally sanctioned housing system certification program. Likewise, system certification will gradually introduce a performance-based framework to the housing sector that will ultimately expand to include all forms of construction through performance-based building regulations. Throughout the timescales, federal incentives and subsidies can evolve to create more synergistic effects on the housing sector and the built environment more broadly. Evolving will require the intentional and persistent leadership of HUD and a host of strategic partners to develop, implement, and further refine standard award criteria, housing system certification, and a performance-based code to cultivate an HTHS and NIS to scale and sustain an ongoing affordable housing supply.

2.1 IMMEDIATE TIMESCALE STRATEGY: STANDARD AWARD CRITERIA

Goal: The immediate goal is to increase housing supply rapidly by accelerating offsite construction capacity through **demand aggregation**.

Strategy: The strategy to accomplish the immediate goal is a *whole-of-government* **standard award criteria** for federal programs coordinated with existing and expanded federal funding that affect offsite construction for housing as a means of demand aggregation.

What Are Standard Award Criteria?

The immediate action to address demand aggregation consists of HUD and federal agency partners defining and implementing a standard set of award criteria for all federally funded projects, incentives, and subsidies that affect offsite housing construction. Federal awards include funding for local governments, nongovernmental organizations, industry, and academic applicants to support housing development projects, housing subsidies, regional offsite manufacturing capacity investments, R&D grants, and other incentive programs. Federal award programs can be either directly or indirectly related to offsite construction for housing. Award criteria for housing supply support within and between federal agencies are fragmented and, in some cases, divergent. Therefore, the goal of standard award criteria is to establish the requisite demand aggregation for scaling and accelerating offsite construction by directing existing federal funds without the need for new government programs and investment. The research demonstrates

that this form of consistent market demand and related funding has been more cost-effective and impactful during mid- to long-term durations than simply increasing direct government funding for offsite construction.

Why Are Standard Award Criteria Needed?

Standard award criteria provide a cost-effective and expedient form of demand aggregation to help the offsite construction scale its 3Cs. The lack of consistent demand required to establish and sustain a manufacturing operation has historically been a significant barrier to scaling offsite construction in the United States (Smith et al., 2022). By standardizing award criteria, HUD, in partnership with other federal agencies and partners, can generate the demand aggregation necessary for the acceleration of offsite construction production capacity required to start up and sustain a manufacturing operation that is reliant on consistent volume throughput. This action will garner attention and a response from the offsite construction supply chain industry to effectively align business operations and delivery methods with the criteria that HUD and other federal agencies establish. In the short term, the award criteria will support and encourage early coordination between design and engineering teams, offsite manufacturers, and onsite construction companies. Over time, the award criteria will enable manufacturers, suppliers, builders, and other stakeholders in housing delivery to expand their scope of services upstream to design and engineering and downstream to onsite activities. Furthermore, this action will advance capacity, competency, and capability of the offsite manufacturing industry without necessarily increasing federal spending. In addition, standard award criteria can provide the basis for bolstering confidence in the housing finance and insurance sectors that generally view offsite construction as a novel and risky approach.

The research supporting the Action Plan demonstrates that standard award criteria have been able to deliver immediate results for demand aggregation and galvanizing offsite construction companies and private investment without major new public investment.[24] The research shows that national standard award criteria establishes the precedent and template for creating more targeted local demand aggregation programs that, in turn, increased offsite acceleration, improved quality, performance, and increased housing supply. The researchers recommend that common award criteria be defined and implemented in the form of an immediate action aligned with the intermediate action of a federally sanctioned, performance-based housing system certification program and, ultimately, a long-term, performance-based model building code, both of which are described in the Action Plan.

How Do Standard Award Criteria Work?

The researchers recommend that HUD lead the development of standard award criteria through the review and coordination of all current federal programs that currently affect offsite construction. The research validates that a key success factor for accelerating offsite construction in international contexts via standard award criteria includes an expansive practice of IHD.[25] Therefore, award criteria should encourage and incentivize IHD methods. Standard award criteria can also affect demand aggregation and capacity building for the offsite construction industry without the need for immediate or long-term regulatory reform by informing and

[24] Refer to Part B of the report for additional examples of how federal award criteria affect the acceleration of offsite construction via relevant country case studies.
[25] To fully leverage offsite construction potential to improve U.S. housing, the sector will need to adopt a different form of project delivery-IHD. Refer to Part A, Section 1.0 of the report.

streamlining the existing regulatory framework via the terminology, priorities, and criteria defined in federal project awards, subsidies, and incentives.[26] Based on the research conducted in support of the Action Plan, the researchers recommend that the following guidelines function as the foundation for developing a standard set of federal award criteria:

1. Develop and utilize consistent terminology related to offsite construction for housing. Current federal award criteria reference various terms for offsite construction for housing, including *advanced building construction*, *modern methods of construction*, *factory-built*, *systems building*, *prefabricated construction*, *modular construction*, and *industrialized construction*, among others. The researchers recommend that HUD establish and encourage the use of universal terms for housing production that include ***offsite construction*, *IC*, and *IHD***.[27] *Offsite construction* has likely become the most widely adopted term in the United States. *Industrialized construction* was employed historically by HUD and is accepted internationally (Larsson et al., 2014). The research concludes that the overall sector must adopt some form of IPD to fully realize the potential of a shift to industrialized offsite construction. The term *industrialized housing delivery* accurately denotes this concept and can be embedded in standard award criteria (Lessing et al., 2015).[28]

2. Utilize premanufactured value and percent value of a project manufactured off site to compare different offsite construction approaches. Award criteria require a universally clear metric for assessing different forms of offsite construction. Some criteria utilize different measures of the degree of prefabrication, employing terms that include *kit of parts* for one-dimensional components, *panelized* for two-dimensional components, and *modular*, *volumetric modular*, and *sectional* for three-dimensional components. Others use different levels of enhancement meaning the degree to which the panel or module is finished in the factory prior to transport (Smith et al., 2022). Based on the successful example adopted by the United Kingdom, Ireland, and several other countries, the researchers recommend utilizing a more consistent metric called *premanufactured value*, which calculates the monetary value percentage of a project that will be produced off site versus the general total construction value of a project.[29]

3. Utilize standard terminology, metrics, and project awardees to document the scale and market share of industrialized offsite construction for housing. Through the application of clear terminology and metrics for federally funded housing projects, the government will be in a position to track and monitor accurate market share of the offsite construction industry for housing nationally.[30] The researchers recommend that HUD collaborate with strategic partners to develop and institute a method for compiling, tracking, and reporting offsite construction for

[26] Refer to case studies of how this process has occurred in the United States and other contexts in Part B of the report.
[27] Refer to Part B of the report.
[28] In the United States, the term *industrialized housing* was used to denote IHD. In Sweden, *IHD* is used to denote the same concept. In Japan, *offsite construction* has become synonymous with *IHD,* and government-managed statistics record only IHD projects as a form of *prefabricated housing.* Reference Part A, section 1.1 for a definition of IHD and Part B of this report for more information about IHD in the case study countries.
[29] Refer to Part B of the report for additional premanufactured value information in the UK.
[30] The manufactured housing industry tracks production volumes and market share. The Modular Building Institute (MBI) has tracked volumetric modular construction for more than 10 years, but no comprehensive standardized or comparative method exists for tracking different forms of offsite construction for housing, as is the case in the EU and Japan.

housing production and market share data in the United States on a quarterly and annual basis (Smith and Rupnik, 2018; Smith et al., 2022).[31]

4. Prioritize IHD for project-based federal funding. IHD has proven to be the most secure approach to ensuring the success of offsite construction as a form of scalable housing production. Standard award criteria can prioritize the use of IHD over other forms of project delivery for housing project subsidies and awards. The researchers recommended that applicants practicing IHD be allotted additional points as part of the award review process versus applicants practicing traditional project delivery. The researchers recommend that HUD collaborate with strategic federal partners to develop and apply standard award criteria for federally funded and subsidized housing-related programs based on IHD characteristics across project delivery, manufacturing, and innovation culture categories.

5. Prioritize funding for IHD projects, integrated project teams, and companies that can fulfill multiple societal goals. Federal programs prioritize funding for addressing a variety of societal goals, including resilience to natural disasters, performance criteria, and high-tech manufacturing jobs. Utilizing IHD as standard award criteria for prioritizing projects can provide an economical solution to further accelerate a more equitable and self-sustaining future housing industry. The researchers recommend establishing common offsite terminology and award criteria, as listed previously, in as many federal programs as possible to attain a diverse range of societal goals for housing.[32]

Who Develops and Implements Standard Award Criteria?

Myriad standard award criteria opportunities exist for IHD across HUD offices internally and other federal agencies, programs, and awards. The researchers recommend that HUD initially focus on internally funded programs by developing IHD-related criteria specific to HUD, followed by proactive engagement of other federal agencies that implement housing awards to adopt and apply the standard criteria as a vehicle for aggregating market demand.[33]

The research demonstrates that immediately implementing *whole-of-governm*ent standard award criteria for federal programs affecting offsite construction is an effective and efficient strategy to generate substantive demand aggregation and rapidly increase housing supply.

2.2 INTERMEDIATE TIMESCALE STRATEGY: HOUSING SYSTEM CERTIFICATION

Goal: The intermediate goal is to cost-effectively streamline building regulations to expand the overall supply, variety, and performance of housing.

Strategy: The strategy for accomplishing the intermediate goal is to develop and implement a performance-based, **federally sanctioned housing system certification program for offsite housing construction**.

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[31] The need for data benchmarking to measure and improve the offsite construction sector has been identified in prior studies by the researchers at MBI, including *5 in 5 Modular Growth Initiative* (Strategy A). Refer to Part B of the report on the importance of data benchmarking from the international case studies.

[32] Refer to the case studies of standard award criteria used to address societal goals in Part B of the report.

[33] HUD's key partners during Operation Breakthrough included the U.S. Department of Commerce's National Bureau of Standards, now NIST, and the U.S. Department of Agriculture, Forest Products Laboratory. Both entities will again be crucial for future offsite acceleration actions. The U.S. Department of Transportation also played a vital role in the historic offsite action initiative. Refer to Part B of the report for additional information on related history.

What Is a Housing System Certification Program?

Most of the essential products used in daily life in the United States are regulated at the system or overall product level. Even relatively complex products like automobiles and airplanes are regulated in this manner. A regulatory framework supports the essential means and methods of industrialization, including the design for manufacturing and assembly, modularization of a product into subassemblies, efficient operation of supply chains and manufacturing facilities, and the ability to offer customers true mass customization. Regulation supports the continual improvement of production processes and products, and, in an increasing number of markets globally, regulations are essential for resource accounting and circularity.[34] Unlike other essential products, mass housing is generally treated like other buildings requiring an assessment of how a particular structure satisfies prescriptively regulated specifications in every building iteration. This requirement continues to be the case even if a housing product has been designed, manufactured, and delivered utilizing IHD. Housing system certification allows IHD-based offsite construction to operate more efficiently by creating an appropriate regulatory environment that acknowledges the significant upfront planning involved in industrialization and the continual improvement derived from its serial production and use over time.

Why is a Housing System Certification Program Needed?

The intermediate goal is to improve the offsite sector's ability to produce and deliver housing types cost-effectively while achieving societal goals, such as resilience from natural disasters and other criteria that conventional construction is currently not able to realize at scale economically.[35] These limits are due primarily to an existing regulatory framework that is not optimized to support offsite construction and housing innovation more broadly. The researchers recommend that HUD lead in the development and adoption of a performance-based housing system certification program for all federally funded projects, incentives, and subsidies that affect offsite construction for housing. This action will further increase capacity growth and help the sector cost-effectively deliver housing types that meet performance criteria currently not offered by conventional construction. Over time, the research suggests that the benefits of housing system certification will be acknowledged by private sector financial and insurance industries, thereby creating demand for this form of certification for housing projects outside of federally funded programs.[36]

The potential positive effect of housing system certification on offsite construction and housing supply acceleration is significant. This type of program benefits companies that have already invested in the development of a housing system to scale and realize the return on investment of R&D. The certification program would also encourage existing companies inside and outside of the housing sector, where regulatory frameworks more closely resemble traditional manufacturing industries, to increase the use of offsite construction. A federally supported system certification program would create more housing supply while maintaining affordability and increasing quality in the intermediate term by allowing companies to invest more profits in

[34] One of the clearest examples of synergy exists between the model performance code used by the EU, the Eurocode, and the political entities' resource efficiency accounting programs. Refer to Part B for additional information.
[35] Refer to Part B for additional data related to the effect of performance-based housing system certification and building code on the cost-effective responses to natural disasters used in Japan.
[36] Refer to Part B for the evolution of system certification on reducing the risk profile for the finance and insurance sectors.

R&D to foster the 3Cs and less in project-by-project design and engineering fees and permitting and inspection costs.

The strategy of standard award criteria recommended in the Action Plan will create the essential catalyst for demand aggregation that would be further strengthened through additional subsidies and incentives connected to the award criteria. The research findings supporting the Action Plan indicate that current regulatory barriers will nevertheless blunt the effect of this action without prerequisite regulatory reform. A housing system certification program that builds on and expands the standard award criteria strategy and coordinated federal incentives and subsidies would provide a streamlined process for innovative companies to navigate the current prescriptive regulatory framework without the significant effort required for a shift to a general performance-based regulatory environment. In support of this endeavor, the researchers recommend that HUD collaborate with other federal agencies and nongovernmental entities involved in building regulation to develop a federally sanctioned housing system certification program. This government-led action will provide a rapid and cost-effective form of regulatory streamlining to accelerate offsite construction for housing, further building on immediate standard award criteria and creating a functional foundation for developing a long-term HTHS and NIS.

How Does a Housing System Certification Program Work?

In a typical housing development project, a design team considers the general specifications defined by an existing client. The regulatory framework governing the project provides a multitude of specifications about spatial planning, structural and material performance, and how the building will respond to the site. In most cases, various builders using multiple forms of production, including offsite construction, estimate costs referring to the design and specifications. After preliminary pricing is formulated, the design is typically reformulated based on the specific conditions defined by a particular production process. During various phases throughout the process, regulatory permitting and inspection phases occur that often require additional design and production considerations.

Housing system certification utilizes an entirely different process. Instead of the typical prescriptive building regulations, housing system certification requires the authorizing certification body to define performance criteria broken down into subcategories of criteria (Gallagher, 1979).[37] An entity applying for housing system certification first reviews these categories and performance criteria and develops or amends a housing system to comply with the requisite categories and criteria. The housing system certification can then be utilized to serve several functions, including the following:

- **Housing system certification as an alternative means for code compliance**. When a specific instance of a housing system is configured for a particular use on a specific site, that project is permitted and inspected in reference to that certification and not to the general building code. This method creates cost savings for the housing system developer

[37] For example, in the United States, HUD and NIST developed four essential criteria groupings: (1) detached structures, (2) semi-detached structures, (3) low-rise multistory buildings, and (4) mid-rise multistory buildings. In Japan, the performance criteria groupings are based on two broad factors: (1) number of stories equal to or less than three stories and (2) basic load-bearing structure, including wood, steel, concrete, or volumetric modular (in steel or concrete), resulting in 15 broad categories. In both cases, these broad categories share various performance criteria regarding the structure and final product performance. Refer to Part B of the report for additional information.

in terms of project development, permitting, and inspection, and allows production of more units in each development cycle.

- **Housing system certification as an award criterion for project awards, subsidies, and incentives.** When a specific instance of a housing system is configured for a particular use, future owners can access certain project awards, subsidies, and incentive programs without going through a lengthy and often unpredictable review process. This approach creates market demand for the system developer and generates savings for the owner. System certification can increase the confidence of financial and insurance entities backing housing construction by virtue of quality assurance that results in a reduced risk profile.
- **Housing system certification as a basis for manufacturing certification**. A primary driver of housing system certification for companies investing in offsite construction 3Cs is to establish confidence that the housing product will benefit from a more streamlined permitting and inspection process and potential eligibility for additional incentives and subsidies. Housing system certification serves not only as a product certification but also as the foundation for the certification of a manufacturing process and facility. The certification of a manufacturing process in support of a housing system serves to create more confidence for regulators managing housing standards, and financial and insurance entities backing the housing projects.

These criteria are used to define categories for housing system providers that are comparable with the types of construction used in the current prescriptive building code. Other performance criteria involving production processes and final products include fire safety, air quality, durability of materials, resistance to natural disasters, ease of maintenance and refurbishment, potential for aging in place, universal access, thermal performance, access to natural illumination, construction worker safety, overall spatial quality, and acoustics, especially for multi-unit buildings. The researchers recommend using the IHD standard award criteria defined in the Action Plan to assess the state of readiness for a company to execute housing system certification. Standard award criteria should be used in concert with the housing system certification program because they will inform the evolution of one another. The researchers recommend that HUD start internally with a systems certification program for its projects and awards to pilot the program.

Who Develops and Implements a Housing System Certification Program?

HUD's Operation Breakthrough culminated with a U.S. congressional mandate for HUD and the newly formed National Institute of Building Sciences (NIBS) to partner on creating the Advanced Building Technology Council and the Advanced Building Technology Program. Following a similar pattern, the researchers recommend that HUD establish a new partnership with NIBS to define future performance-based regulatory reform, starting with housing system certification.

The research demonstrates that cultivating targeted strategic partnerships to implement a performance-based, federally sanctioned housing system certification program for offsite construction is a cost-effective strategy for streamlining building regulations to expand the overall supply, variety, and performance of housing.

2.3 LONG-TERM TIMESCALE STRATEGY: PERFORMANCE-BASED BUILDING CODE

Goal: The long-term goal is to create an HTHS and NIS to sustain the housing supply into the future.

Strategy: The strategy to accomplish the long-term goal is to develop and implement a **performance-based building code** as a means for further increasing and maintaining a high-quality housing supply and fostering a functional HTHS and NIS.

What is a Performance-Based Building Code?

According to a National Bureau of Standards report (Gallagher, 1979), performance-based building code sets "forth the function to be performed by a building material, component, or system regardless of the means employed." Most of the building codes in the United States today utilize a prescriptive approach that "specifies how the desired performance is to be delivered," "dictates construction particulars," and "limits the solution to these particulars." Prescriptive codes specify approved materials and assemblies rather than performance characteristics and have been developed to support and unintentionally bias a variety of site-built approaches. Alternatively, performance codes rely on simulation or physical testing to demonstrate compliance with performance specifications. For example, performance-based code pathways exist for fire, seismic activity, and energy in the U.S. building industry, although they are underutilized. In countries where performance codes have been most successfully deployed, the codes have been supported by building product regulations that utilize common performance-based criteria that allow for a direct comparison of different materials across subsectors.[38]

Why is a Performance-Based Building Code Needed?

A performance-based code is impartial to traditional and offsite technologies and thereby fosters competition and innovation. According to the research, performance code has ultimately benefited all forms of housing delivery because it avoids overregulation and nurtures benefit-cost gains in design, engineering, permitting, and inspection processes. It also provides indirect cost savings by supporting widespread R&D and a continual improvement culture essential to process and product improvements. Performance-based codes force examination of the needs of building users and the consequent evaluation of candidate technologies in the context of those needs. Performance specifications expand the focus of building codes from life safety to human comfort. The focus on a variety of performance factors and the introduction of an R&D culture not only reward interdisciplinarity, they also open the housing sector to expertise from other sectors of the economy in which regulatory environments are already performance-based. A growing body of research has evidenced the potential effect of a national shift to a performance-based regulatory environment for some time and is widely supported globally (ICC, 2018; Meacham, 2010, 2022; Meacham et al., 2005; Smith et al., 2022).[39]

[38] The most important example of this criterion is the relationship between the Eurocode, a performance-based model building code that the 27 EU member states utilize, and the Construction Products Regulation; the relationship requires a consistent declaration of performance for construction products. Refer to Part B for additional information.
[39] Refer to Part B for additional information.

How Does a Performance-Based Building Code Work?

The researchers recommend that HUD utilize the immediate strategy of standard award criteria and an intermediate strategy of a housing system certification program as critical steps toward the creation of a functional NIS and related HTHS. Such a context will function without the need for future structural government-led regulatory reform and demand aggregation efforts. The final action required to realize this goal of an innovation ecosystem is developing a model performance-based building code. This government-led regulatory reform action will help create a self-sufficient system in which national, state, and local government, the nongovernmental sector, and industry can respond to future housing challenges efficiently and economically. This type of regulatory reform is not only essential for the full acceleration of offsite construction, it has also proven to be beneficial for improving onsite construction in other countries (Gallagher, 1979).[40]

To support the long-term viability of HUD's Action Plan for Accelerating U.S. Offsite Construction for Housing, the researchers recommend that HUD spearhead a coalition of federal agencies, state and local governments, academia, nonprofit entities, and industry to develop and adopt a model performance-based building code that expands on the intermediate system certification program. The recommendation is to apply the performance code for federally funded projects to access incentives and subsidies to incentivize its adoption for authorities having jurisdiction (AHJ) in state and local governments. This action will ensure a more consistent and stable regulatory framework for the development of an HTHS and construction generally, thereby enabling more attainable macro-societal goals.

To develop a performance-based building code and associated performance-based building product standards and certification process, HUD can turn to various precedents in the United States and overseas, all which share common characteristics and benefits. The evidence research report for the Action Plan provides data on performance-based code frameworks from the HUD Code (1976) and more recent international examples of the Eurocode and European Construction Products Regulation, Japan's Performance-Based Building Code, and ICC's Performance Code for Buildings and Facilities.

Who Develops and Implements a Performance-Based Building Code?

The researchers recommend that HUD establish a myriad of targeted strategic partnerships deemed essential to enable a shift to performance-based code in the United States. The research demonstrates that developing and implementing a performance-based building code to increase and maintain a high-quality housing supply and foster a functional HTHS and NIS is an effective strategy to sustain housing supply at scale into the future.

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[40] The referenced reform efforts would create a regulatory environment for housing production and delivery comparable with that of most essential products and have been advocated for in the United States for nearly a century by NIST's predecessor, the National Bureau of Standards. More than a half a century ago, the U.S. Government and industry viewed a performance-based regulatory environment as inevitable, with Operation Breakthrough serving as a demonstration project for a future framework and housing sector. In 1976, the United States was the first G7 country to adopt a national performance-based building code, the HUD Code. Norway, Sweden, and New Zealand were some of the earliest adopters of national performance-based building codes in the early 1990s, with Japan shifting to this form of regulation in 2000. In 2010, all members of the EU adopted performance-based building codes and building product standards, completing a regulatory reform project that the European Community first defined around the same time the HUD Code was launched. Today, the United States and Canada are the only G7 countries that have not adopted this form of regulatory environment. The overall economic potential and societal benefits of the United States, the EU, and Japan all sharing this regulatory approach would be significant. Refer to the Part B for additional performance code information.

A.3 ACTION PLAN CONCLUSION

The researchers recommend that HUD enact the immediate, intermediate, and long-term timescale strategies concurrently. The recommended actionable strategies, as evidenced in the research, have compounding effects in realizing the goals of developing a rapid housing supply and affordability. Standard award criteria as a means of demand aggregation should be applied to housing system certification. Likewise, housing system certification is intended to work in concert with a performance-based code as parallel regulatory reform action. The Offsite Action Plan calls for the intentional and persistent leadership of HUD in developing standard award criteria, housing system certification, and a performance-based code framework to foster an HTHS and NIS. Fostering HUD leadership in offsite construction can only be realized with strategic industrialized housing partnerships with federal, state, and local government, nongovernmental entities, industry, academia, and international corollary organizations. As cited in the *Offsite Construction for Housing: Research Roadmap* and bolstered by the current research, these strategic partnerships offer the best possible opportunity for leveraging offsite construction to increase housing supply, affordability, resilience, and building performance rapidly and to scale across the United States in the long term.

PART B – CASE STUDIES IN EFFECTIVE GOVERNMENT-LED ACTION TO ACCELERATE OFFSITE CONSTRUCTION FOR HOUSING

B.1 COMPARATIVE OVERVIEW OF EFFECTIVE GOVERNMENT ACTION TO ACCELERATE OFFSITE CONSTRUCTION IN HOUSING: UNITED STATES, SWEDEN, AND JAPAN

To inform **Part A** recommendations related to government-led actions to accelerate offsite construction in the United States, the research team examined previous actions in three contexts where offsite industrialized construction is commonplace and effective, including the United States, Japan, and Sweden, and where offsite is currently being accelerated, the United Kingdom (Patman et al., 1968).[41] **Part B** provides a synopsis of the actions undertaken in each country to **increase housing supply and affordability rapidly via offsite construction**. Each case study is presented using the following logic: reviewing the motivations for government support of offsite construction, followed by a systematic analysis of the key government-led actions and partnerships that supported the acceleration of offsite construction in the specific contexts. The last section of **Part B** compares the country case studies and summarizes key lessons for government action referenced in **Part A**.

B.2 HUD'S PAST AND PRESENT ROLE IN ACCELERATING OFFSITE CONSTRUCTION FOR HOUSING

HUD is the only U.S. Government agency with an offsite construction-specific housing acceleration program, the **Manufactured Housing Program**. The program was established between 1974 and 1976 in response to a mandate by the United States Congress included in the **Housing and Community Development Act of 1974**. HUD is also the only agency to have completed a pilot program to inform offsite construction's future acceleration, **Operation Breakthrough (1969–1973)**. This section analyzes the following key policies and programs:

- Housing and Urban Development Act of 1968
- State Industrialized Building Programs (starting in 1969)
- Operation Breakthrough
- Housing and Community Development Act of 1974
- Manufactured Housing Program
- Advanced Building Technology Program

These policies and programs have affected the U.S. housing sector and framework in addition to those of other countries and informed the recommendations for future actions posited in Part A.

2.1 UNITED STATES CASE STUDY

Motivations for Government-Led Offsite Acceleration Action in the United States (c. 1968)

Factors that supported government-led offsite construction action in the United States between 1968 and 1976 include:

[41] In preparation for the passage of the Housing and Urban Development Act of 1968 and subsequent development of Operation Breakthrough, HUD surveyed every major government-led offsite construction program until the mid-1960s to inform future action. That study not only informed Operation Breakthrough but also constituted one of the first efforts to develop a comparative approach to analyzing effective government action to accelerate offsite construction in housing. The research included in that HUD report informed the Action Plan recommendations in this subject area.

1. **Declining Housing Supply, Stagnant Productivity, Low Quality.** Like other countries during the postwar period, the United States turned to offsite construction to help rapidly accelerate housing supply, stabilize housing costs to end users, and improve the quality and accessibility of housing products. General postwar housing policy around market-rate detached homes had supported the acceleration of housing for much of the 1940s and 1950s but began to stagnate by the 1960s. After a period of growth, productivity in the construction sector became stagnant, with labor, materials, and land costs all gradually escalating. Housing quality, including durability and energy efficiency, was also identified as an area for improvement (Joint Economic Committee, 1969; Kaiser, 1969).[42] The civil rights movement also pointed to the need to support housing affordability in underserved urban neighborhoods.[43] These motivations led to the passage of the Housing and Urban Development Act of 1968 and the related policies that the newly formed HUD (1965) largely enacted.
2. **Need for Regulatory Reform and Support for Innovation.** In 1966, the Johnson Administration commissioned a series of studies to assess the reasons for the growing housing affordability crisis and propose solutions, particularly for government-led action (Kaiser, 1969).[44]

   Two key motivations for action were:

   A. Reform of the regulatory framework that would require a combination of federal, state, and local efforts and subsequently lead to state industrialized building programs.
   B. Support for creating a **high-technology housing industry** requiring strategic government investment to support research and development (R&D), which led to the advent of Operation Breakthrough (Kaiser, 1969: 188–191).[45]

   The two motivations were seen as interrelated, with an optimal long-term outcome being a **national innovation system** for housing comparable with the one supporting and sustaining other American economic sectors.[46]
3. **Belief in American Industrial Innovation.** The housing crisis was seen as a societal problem and a stigma for a country that had helped defeat global fascism. Comparisons with the automotive industry, aerospace, and even agriculture, a relatively low-technology sector that had recently shifted to a **high-technology sector** with the help of government-led action, were all frequently made to housing. In addition, the Soviet Union, the nation's primary international rival, had successfully accelerated its national housing supply by creating a

[42] These two reports provide an excellent overview of housing production and delivery at this time and serve as direct insight into what the federal government, HUD, and HUD's partners were referencing as a basis for acceleration actions.
[43] The Fair Housing Act of 1968, often confused with but distinct from the Housing and Urban Development Act of 1968, prohibited discrimination by direct providers of housing.
[44] The *Decent Home* report was a culmination of a series of studies commissioned by the Johnson Administration between 1965 and 1968, leading to the Housing and Urban Development Act of 1968.
[45] The argument directly influenced the New Technologies Program portion of the 1968 HUD Act that ultimately funded much of Operation Breakthrough.
[46] For a definition of *national innovation system*, refer to Part A, 1.1, Terms and Concepts. A very similar goal was set out in the *Decent Home* report, reflecting a bipartisan belief on the part of the committee in a combination of strategic government-led action to structure a framework for a sector that could then operate independently of direct government-led action in the future.

high-technology housing sector (Joint Economic Committee, 1969: 6–7).[47] Even though the housing produced in the Soviet Union was seen as low quality, the sheer scale of the endeavor compared to that of the United States created an impression that led to action. This motivation resulted in the Nixon Administration appointing George Romney, an automobile manufacturing executive, as Secretary of HUD and head of the industrialized housing program to encourage participation from advanced manufacturing sectors for knowledge and technology transfer to the housing sector.[48]

4. **Success of Offsite Construction and Industrialized Onsite Construction Internationally.** The Soviet Union was only one of many countries creating or accelerating offsite construction to increase housing supply and improve affordability and housing quality. Soon after the formation of HUD in 1965, the department thoroughly researched the Soviet programs, positively affirming similar action in the United States (Patman et al., 1968). Earlier attempts to combine quality and affordability in housing production were unsuccessful. However, improvements in production technology combined with a better understanding of how to apply a *manufacturing mindset* to housing delivery provided the requisite impetus to try again. Most importantly, policy changes necessary to sustain an industrialized transition in housing were poised to deliver demonstrable results to increased supply. On the eve of Operation Breakthrough in 1968, the most rapid acceleration in the world occurred in Sweden and Japan, where political and economic values were seen as more compatible with those of the United States (Joint Economic Committee, 1969).[49]

5. **Success of Offsite Construction and Industrialized Onsite Construction Domestically.** To recognize the potential of offsite construction, Americans looked internally as well. Since the end of the war, the industry has been growing steadily. National Homes Corporation, based in Indiana, was one of the leading companies in the world in terms of scale and sophistication (Joint Economic Committee, 1969; Kaiser, 1969; Testa, 1972).[50] With respect to affordability and accessibility, the most impressive results were being generated by the mobile home industry that had emerged from the recreational vehicle industry. Since defining an industrywide product standard in 1960, the mobile home industry had expanded fivefold and offered the lowest-cost detached housing in the country. Persistent concerns about the quality of this self-regulated product led many local communities to proactively ban this

[47] During the 1960s, the Soviet Union outpaced the United States in arms production, the space race, and housing supply. By 1969, the United States successfully landed on the moon, but in terms of housing supply, as measured by new units per thousand inhabitants, the Soviet Union was producing 10 units versus 7 units in the United States. These statistics were discussed as part of the *Industrialized Housing Hearings*.

[48] During the *Industrialized Housing Hearings,* several congressional committee members expressed an interest in conducting a knowledge exchange with more industrialized sectors of the U.S. economy. A similar sentiment can be detected in the *Decent Home* report. Romney negotiated contracts between the U.S. Government and the American Automobile Manufacturers Association to assist with the effort during World War II. Following the end of the war, Romney served as the CEO of American Motors and was also one of the first outspoken critics of the U.S. automotive industry for producing "gas-guzzling dinosaurs." During the 1960s, Romney served as Governor of Michigan before being appointed Secretary of HUD by President Nixon.

[49] Sweden's offsite efforts were featured prominently as part of the *Industrialized Housing Hearings.* Japan's offsite acceleration efforts were significant enough to warrant a HUD delegation visit on December 1–12, 1970, as part of a cooperative exchange program with the Japanese Ministry of Construction, which was followed by a Japanese delegation to the United States in October 1971.

[50] Essentially lost to history, the National Homes Corporation was one of the largest and most well-known U.S. offsite construction companies of the period. The company was referenced as an exemplary case study in the *Decent Homes* report, and its CEO testified as a leading industry voice during the *Industrialized Housing Hearings* in 1969. The National Homes Corporation was also referenced in Testa (1972) as the most successful example of a conventional home builder adopting a true *manufacturing mindset* and was assumed to be the model for the future of housing delivery in the United States.

form of offsite construction. Furthermore, the financial sector offered only limited financing, which drove up the actual cost of the housing solution (Kaiser, 1969).[51] At the same time, leading onsite production builders, including Levitt and Sons, demonstrated the benefits of onsite industrialization and made their plans for offsite construction known to the government (Joint Economic Committee, 1969).[52]

Case Study: HUD's Operation Breakthrough (1968–74)

Two significant housing policies bookended United States government-led acceleration of the country's existing offsite construction sector: the Housing and Urban Development Act of 1968 and the Housing and Community Development Act of 1974. Several federal agencies, state and local governments, academia, and industry inside and outside the offsite construction industry made significant contributions. However, HUD was the key player in executing the policies of the 1968 and 1974 acts, just 3 years after its founding. The following is a timeline of key events leading up to the development of HUD's Operation Breakthrough:

U.S. Offsite Construction Acceleration | Year 1 (1968)

Setting a Rapid Housing Supply Acceleration Target: 26 Milli on Homes in 10 Years

Informed by a series of reports commissioned by the Johnson Administration, research conducted by HUD, and testimonials from American industry, the United States Congress passed the Housing and Urban Development Act of 1968. As part of the Act, Congress aimed to deliver 26 million new or renovated units, including 6 million subsidized units for low- and moderate-income residents (Public Law, 1968: 601). The goal of the American Housing Act of 1949, to provide a "decent home and suitable living environment" to every American, had not been met (Public Law, 1968: 476). Only by committing to a concrete increased housing supply in a specific period of time could housing affordability be improved for most Americans and housing access created for those for whom housing was no longer being built, especially those in rural areas and dense urban centers.

Creating a High-Technology Housing Sector: The New Technologies Program

Congress introduced several programs to support the creation of 26 million homes in 10 years, with one being the most directly focused on offsite construction: the New Technologies Program (Public Law, 1968: 495–496).[53] Industry testimonials and independent research have all confirmed that the proposed rapid housing supply acceleration would only be possible with some transformation to the regulatory framework and the sector. As the program's title suggested, **bipartisan support** existed for creating a new HTHS, but the form in which regulatory reform needed to support this acceleration was largely unclear (Kaiser, 1969: 189–192).

Congress tasked HUD with three action areas:

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[51] The *Decent Home* report analyzed the mobile home industry as an example of what was possible, in terms of affordability, but also what challenges remained in terms of quality, product safety, financing, and zoning.

[52] Charles Biederman, the Vice President for Technology at Levitt and Sons, and the CEO of National Homes Corporation were key industry representatives at the *Industrialized Housing Hearings* in 1969. Biederman provided first-hand accounts of the structural challenges facing the housing sector, most of which remain to this day. Biederman also provided evidence of the benefits of onsite industrialization of traditional construction but warned that it would not be enough to counter the increasing cost of labor, land, and materials, calling on government action to overcome barriers to offsite construction and increased density.

[53] The full title of the program was *New Technologies in the Development of Housing for Lower-Income Households*.

1. **Encourage Large-Scale Experimentation in the Use of Such Technologies.** Although many innovative housing production and delivery technologies existed, clarifying which had the greatest potential benefit and could be most rapidly accelerated was necessary. HUD was required to experiment at the scale of design, production, assembly, and occupancy to assess which technologies would have the greatest potential effect.
2. **Provide a Basis for Comparison of Such Technologies with Existing Housing Technologies in Providing Such Housing.** HUD would be charged with experimentally deriving the potential benefits of new housing technologies and how they differed from existing production and delivery approaches.
3. **Evaluate the Effect of Local Housing Codes and Zoning Regulations on the Large-Scale Use of New Housing Technologies in the Provision of Such Housing.** The most direct and complex of the three congressional directives required that HUD assess the negative effect of the current regulatory framework on new housing technologies. The request went as far as to outline that HUD "evaluate… [the] effect which local housing codes and zoning regulations have, or would have if applicable, on the cost per dwelling unit" (Operation Breakthrough, 1976; Public Law, 1968: 495).[54]

HUD responded to these three action areas through the Operation Breakthrough pilot projects.

To support these actions, HUD received financial support for the construction of 5,000 units for 5 years to determine two key decisions experimentally:

1. Which systems would be further supported by coordinated demand aggregation?
2. What regulatory reforms would need to be made to further accelerate the adoption and scaling of innovative housing technologies, including offsite construction?

U.S. Offsite Construction Acceleration | Year 2 (1969)

Immediate Regulatory Reform: The Creation of State Industrialized Building Programs

As Congress awaited HUD's research to determine regulatory reform and market demand acceleration efforts at the federal level through the New Technologies Program, the executive branch encouraged regulatory reform for states in the form of industrialized building programs. The Nixon Administration encouraged California Republican Governor Ronald Reagan to introduce the first state industrialized building program in 1969. Washington State Republican Governor Daniel Evans quickly followed suit, reflecting bipartisan support for offsite construction acceleration.[55] By the time the construction of HUD's experimental units started two years later, 20 states had similar industrialized building programs, and 35 states adopted similar measures by 1974.

Statewide industrialized building programs created a degree of regulatory harmonization for the permitting and inspection of offsite construction in the factory and on the construction site. Offsite construction home builders still had to consider hundreds of different local building codes and zoning requirements in addition to interpretation by local building officials. However, the

[54] Congress would refer to the research from Operation Breakthrough in the Housing and Community Development Act of 1974. For reasons that remain unclear, this key action was not discussed as a significant outcome of Operation Breakthrough in the official assessment of the program. The report primarily focused on the first two actions.

[55] A Democratic executive branch and a Democratic-controlled Congress passed the Housing and Urban Development Act of 1968, which a Republican executive branch initially supported and executed with the support of Republican and Democratic state governors.

standardization of the permitting and inspection process was a significant step in the right direction. Today, the manufactured housing sector, volumetric modular, and enhanced closed-panel systems in the United States rely on this regulatory reform of state industrialized housing permit and inspection programs (ICC/MBI, 2021; Smith and Rupnik, 2018).[56]

Modeling a U.S. National Innovation System: Operation Breakthrough

HUD slightly reorganized and rebranded the New Technologies Program as Operation Breakthrough, also known as *BREAKTHROUGH*. The program was structured in three phases, two of which received funding from Congress, and the third reflected the anticipated rapid acceleration of those systems that proved most effective in the first two phases. Operation Breakthrough demonstrated to Congress, states, industry, the public, and international partners how an NIS could affect housing at scale. The three Phases of Operation Breakthrough that developed between 1970 and 1973 were as follows:

U.S. Offsite Construction Acceleration | Year 3 (1970)

Operation Breakthrough Phase I

Phase I of Operation Breakthrough included four major partnerships:

1. **HUD and the National Bureau of Standards (NBS) developed a regulatory framework appropriate for offsite construction.** With the congressional mandate to assess the cost of regulatory barriers, HUD worked with the U.S. Department of Commerce's NBS to develop a regulatory framework more appropriate for an HTHS, namely a *performance-based housing system certification* program.[57] HUD and NBS, renamed the National Institute of Standards and Technology (NIST), also collaborated on *award criteria* for selecting participants in Phase I of the program.
2. **HUD and the offsite construction industry identified housing systems for certification and further development.** Before the housing systems certification program was completed, HUD invited hundreds of American companies, including offsite construction companies (e.g., National Housing Corporation), onsite builders (e.g., Levitt and Sons), and innovative companies from other parts of the economy with an interest in housing (e.g., Boeing and General Electric), to submit proposals for housing systems, with 25 companies ultimately selected to participate in the program.
3. **HUD, states, and local governments identified sites for experimentation.** HUD also solicited proposals from various states and local governments for sites where the systems could be further tested in terms of construction, delivery, and occupancy. Nine sites in eight states were ultimately selected. In all cases, the state would have to agree to allow HUD to preempt local building and zoning codes to test the new regulatory framework. In practice,

[56] Despite the creation of state industrialized housing programs in the 1970s, regulatory challenges continued to be a barrier to scaling offsite construction. Following the publication of the *5 in 5 Modular Growth Initiative*, which identified regulations as a perennial barrier to scaling offsite construction and recommended standards development, the International Code Council and the Modular Building Institute created new standards (1200 and 1205) for the process of permitting and inspection of offsite construction. Since that time, Utah, a state without a statewide industrialized building program, and Virginia, a state with one of the most developed statewide industrialized building programs, have both adopted the standards as a means of attempting to overcome the challenge of regional discrepancies in regulatory processes for offsite construction permitting and inspection.
[57] Refer to Part A of the report for a definition of system certification.

the degree of preemption varied significantly and directly affected the speed and effectiveness of the program.

4. **HUD and real estate developers, general contractors, and architects developed neighborhood plans, worked with the housing systems, and helped execute onsite work.** Ultimately, the experiments were projects that required developer support, master planning, and configuration of housing systems by planners, architects, and engineers. The projects required coordination with general contractors that would complete the onsite work. Lack of stakeholder experience and differing levels of knowledge concerning industrialization by project likewise directly affected the planning timelines of the program.

The combination of a clear overall strategy set in the Housing and Urban Development Act of 1968 and the straightforward tactics that Congress defined through the New Technologies program and adapted by HUD into Operation Breakthrough made these partnerships highly effective. Despite many challenges during execution, the research supports that similar entities and partnerships will be critical to future government-led acceleration efforts.

U.S. Offsite Construction Acceleration | Years 4–6 (1971–73)

Operation Breakthrough Phase II

Phase II of Operation Breakthrough included the manufacturing, onsite construction occupation, and post-occupancy assessment of the 25 systems on 9 sites, resulting in nearly 4,000 units. During Phase II, the regulatory framework developed by HUD and NBS was also continually improved in response to the different phases of experimental work (Gallagher, 1979; GAO, 1976).[58]

Although delayed by various factors, Operation Breakthrough proved successful in the two key areas HUD was tasked with, including:

1. HUD identified which housing systems had the most potential for further demand aggregation efforts in Phase III.
2. HUD also identified a cost-effective regulatory reform compatible with state industrialized building programs through the NBS housing system certification program.

Rapidly Decelerating Housing Supply: A Moratorium on Federal Subsidies for Housing

The Nixon Administration placed a moratorium on all federal housing subsidies in early 1973, decelerating the rapid housing supply drive and making Phase III nearly impossible to achieve at scale (Freemark, 2015).

The Energy Crisis and Economic Recession (1973–75)

Although the withdrawal of federal housing subsidies decelerated the housing supply rate, the largest and most established participants in Operation Breakthrough (e.g., National Homes Corporation) relied on existing demand for market-rate housing. This pipeline also rapidly disappeared because of the first global energy crisis and a 2-year economic recession. The New Technologies Program provided much of the funding to build the nearly 4,000 housing units. It

[58] NBS documented its significant role in Operation Breakthrough in the Gallagher (1979) report. NBS and HUD also published a multivolume set of reports documenting the process, the *Guide and Format for the Preparation of Housing System Testing and Analysis.* More than the units delivered, the research constitutes the most significant outcome of Operation Breakthrough and should serve as the basis of future work on this subject.

also supported the work of HUD and NBS in developing the housing system certification program. Regardless, the 25 companies made significant investments in capacity, competency, and capability that could only be amortized through some degree of pipeline security, which ideally would come in the form of subsidized and market-rate housing. With both forms of housing depleted, most companies went bankrupt by the end of the decade (*Chicago Tribune*, 1987).[59] In Japan and Sweden, a similarly severe crisis proved less devastating for countries accelerating their offsite construction sectors because of small but significant differences in strategies and tactics, presented in sections Part B, 3.1 and 3.2.

Case Study: Manufacturing Housing Program Foundation (1974–76)

By 1974, HUD had completed the two core tasks that Congress set forth in the New Technologies Program: (1) identification of viable housing systems and (2) a regulatory framework needed to accelerate offsite construction. The rapid housing supply drive was effectively abandoned by 1974 at the federal level. Although Americans still lacked access to affordable housing, the cost of energy and a general economic recession exacerbated the situation. During this crisis, Congress passed the Housing and Community Development Act of 1974 and included two major pieces of legislation informed by Operation Breakthrough that have impacted U.S. offsite construction to the present day.

HUD Manufactured Housing Program (1974–76)

Since 1960, mobile homes have filled a unique niche for low-cost detached housing, particularly in rural areas where construction labor is scarce. By 1973, the mobile home industry had reached an all-time production peak of more than 5 million units, or 1 in 4 housing units (U.S. Census Bureau, 1973).[60] Despite the product's low cost, by 1974, the recession, combined with extremely high fuel prices, made this form of housing unaffordable for many Americans. For the first time since 1960, unit sales of manufactured homes dropped by nearly 50 percent. As a result, several congressional representatives of states where the mobile home industry represented the dominant form of housing delivery and an essential part of the regional economy, lobbied Congress for action. HUD had not intentionally focused on mobile homes as part of Operation Breakthrough, but the program's success would influence the future of the mobile home industry.

Congress stated that *manufactured housing*, a term explicitly used previously for nonmobile home offsite construction as part of Operation Breakthrough, "plays a vital role in meeting the

[59] Many of the participants were relatively small in scale. The disappearance of the most prominent players, National Homes Corporation and Levitt and Sons, which were both active housing suppliers, broadly resulted in significant negative effect on the housing sector. Charles Biederman established Levitt and Sons in 1970 in direct response to Operation Breakthrough, and the company essentially ceased operations along with the program. National Homes Corporation, founded in 1945, hit peak production during the first year of Operation Breakthrough (1969) and made significant expansions in capacity, competency, and capability during the program. In 1973, after 4 years of development of volumetric modular construction, it closed that business, refocusing on its core system of closed-panel construction. Nevertheless, the severe economic downturn during the period led the company to lay off one-third of its employees by 1975, many of whom had unique experiences unmatched in the U.S. housing sector. Between 1976 and 1978, the company scaled back to focus almost exclusively on mobile home production, but it also proved inadequate, and the company ceased operations in 1979, ironically, the same year that should have been the peak of the Housing and Urban Development Act's target supply goal. The company attempted to restructure during the 1980s but was unsuccessful.

[60] According to U.S. Census Bureau data, 579,900 mobile homes were delivered in 1973. Manufactured housing is the best-tracked housing product in the United States because of the HUD Manufactured Housing Program. Prior to the Manufactured Housing Program, the mobile home industry, through the predecessor of the Manufactured Housing Institute, utilized an industrywide standard (starting in 1960) that resulted in measurable and consistent industry data.

housing needs of the Nation" and "provide[s] a significant resource for affordable homeownership and rental housing accessible to all Americans." (Public Law, 1974: 63) Congress also acknowledged the internal quality issues of the product, calling on the *protection* of the "quality, durability, safety," and the "affordability" of the product. At the same time, Congress acknowledged the successful demonstration work of HUD and NBS and required the establishment "of practical, uniform, and, to the extent possible, performance-based Federal construction standards for manufactured homes." Furthermore, it called on actions to "encourage innovative and cost-effective construction techniques for manufactured homes" without providing specific examples of how it would be accomplished (Public Law, 1974).

HUD was charged with replacing the industry-developed product standard with a ''federal manufactured home construction and safety standard.'' In a unique shift in regulatory policy, **Congress utilized the interstate Commerce Clause to create the first preemptive U.S. national building code and the first performance-based national code in the world** (Public Law, 1974). Congress stated the following:

> Whenever a Federal manufactured home construction and safety standard established under this title is in effect, no State or political subdivision of a State shall have any authority either to establish, or to continue in effect, with respect to any manufactured home covered, any standard regarding construction or safety applicable to the same aspect of performance of such manufactured home which is not identical to the Federal manufactured home construction and safety standard (Public Law, 1974: 73). [61]

The new federal standard was published in 1974, and the preemptive performance-based HUD Code was introduced in 1976 as the manufactured housing industry began producing more housing units. In 1998, the higher quality manufactured housing achieved a comparable market share with that of mobile homes in 1973, with one in four units delivered that year (U.S. Census Bureau, 1973, 1998).[62] Since then, the manufactured housing industry has lost market share, partially because of a lack of access to the key federal housing subsidy, securitized mortgages, and associated tax breaks and partially because of shrinking access to land zoned for this type of construction. Nevertheless, more than 9 million housing units have been produced and delivered with this method since 1976, providing housing that would likely only be available with government-led acceleration.

National Institute of Building Sciences (NIBS), HUD, and the Proposed Advanced Building Technology Program

HUD's efforts with Operation Breakthrough had the most direct and tangible effect on U.S. housing supply, affordability, and accessibility through the Manufactured Housing Program. However, the goal set forth by the New Technologies Program was more directly fulfilled through another piece of housing policy introduced in 1974, namely the establishment of the National Institute of Building Sciences (NIBS). Developed concurrently with the 1968 Act and published immediately following its passage, the final report outlining the problems of and solutions to the American housing supply indicated the need for NIBS—a "national institution" that would address the current misalignment between "new technology and building codes"

[61] Congress has the power "to regulate Commerce with foreign Nations, and among the several States, and with the Indian Tribes," according to the U.S. Constitution (Article I, Section 8, Clause 3).
[62] In 1998, 373,000 manufactured homes were delivered, representing the largest production since the start of the manufactured housing program and comparable in market share with the peak of mobile home production in 1973.

(Joint Economic Committee, 1969; Kaiser, 1969: 28–31).[63] As such, NIBS and HUD's congressionally mandated roles in accelerating offsite construction provide a foundation for future federal actions included in Part A of the Action Plan report.

The 1968 bipartisan *Decent Home* report stated the "lack of uniformity in local building codes and standards … has seriously inhibited technological change and marketing in the housing industry (Kaiser, 1969: 28)." However, the authors could not agree on the viability or desirability of the "adoption of uniform National codes" despite concluding that the "the Federal Government appears to have the power to promulgate a uniform National building code under the Commerce Clause of the United States Constitution" (Kaiser, 1969: 28). Instead, the report supported the creation of a new entity that could permanently fulfill the role that NBS fulfilled during the New Technologies Program and accomplish two primary tasks, including:

1. Supporting the federal government in "providing technical assistance" for "code reexaminations and revisions" at the local level.
2. Supporting HUD in preempting "the application of state and local building and mechanical codes to any specific federally subsidized projects" (Kaiser, 1969: 28–29).

Because this national institution did not exist during Operation Breakthrough, HUD had to negotiate the use of new technologies, certified through an innovative regulatory framework, on a case-by-case basis. The additional time and monetary costs limited the increase in housing supply and the acceleration of the offsite sector in becoming the HTHS that the country urgently required.

Additional support for establishing an entity of this kind emanated from the housing industry during a series of testimonials to Congress in 1969 (Joint Economic Committee, 1969).[64] By 1974, Congress deemed Operation Breakthrough a success in terms of demonstrating the value of the establishment of a national innovation system (NIS) with NIBS at its center, stating:

> …the lack of an authoritative national source to make findings and to advise both the public and private sectors of the economy with respect to the use of building science and technology in achieving nationally acceptable standards and other technical provision for use in Federal, State, and local housing and building regulations is an obstacle to efforts by and imposes severe burdens upon all those who procure, design, construct, use, operate, maintain, and retire physical facilities, and frequently results in the failure to take full advantage of new and useful developments in technology which could improve our living environment (Public Law, 1974: 97).

Somewhat in contradiction to the proposed Manufactured Housing Program and echoing earlier reluctance regarding a uniform national code, Congress also stated the following:

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[63] Such an entity was called for by Charles Biederman during the *Industrialized Housing Hearings* in 1969 and in the *Decent Home* report. The latter report concluded that the "United States of America Standards Institute, the American Society for Testing and Materials and the National Bureau of Standards of the Department of Commerce" did not have "sufficient [congressional] authority to perform this role."

[64] Charles Biederman referenced the name "National Institute of Building Sciences" as part of his testimony to Congress in 1969. Biederman had previously worked in France, where a similar certification program for nationally funded housing had been in place for some time. Biederman noted that most of the countries where offsite construction was delivering results, including Sweden, had similar certification systems. Biederman also advocated for a second entity, the National Institute of Environmental Sciences, to standardize regulations and do for zoning what NIBS would do for building code.

> [T]he establishment of model buildings codes or of a single national building code will not completely resolve the problem because of the difficulty at all levels of government in updating their housing and building regulations to reflect new developments in technology, as well as the irregularities and inconsistencies which arise in applying such requirements to particular localities or special local conditions (Public Law, 1974: 97).

Operation Breakthrough successfully confirmed the 1968 hypothesis that the regulatory framework was a key barrier to increased housing supply because the "lack of uniform housing and building regulatory provisions increases the costs of construction and thereby reduces the amount of housing and other community facilities which can be provided." It had also demonstrated that "a single authoritative nationally recognized institution" could provide "the evaluation of new technology that could facilitate the introduction of such innovations and their acceptance at the Federal, State, and local levels" despite a general regulatory framework that blocked innovation and supply (Public Law, 1974: 97).

Based on these findings, in 1974 Congress granted NIBS "functions and responsibilities in four general areas, relating to building regulations," as follows (Public Law: 1974: 98):

1. Development, promulgation, and maintenance of nationally recognized performance criteria, standards, and other technical provisions for maintenance of life, safety, health, and public welfare suitable for adoption by building regulations jurisdictions and agencies, including test methods and other evaluative techniques relating to building systems, subsystems, components, products, and materials with due regard for consumer problems. In other words, Congress expected NIBS to continue the efforts started by HUD and NIST to develop performance criteria for advanced building technology, including offsite construction, and to assist states in adopting those criteria for use in their local contexts.
2. Evaluation and prequalification of existing and new building technology in accordance with the previous function and responsibility. Congress essentially outlines a role for NIBS that is similar to that of Building Center Japan (BCJ) in regard to system certification. Section B3.1 presents this role further, and it is included in the Action Plan.
3. Conduct of needed investigations in direct support of 1 and 2. Although NIBS was mandated as the key coordinator of these activities, Congress encouraged partnerships with other federal agencies, national laboratories, academia, and industry.
4. Assembly, storage, and dissemination of technical data and other information directly related to 1, 2, and 3.

Considering the intent that NIBS permanently replace the role temporarily played by NBS in collaboration with HUD, Congress also mandated the creation of an **Advanced Building Technology Council** to carry out an **Advanced Building Technology Program**, a continuation of the New Technologies Program, in partnership with HUD. The council and program were necessary actions to fulfill many of the functions and responsibilities defined previously.

This program proposed to carry out the following six activities:

1. Identifying, selecting, and evaluating existing and new building technologies, including cost-savings technologies of energy that conform to recognized performance criteria and meet applicable test standards for maintaining life, safety, health, and public welfare when used in occupied buildings.

2. Developing criteria for the use of such technology.
3. Conducting economic analyses of proposed new technologies when produced and installed in buildings at volumes associated with comparable conventional technologies.
4. In cooperation with the appropriate federal agencies, advising building designers, installers, subcontractors, contractors, and supervisory officials on the appropriate design and use of new building technology incorporated in federally owned or operated buildings.
5. In cooperation with the appropriate federal agencies, monitoring and evaluating the performance of new building technologies for at least 1 year after installation and building occupancy.
6. Disseminating resulting data to affected parties through automated information management systems.

The Advanced Building Technology Council and the Advanced Building Technology Program were the direct outgrowth of the successful demonstration work of Operation Breakthrough. This success placed HUD and NIBS at the center of a future NIS intended to help direct regulatory reform, focus demand aggregation, and foster the creation of an HTHS to meet and exceed the needs of the nation. Similar to HUD's role during Operation Breakthrough, these agencies were not meant to do this work alone, but rather to coordinate a coalition of other federal agencies, state and local governments with authorities having jurisdiction (AHJs), industry partners, academia, and nongovernmental organizations. Although neither the council nor the program was ever formed because of the Nixon Administration's moratorium on federal housing subsidies, NIBS and HUD still technically possess congressional authority to directly assume these activities.

In summary, Congress granted HUD and NIBS the authority and responsibility for developing, disseminating, facilitating, and maintaining a building systems standards and certification program based on performance criteria. The standards and program were to be adopted by local or state AHJs to promote innovations that balance quality and protection of occupant health, safety, and welfare with rapidly increasing supply and, by extension, affordability to meet societal needs. This authority remains to this day but is not being currently exercised. The need for a national institution is more acute than ever to streamline regulations to achieve the rapid supply of affordable housing through offsite construction.

Today, the United States has two building code frameworks. The first is the manufactured home code of 1976, a performance-based preemptive code that HUD regulates. The second includes all other forms of construction nationwide that are regulated at the local jurisdictional or state level. These regional AHJs often adopt model codes that the International Code Council (ICC) developed, including the International Residential Code (IRC) and the International Building Code (IBC). The model codes are developed using the American National Standards Institute consensus process of public and private stakeholders. AHJs adopt, interpret, enforce, and augment these national prescriptive codes within their jurisdictions.

Offsite construction needs to be clearly defined and referenced in model codes. Although states with industrialized building programs operate to manage the permitting and inspection of housing projects using offsite construction, each state and locality has a different interpretation of the model code in relation to industrialized building. For example, third-party evaluation is acceptable in some jurisdictions and not in others, and prescriptive material is required in some

cities and not in others. The fragmented and disparate condition of how AHJs interpret the model code and subsequently how offsite construction is viewed, reviewed, and managed makes scaling a manufacturing-oriented construction and fostering an HTHS challenging, if not implausible.

The following section reports on the systematic analysis of HUD's role in government-led efforts for offsite construction, including Operation Breakthrough and the subsequent Advanced Building Technologies Program. These programs were strategic actions that HUD undertook in the 1960s and 1970s to accelerate housing supply via offsite construction. The lessons learned from this period in the United States guided HUD's future actions in offsite construction acceleration, presented in Part A of the report. The next section will illustrate how an approach to an NIS that fosters aggregated demand and regulatory innovation has been successfully implemented internationally. In Japan, this approach was directly based on the Operation Breakthrough and NIBS model. A similar approach has also been applied in Sweden, and some of the most successful and economical efforts are currently underway in the United Kingdom.

B.3 COMPARATIVE ANALYSIS OF PEER GOVERNMENT AGENCY ROLES IN OFFSITE CONSTRUCTION ACCELERATION IN JAPAN, SWEDEN, AND THE UNITED KINGDOM

HUD's successful offsite acceleration efforts in the 1960s and 1970s were deeply rooted in knowledge of and partnership with peer government agencies overseas. In preparation for the passage of the 1968 Housing and Urban Development Act, HUD researched every significant international program conducted between 1945 and 1965 (Patman, 1968). During Operation Breakthrough, HUD closely followed the developments of Europe's most rapidly accelerating housing supply program, Sweden's Million Homes Program, and reported Sweden's efforts to Congress in 1969. HUD also developed a strong relationship with Japanese governmental organizations, including the Ministry of Construction (renamed the Ministry of Land, Infrastructure, Transport and Tourism or MLIT), the Ministry of International Trade and Industry (MITI), and the Government Housing Loan Corporation (renamed the Japan Housing Finance Agency or JHF) (HUD, 1972: 16–18).[65] Japan carried out an offsite construction acceleration program concurrently with Operation Breakthrough partially based on this dialogue. The UK is a particularly relevant case study because England is currently accelerating offsite construction through the support of a recently formed agency, Homes England. At the same time, Scotland has sustainably evolved its national innovation system for decades.

Each of the three subsections that follow describe the most significant government-led offsite construction acceleration actions from peer government agencies. These case studies directly informed the recommendations for action and partnerships delivered to HUD as part of the Action Plan in Part A of the report.

3.1 JAPAN CASE STUDY

Japan's housing stock and industrial base were severely damaged in World War II compared with the United States and Sweden. Economic growth and population increase marked the postwar period in Japan, placing additional pressure on housing access every year after the war that continued through the mid-1990s. Japan urgently needed a plan to rapidly accelerate housing

[65] HUD and the Japanese Ministry of Construction hosted corresponding delegations in 1970 and 1971.

supply and increase the quality and resilience of housing by making it more resistant to frequent natural disasters. All these factors ushered in new housing types, unique regulations, and effective incentives for increasing supply and quality through industrialization and the increased use of offsite construction.[66] Japan's current industrialized offsite construction industry and framework grew out of a series of policies and programs developed in tandem with the foundation of HUD and the completion of Operation Breakthrough during the 1960s and 1970s. These agencies, together with several leading companies, prepared a detailed analysis of the program specifically for this report (BCJ, 2023; JHF, 2023; JPCSMA, 2022; MLIT, 2023; Sekisui, 2023).[67]

Motivations For Government-Led Offsite Acceleration Action in Japan (c. 1962)

To address declining post-war housing conditions, the Japanese government established three new agencies during the 1950s, with each affecting the establishment and acceleration of offsite construction in the country.

1. **Government Housing Loan Corporation (GHLC)—Increasing housing supply, affordability, and resilience.** In 1950, the Ministries of Commerce and Construction established the first agency, GHLC, renamed JHF. GHLC was formed to promote increased housing supply by the private market through public financing of long-term fixed-rate loans. It was closely modeled on FHA and Ginnie Mae, both HUD programs. Similar to the United States, detached housing dominated the private housing market in Japan and much of the funding was directed to support the sector. Starting around 1960, GHLC expanded the focus from simply increasing housing supply to improving housing quality, with specific focus on resilience to natural disasters, including earthquakes, tsunamis, and fire. In 1962, GHLC developed award criteria for securitized mortgages supporting offsite construction to achieve this goal economically. In 1973, that program evolved into a complete housing system certification program, the key government-led regulatory reform and demand aggregation action that helped accelerate offsite construction in Japan. This certification program created a stable national innovation system that exists today.
2. **Public Rental Housing Agency—Increasing affordable housing for low-income residents.** Following the establishment of GHLC, Japan founded the Public Rental Housing Agency in 1951. This second agency was focused on delivering publicly owned and managed rental housing for low-income residents. The program helped create aggregated market demand for precast concrete construction used in multistory housing.[68] The program peaked in the 1960s, resulting in the acceleration of this form of offsite construction, when as much as 40 percent of housing was publicly financed. Starting in the 1970s, public housing funding declined along with the market share of precast concrete.
3. **Japan Housing Corporation—Increasing housing affordability for moderate-income residents.** The third agency, the Japan Housing Corporation, renamed the Urban Renaissance

[66] Japan needed an estimated 4 million housing units following World War II. A series of interviews conducted with Professor Shuichi Matsumura at the University of Tokyo (2015, 2019, 2023) informed research conclusions related to the period.
[67] BCJ was a key project partner for this research. Formerly a government agency that has since transitioned to a nonprofit entity, the BCJ Technical Appraisal Department prepared an original report and commissioned JHF and the Japan Prefabricated Construction Suppliers and Manufacturers Association to prepare a report. These reports were further corroborated by original documents prepared by two of the largest industrialized offsite construction companies in Japan, Sekisui House and Sekisui Heim, each of which provided valuable perspective on the industry and framework.
[68] Refer to Part A for additional information related to demand aggregation.

Agency, was established in 1955. It was focused on supporting the construction of multistory cohousing for moderate-income residents living in high-cost urban areas and providing large-scale residential land for development in rural and some urban areas. This program indirectly affected precast construction and the various forms of detached, semi-detached, and low-rise multistory "prefabricated houses" of wood, steel, and concrete.

Japan's offsite construction sector was initially tied to the reconstruction, rapid economic expansion, and population growth of the late postwar period. Since 1992, Japan has struggled with population stagnation/decline and economic recession, placing additional strain on the housing sector, especially the capital-intensive consolidated offsite construction industry. This condition has evolved the focus of housing and offsite construction in Japan to meet additional societal goals beyond affordability and resilience. Japanese housing is now expected to be more accessible for seniors and persons with disabilities, more energy efficient and even energy neutral, and easy to retrofit or recycle, to name a few new targets. Instead of needing to create new government-led acceleration programs, Japan has adapted the more than half-century-old system certification program for offsite construction, first developed by GHLC, and the national innovation system that has grown up around it to address these new goals, as evidenced by the following case studies.

Case Study: Japan's Housing System Certification Program (1962–Present)

In 1962, the Japanese Ministry of Construction, renamed the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in 2001 through the merger of several existing ministries, and the Ministry of International Trade and Industry (MITI) defined a target objective for accelerating the small Japanese offsite construction industry from < 1- to 15-percent market share of the construction sector in a decade. Consensus existed that only industrialization, including a shift of production off site to a factory, could increase housing supply and improve housing quality at scale economically. Despite the existence and continued growth of precast concrete structural systems, most of the acceleration efforts focused on the larger, primarily market-rate, detached housing sector that eventually expanded to include low-rise multistory. Preference was given to turnkey companies that combined design, engineering, manufacturing, onsite assembly, and customer sales in a single entity.

The three initial goals of the program were defined as follows:

1. Accelerating the growth of offsite construction, particularly the "prefabricated house" sector, through demand aggregation.
2. Encouraging the improvement of the quality of the "prefabricated house" sector through the support of a system-based approach to the full spectrum of housing production and delivery activities.
3. Streamlining the permitting and inspection process using system certification.

This early product definition still informs what is considered a *prefabricated house* in Japan today, despite the scale of building type or even the degree of prefabrication in the factory, as long as one entity is responsible for the full process. This process is distinctly different from other forms of offsite construction, in which a manufacturer supplies only structural components, such as precut timber, precast or mass timber, enhanced panels, or volumetric modules in wood

or steel, but does not provide design or onsite assembly integrated services.[69] Therefore, the term *prefabricated house* denotes a vertically integrated product and service that provides complete turnkey services and products for housing development utilizing industrialized manufacturing and customer-centric principles.[70]

Japan's Offsite Construction Acceleration | Year 1 (1962)

Market Share Targets and GHLC Prefabricated House Certification. The three ministries published their 15-percent market share target for Japanese prefabricated houses. In this report, GHLC was the key agency for initial acceleration efforts, forming a committee of experts from academia and industry to review project candidates for the program.

The three following actions enabled acceleration:

1. Developing a simple certification program for awarding financing for prefabricated house designs constructed of light-gauge steel, a newly introduced noncombustible structural material with an ample supply chain developed through Japan's automotive industry.[71]
2. Expanding securitized mortgages to homeowners of light-gauge steel prefabricated houses.
3. Streamlining local permitting and inspection by circulating and explaining certified designs to local building inspection departments that were still under the authority of the Ministry of Construction, to help them become more familiar with offsite construction (i.e., education).

These initial efforts proved effective, with pioneering companies like Daiwa House (1955) and Sekisui House (1960) benefiting from demand aggregation and regulatory reform even before a fully-fledged housing system certification system was enacted in 1973.

Japan's Offsite Construction Acceleration | Years 2–3 (1963–64)

Industry Consolidation and Expansion of Certification. Following the initial success of the GHLC program and the growth of the offsite construction industry, MLIT together with the offsite industry founded the Japan Prefabricated Construction Suppliers and Manufacturers Association. This association brought together prefabricated house companies, like Daiwa House and Sekisui House, precast construction companies, and suppliers to the industry. GHLC's certification program expanded from steel to concrete to wood prefabricated house systems.

Japan's Offsite Construction Acceleration | Years 4–5 (1965–66)

Further Expansion of Certification and the Creation of BCJ. The certification program expanded from detached and semi-detached housing to low-rise multistory structures of up to three stories through the Ministry of Construction's "Basic Plan of the Industrialization of House-building." Due in part to the growth of the sector and the expansion of the certification program, prefabricated house certification fell under the jurisdiction of a new entity, the BCJ, now directly under the Ministry of Construction, but with a continued direct link to GHLC financing programs.

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[69] Like Japan, the common European market has tracked "prefabricated buildings in wood" and "prefabricated buildings in steel" as *products* since 2000. In terms of consistency, the closest dataset in the United States is manufactured housing. In all three cases, integrating project responsibilities into one single entity is as crucial as using industrialization or offsite construction.
[70] Refer to Part A for a definition of industrialized housing delivery that is based in part on this case study.
[71] This early certification form initially relied on existing standards defined by Japan's already established light-gauge steel industry. By 1973, certification became much more standardized across material systems.

Japan's Offsite Construction Acceleration | Years 6–7 (1967–68)

Praise and Critique for Offsite Construction Acceleration. Five years into the acceleration program, the Japanese offsite construction sector, particularly the prefabricated house sector, showed great promise. Although it was believed that the industry would eventually outpace the automotive industry in importance for the domestic market, several issues were not fully resolved. Despite demonstrating growth and promise, the offsite construction industry was not growing at a rate adequate to meet the 1962 goal of a 15-percent market share by 1972, hovering at less than 7 percent. In addition, although prefabricated houses met the more stringent life safety and resilience requirements, homeowners complained of the generally low quality of the final product. MITI, represented by Genkou Uchida, critiqued their colleagues at the Ministry of Construction for not doing enough to ensure that the Japanese offsite construction industry was growing in capacity, competency, and capability (3Cs) to become a functional *high-technology housing sector.*

Japan's Offsite Construction Acceleration | Year 8 (1969)

Response to Challenges to Rapid Acceleration of the Offsite Construction Industry. The Ministry of Construction responded to their MITI colleagues' critiques and the slow market-share growth with an updated action plan, the *Long-Term Plan of Industrialization of House-Building*. The plan's goal was to reach the target objective of 15-percent market share for prefabricated houses and complete the transformation of the subsector into an HTHS comparable in sophistication with other sectors of the Japanese economy (e.g., automotive industry). For the key acceleration initiative, the Ministry of Construction organized two competitions, one for detached and low-rise prefabricated house systems and another for multistory precast systems.

Japan's Offsite Construction Acceleration | Years 9–11 (1970–72)

HUD-led delegation visits to Japan. With Japan and the United States relations in good standing and both countries intending to embark on government-led offsite construction acceleration efforts, the countries planned reciprocal visits. In 1970, HUD led a U.S. delegation to Japan, and in 1971, Japan led the "Uchida Delegation," organized by MITI's Genkou Uchida. The Uchida Delegation visited Operation Breakthrough sites and was presented with a comprehensive overview of the U.S. housing system certification that HUD and NBS were developing.

Pilot House Technology Invention Competition. Organized by the Ministry of Construction and conducted between 1970 and 1972, the Pilot House Technology Invention Competition developed performance-based system criteria, leaving the system design to the competitors. Up to that point, offsite construction companies developed typical designs, following more prescriptive requirements. The focus of the competition was on detached and semi-detached housing types, similar in range to what the prefabricated house subsector focuses on today. Competitors were encouraged to explore increased systems enhancement and levels of prefabrication and finish in the factory, leading to several volumetric modular proposals. Until this time, most systems utilized a kit of parts or panelization. Winners of the competition received support to develop these systems further.

The three competition goals were as follows:

1. Developing substantial technological innovation to supply high-quality, resilient, affordable housing for the private market.

2. Encouraging advanced manufacturing industries outside of offsite construction to enter the industry and improve the general innovation culture.
3. Furthering the consolidation of offsite construction companies to include design, engineering, manufacturing, onsite assembly, and finishes and more customer-focused sales and support services.

The competition received 145 system proposals from 112 companies. Of those, 17 systems developed by 16 companies were selected for development, production, delivery, and assessment, completed by 1972. All three of the goals were ultimately met, and all the major prefabricated house companies operating today, including Daiwa House, Sekisui House, Sekisui Heim, Panasonic, Toyota, and Misawa, participated in leveraging the program to finalize a transition into a high-tech approach to the production and delivery of housing.

Ashiyahama Highrise Housing Project Competition. Following the success of the Pilot competition, a second competition focused on multistory highrise housing utilizing precast concrete construction was held between 1972 and 1973. Twenty-five proposals from 22 companies resulted in a single system being selected, developed, and deployed, with the winning project built in Ashiyahama, Japan, using an experimental structural system that did not see wide adoption in the market.

Japan's Offsite Construction Acceleration | Year 12 (1973)

Creation of a Fully Functioning Housing System Certification Program. Following the successful completion of the Pilot competition, the Ministry of Construction utilized the performance-based approach to housing system certification to update the existing program overseen by BCJ and linked to GHLC financing. The new program, called the *Certification Program for the Performance of Prefabricated Houses*, combined aspects of regulatory reform and demand aggregation to ensure a steady acceleration of the capacity, competency, and capability (3Cs) of the prefabricated house subsector of the Japanese offsite construction industry.

Japan's certification system first began as a more straightforward award criterion for access to securitized mortgages that encouraged offsite construction. Certification criteria first mirrored the prescriptive code that regulated all housing, with completed certifications essentially being standard, repeatable designs. The program grew more sophisticated in 1973, when criteria shifted from prescriptive- to performance-based and certification resulted in a certified system that could be configured to different designs as opposed to a repeatable, set housing product. Since then, the housing system certification program has proven to be (1) resilient, continuing to certify systems based on performance criteria, and (2) flexible, able to respond to external pressures while maintaining comparable results. In Part A of the Action Plan, the researchers recommend a similar system certification program for the U.S. offsite construction industry.

Evolution Of the Industry and Framework From 1973 Until Today

Privatization and Expansion of Housing System Certification (1987). In 1987, BCJ became a private entity independent of the Ministry of Construction. The Ministry of Construction, in turn, established a program for accrediting private certification agencies, the "provisions for accreditation of building performance and business registration," leading to the establishment of several more certification companies that could support the continued growth of the offsite construction industry.

Housing System Certification After Industry-Wide Transition to Performance-Based Codes (2000). Japan's national building code transitioned from prescriptive- to performance-based criteria in 2000, affording the housing system certification program, which had been using performance-based criteria for nearly 30 years, the opportunity to further evolve and continue growing. Portions of the housing system certification were reworked to align with general performance-based code criteria and procedures. A larger number of housing production and delivery systems could now access some of the precertification benefits afforded to prefabricated house systems. As of 2021, one in three housing units in Japan utilizes this expanded form of precertification, with more than 50 percent as non-prefabricated units. In other words, the same program that helped Japan's vertically integrated offsite construction industry accelerate in the 1970s and 1980s has effectively expanded to include other forms of production and delivery. All housing and all construction in general must now fulfill performance standards with housing system certification in Japan.

GHLC to JHF (2007). The other essential entity and the program's originator, GHLC, was restructured into JHF in 2007. The key shift in its role was from focusing on origination in the primary mortgage market, where it competed with the private sector, to securitization, where it supports the private financing sector to this day.

The agency continues to focus on a two-part mission:

1. Providing liquidity to mortgage markets that support low- and moderate-income households.
2. Improving the overall quality of housing.

JHF is still the originator of loans for natural disaster relief, a role GHLC historically held.

Sumstock Certification for Existing Prefabricated Houses. The most recent development in the long line of system certification and demand aggregation actions in Japan is the addition of Sumstock Certification. In this program, JHF supports an additional certification system for purchasing or renovating existing prefabricated houses. This system supports Japan's circular economy goals for the refurbishment and reuse of offsite constructed housing, giving products deployed decades earlier another life, and supported via data on file with JHF on prefabricated housing technical systems in the market. At a minimum, finishes may be updated. Remarkably, entire volumetric modules are being disassembled and refurbished for reconfiguration in new housing developments.

Overview Of the Current Industry and Framework

Japan's industrialized offsite construction industry and framework have evolved in dialogue with one another, following a timeline like that of the United States, albeit with differing results.

The current housing system certification process in Japan's offsite construction industry is conducted following six key steps:

1. **Application for Certification:** The home builder develops a housing system design and applies to an accredited housing system certification entity (BCJ or equivalent).
2. **Certification:** The accredited housing system certification entity certifies the home builder's system.
3. **Application to JHF:** The home builder applies to JHF using the certification from the accredited housing system certification entity.

4. **Registration:** JHF registers the housing system for use in local inspections and for potential access to reduced-rate mortgages.
5. **Application to Local Inspection Entity:** Upon receiving certification and registration, the home builder can apply for a streamlined permitting and inspection process from a local inspection entity.
6. **Certification of Conformity:** On completion of the specific project, the local inspection institution issues a certification of conformity to the certification registered with JHF. Three inspections occur:

   1. Inspection of technical drawings and specifications.
   2. Inspection of the structure during onsite construction.
   3. Inspection of the structure on completion.

   The final certification of conformity is issued on completion of the onsite construction. Currently, 130 private inspection agencies have contracts with JHF to conduct certification of conformity. JHF monitors these agencies and supplies them with inspection manuals.

Housing System Certification Today. In 2021, the housing system certification program, which had been in place since 2000, was utilized by 28.2 percent of housing units, approximately 50 percent detached and 50 percent multi-unit**.** In addition to a streamlined permitting and inspection process, which provides significant cost savings to the home builder and ensures that the Japanese housing supply remains one of the highest in the world, substantial follow-on customer benefits have been realized by virtue of system certification.

These customer benefits include:

1. **Loans:** Since 1962, one key benefit of certification for the home builder and the owner has been access to securitized mortgages. With the shift in housing finance policy since 2007, JHF provides mortgage rate reductions for the following performance criteria as part of their Flat 35S Program:

   - Highly energy-efficient housing.
   - Superior seismic resistance.
   - Superior barrier-free housing.
   - Superior durability and flexibility of the housing structure.
2. **Subsidies:** The Ministry of Forestry has been promoting the increased use of home-grown wood, combined with incentives for housing to be net-zero energy, through regional housing projects and programs.
3. **Tax Reduction:** Housing system certification grants homeowners reduced liability on income tax, registration and license tax, real estate tax, and property tax.
4. **Insurance:** 10- to 50-percent discount on earthquake insurance is determined based on performance criteria met during the housing system certification process.

Housing System Certified House Overall Performance Results. In addition to benefiting home builders and owners in terms of cost, certification has helped Japanese society reach many of the goals for which the program was restructured to address, including:

- **Increased disaster-resilient housing stock:** Housing system-certified housing is nearly three times less likely to experience “severe damage” during earthquakes.

- **Increased energy-efficient housing stock:** Sixty-seven percent of housing system-certified housing is Net Zero Energy Buildings (ZEB), with many of the leading "prefab house" companies producing 90 percent or more ZEB units. Japan plans to reach 100 percent ZEB for new construction by 2030.
- **Increased barrier-free housing stock:** Sixty-four percent of housing system-certified housing is barrier-free, a key metric for Japan's aging population.
- **Increased durable and reusable housing stock:** One hundred percent of system-certified housing is deemed "durable" and appropriate for multiple generations of use and renovation simplicity.

In summary, the preceding section presents a case study of the critical role that government agencies in Japan played in accelerating offsite construction from 1962 to the present day. Like the United States post World War II, Japan's rapid housing supply need was acute to replace damaged stock and provide for a growing population. This need led to the development of a system certification regulatory program that aggregated demand and created more affordable and safer housing. Today, the same certification system is being used to meet additional societal goals. The creation of a national innovation system to meet housing needs would not have been possible in Japan without direct government-led action and the partnerships between MLIT, BCJ, and JHF focused on accelerating Japan's offsite construction industry. The lessons learned from Japan's efforts reinforce those from the United States and can be used to inform HUD's future actions to accelerate the evolution of the offsite construction industry to meet housing needs.

The following section reviews lessons from Sweden, another country that has led in accelerating offsite construction through effective government action.

3.2 SWEDEN CASE STUDY

During the post-World War II period, several European countries focused their offsite construction acceleration programs on multistory housing typologies because of the inherent economy of this mode of housing delivery. This was especially the case for housing of five stories or fewer, which was the maximum height without requiring an elevator. Precast concrete was often used as the primary offsite construction technology, mostly in a large-panel format.[72] Despite major regulatory reform and demand aggregation to support precast concrete construction, this mode of offsite construction lost significant market share after government-led acceleration efforts ended during the 1970s and, by the 1980s, was virtually nonexistent. Today, in most mature offsite construction sectors of Europe, the highest market share is in detached and semi-detached housing that utilizes wood or steel as the primary structural material (Prodcom, n.d.).[73] One key exception is Sweden, where nearly 20 percent of multistory housing that is up to 10 stories in height utilizes light wood-frame offsite construction. This market share is unique worldwide and results from a successful combination of government-led and industry-led

[72] The German word for this approach, *plattenbau,* still carries negative market connotations of cheap, repeatable, low-quality mass housing.

[73] Since 2000, Prodcom, PRODuction COMmunautaire (Community Production) in French, a European Union-wide survey of industrial goods, has documented the relative value of prefabricated buildings in wood and steel as well as other major prefabricated structural components in all member states, the UK, Switzerland, and Norway. Germany has the largest prefabricated wood building sector in value, totaling 3.6 billion euros in domestic consumption in 2021, followed closely by Sweden, with 1.5 billion euros in domestic consumption. When adjusted for population, Sweden's domestic consumption of prefabricated wood buildings is by far the largest in the European Union and is the only country where it is the top domestically sold construction product. Italy leads in the value of metal prefabricated buildings.

acceleration actions highly relevant to the U.S. context. This country case study will review two key government-led offsite construction acceleration programs developed to increase housing affordability and quality through the increased use of offsite construction:

1. **Million Homes Program.** This program was a market demand acceleration effort that successfully stabilized housing access and affordability through government-coordinated procurement of offsite construction between 1965 and 1975 but did not create an entirely self-sufficient offsite construction industry (Lidelöw, 2017–24; Hall and Viden, 2006; Terner, 2017; Olsen, 1972; Nesslein, 1982).
2. **Sweden's Performance Code and Performance-Based Standards for Multistory Wood-Based Construction.** Boverket, the Swedish National Board of Housing, Building and Planning, oversaw a regulatory reform acceleration effort that combined government-led action between 1989 and 1995. The series of industry-led actions supported R&D and finalized the formation of Sweden's offsite construction sector between 1995 and 2000 (Boverket, 2023).[74]

Motivations For Offsite Construction Acceleration in Sweden (c. 1965)

The current Swedish national innovation system for offsite construction results from sustained efforts to meet housing demand. Sweden's current offsite construction industry can trace its roots to modest but effective government actions.

1. **Research and Development Investment:** The first government-led action was strategic R&D investment in offsite construction before more significant large-scale acceleration. In this initial investment during the 1930s, the Swedish government supported the nascent detached and semi-detached wood-based offsite construction subsector, helping them develop the core technology still in use today.
2. **Low-Interest Loans for Forestry Sector Modernization:** During the 1930s, the Swedish government supplied low-interest loans to increase the industrialization and mechanization of the forestry sector, of which wood-based construction was part. This financing vehicle, combined with R&D support, placed the emerging offsite construction sector on solid footing.
3. **Performance-Based Building Product Specifications:** Like Japan, Sweden replaced many local building codes with a single national building code in 1950. Land use and zoning were also more unified by this time. In addition, Sweden had building products and assembly certification systems comparable with Germany's DIN-Norm program and France's agreement system, providing a performance-based approval process for more advanced building components within a prescriptive building code environment. This early adoption and long-term experience with performance-based specification for building products starting in the 1960s, and then sub-assemblies, thereafter, helped make the later transition to a full performance-based regulatory environment much easier to accomplish.
4. **Tenure-Equity:** During the same period in 1950, Swedish housing policy provided demand aggregation in the form of coordinated procurement through its system of municipal housing

[74] Sweden's pioneering adoption of a performance building code in 1995 was made possible by Boverket, a Swedish government agency founded in 1988, during a period of major restructuring of the Swedish public sector and economy. Boverket provided archival documents recording the process of code adoption and has supported the research through interviews and discussions.

agencies and through other subsidies, all guided by the principle of "tenure equity," meant to ensure that public subsidies equally benefited all occupants regardless of tenure type.

Case Study: Million Homes Program (1965–74)

Sweden's housing policy operated successfully during the immediate postwar years. However, a combination of solid economic growth and a housing policy focused on keeping housing costs low without ensuring increased supply, resulted in a significant housing affordability and accessibility crisis during the 1960s. Sweden's geographic population centers, where economic activity flourished, and its rural areas lacked an adequate housing supply across the tenure types. The Million Homes Program became a central policy focus of the ruling Social Democratic Party, which had enjoyed a parliamentary majority for decades. The Million Homes Program was intended to stabilize housing costs across tenure types by rapidly oversupplying housing.

When adjusted to population, Sweden's target of 1 million homes in 10 years was comparable with the United States target of 26 million homes. Like the United States, but unlike Japan, Sweden already had a strong offsite construction industry to accelerate, especially in the detached, semi-detached, and multistory subsectors. Conversely, like Japan but unlike the United States, Sweden had already undertaken significant regulatory reform in the form of a national building code and more unified land use and zoning policies, and as a result, realized some improvement in housing supply growth. In 1955, Sweden's new units per 1,000 inhabitants were seven, only slightly higher than in the United States. During the peak years of the Million Homes Program (1966–70), Sweden averaged 12.9 new homes per year per thousand inhabitants (Joint Economic Committee, 1969).[75] This average met the goals set in 1965, and globally was only exceeded by Japan, with an industrialized government-led acceleration program.

Million Homes Program Year | 1–5 (1965–69)

Improving Offsite Construction by Optimizing Design and Engineering of Housing and Neighborhoods. The Million Homes Program did prioritize industrialization and offsite production as part of the housing program. The primary criterion for project awards and subsidies was the "rationalization" or optimization of design and engineering for efficient production.

Million Homes Program | Year 6 (1970)

From Supply to Oversupply of Housing. The program had already achieved many of its goals by 1970. Even so, the decision was made to continue supporting the program to reach the aspiration of 1 million housing units by 1974.

Million Homes Program | Years 7–10 (1971–74)

Completing the Program During a Global Energy Crisis and Economic Downturn. The housing supply targets were reached, resulting in increased affordability and accessibility. Sweden was not spared the impacts of the global energy and economic downturn, but the increased housing supply nevertheless softened the effect of this crisis on its citizens. The strong detached and semi-detached wood-based offsite construction subsector continued growing, expanding, and consolidating as a result of the Million Homes Program. The steady pipeline

[75] The population of Sweden at this time was around 8 million and correlated to a production total of approximately 1 million homes per year.

created by the demand aggregation also helped the precast concrete sector reach its market share peak.

Million Homes Program Effects

Between 1965 and 1974, 1 million homes were produced in Sweden. The following statistics provide a breakdown of housing types:

- 34 percent detached and semi-detached housing that was primarily owner-occupied used almost entirely offsite-constructed wood frames.
- 66 percent concrete with approximately one-fourth precast and the remainder site-cast. These concrete types utilized significant "rationalization" for the designs and onsite industrialization and mechanization. In the multifamily category, 50 percent were three stories, 20 percent were two-story garden apartments, and the remainder were 8–10 stories.
- 50 percent municipal housing (public housing with a high degree of local autonomy), 30 percent cooperative housing (which combined aspects of renting and owning), and 20 percent market-rate rental units.
- 50 percent of the housing units in total utilized offsite construction, with 15–20 percent precast multistory and the remainder wood-based detached and semi-detached.

Million Homes Program Award Criteria

The Million Homes Program leveraged standard award criteria to prioritize the allocation of funding for projects. Two categories of award criteria were employed, "rationalization" and "industrialization," with the following parameters:

1. **Rationalization:** The term was used to assess the design and engineering of housing, a precursor to today's concept of design for manufacturing and assembly (DfMA). Several criteria were used to assess projects:
   - Multistory neighborhoods of 1,000 units or more were prioritized for access to financing, although only some projects achieved this scale.
   - Multistory projects utilizing at least ten repeated housing designs were also prioritized. About 50 percent of the multistory developments built during the program fell under this criterion while 25 percent used at least nine buildings of the same or similar design. The remaining 25 percent used much smaller groupings of similar structures.
   - Detached and semi-detached housing was also encouraged to use rationalized or standard plans, with approximately 50 percent of houses using some standard design.
2. **Industrialization:** Prefabrication and onsite industrialization were also prioritized in award criteria, but these criteria were secondary to the efficiency of project design and management. Industrialization on site and a move to a greater degree of production off site were key to ensuring that the larger supply targets were met. However, it was the award criteria around optimized design and management that ensured that these approaches could fulfill their potential.

The more highly prefabricated and enhanced wood-based offsite construction sector continued to grow in Sweden because of the Million Homes program, but it was limited to detached, semi-

detached, and low-rise, multifamily housing types. These limits were due to the limitations of wood structures set by the prescriptive code of a maximum height of two stories or fewer. With the greater focus on multistory housing, the precast concrete sector did grow as a result but accounted only for a maximum of 15 to 20 percent of all housing constructed. Moreover, the site-cast concrete sector further increased in onsite industrialization.

Overall housing quality improved. Like Japan and the United States, Sweden turned to industrialization and offsite construction to increase supply and economically improve the overall quality of the housing stock. Housing standards were raised during this period in terms of the overall square footage of housing and the equipment supplied while maintaining or reducing housing costs.

Motivation For Offsite Construction Acceleration in Sweden (c. 1988)

During the 1970s and 1980s, various global and local factors led Sweden to liberalize its economy, gradually eliminating many housing subsidies. Sweden's municipal housing agencies transitioned from being governmental entities to nongovernmental entities. Sweden's detached and semi-detached wood-based offsite construction subsector maintained its market share during this period, whereas the precast sector lost market share to site-cast concrete that had continued to industrialize onsite construction. Sweden's preparation to join the European Union (EU) in 1995 drove the next significant transformation of Sweden's offsite construction sector.

The EU and a *Supranational Innovation System*. Starting in 1975, a year after the United States Congress mandated that HUD establish a national performance-based framework for mobile home production and delivery, the European Community, the predecessor of the EU, started developing a supranational innovation system to accomplish the following goals:

1. Eliminating barriers to trade within the European market.
2. Harmonizing technical specifications in the field of construction.

For more than 15 years, the European Community developed two instruments to accomplish these goals that remain to this day:

1. **Construction Products Regulation (CPR):** CPR provides a common product registration system across the EU, which includes all building products, regardless of the country of origin or the industry. For the first time, all products could be compared across sectors using common performance criteria (European Commission, n.d.a.).
2. **Eurocode:** Developed by the European Committee for Standardization, the Eurocode is a set of 10 performance-based European standards regulating building construction (European Commission, n.d.b.).

The first report outlining these actions was published in 1989, with the Eurocode first mandated in 2010 and the CPR system in 2011. Together, these two regulatory reforms created a common performance-based innovation framework for the EU and other countries operating on the common European market. CPR provides the performance characteristics of every building product on the market, whereas Eurocode provides the criteria for their assembly into structures and use cases.

Sweden's Migration to Performance Code. During the 1970s and 1980s, Nordic countries undertook a similar exercise to that of the European Community to create a common market. A core part of that effort was the shift in the regulation of building products and structures from

myriad prescriptive codes, based on rule-of-thumb, to common and scientifically derived performance standards. During this process, Norway developed a performance-code framework model still used in most performance codes, including the Eurocode and the ICC Performance Code (ICC, 2018; Meacham, 2010, 2022; Meacham et al., 2005).[76]

Sweden decided to join the EU in 1988 and formally applied for membership in 1991. In anticipation of EU membership and participation in a common market for building services and products, Sweden began developing a national performance-based building code to replace the current prescriptive code. During the Million Homes Program, the industry provided positive feedback about performance-based specifications utilized within existing prescriptive codes that had proven successful, particularly by those companies at the forefront of rationalization and industrialization. The new performance code was completed in 1994, 16 years before the first edition of the Eurocode was published. The shift from local codes to a single national code was a complex process. However, the shift from prescriptive to performance code was welcomed by the sector at large. During that period, Sweden's performance code enabled the established detached and semi-detached wood-based housing sector to expand into multistory housing production.

Boverket. Boverket, Sweden's National Board for Housing, Building, and Planning, founded in 1988, became the key agency developing and enforcing Sweden's performance code. The agency oversees urban and regional planning, urban development, building, and housing and is the central administrative authority for the built environment in Sweden, which covers construction and administration, housing, and finance. Boverket's scope of activities can be grouped into three broad categories, all which directly affect offsite construction for housing:

1. **Building Codes:** Developing Sweden's building code in harmonization with the Eurocode, including technical standards for products, design standards for the design of structures and environments, and competency standards for architecture, engineering, and construction professionals.
2. **Subsidies:** Defining targeted subsidies and technical assistance to local communities, financing to develop land use plans for detached housing districts, and providing seed funding for innovative projects.
3. **Credit Guarantees:** Boverket provides credit guarantees for lender insurance for housing projects and credit guarantees for residents who may not otherwise qualify for financing.

Case Study: Performance Building Code Development (1989–2010)

The establishment of Boverket led to a different approach to offsite construction acceleration than had been the case with the Million Homes Program. Government-led action was more strategic in scope, reforming the regulatory framework and encouraging the industry to provide the key innovations. Demand aggregation was left to Sweden's municipal housing agencies, which also shifted from government to nongovernmental entities during this time.

Sweden Offsite Construction Acceleration | Years 1–6 (1989–95)

[76] ICC is a model-building codes consensus organization and an accredited American National Standards Institute standards developer for building construction standards. Between 1996 and 2000, the ICC Performance Code was developed, with a minor revision in 2021 and 2024. Few, if any, AHJs have adopted this model code to date. Most jurisdictions use a prescriptive model code developed and maintained by ICC called the International Residential Code and the International Building Code.

Under Sweden's existing prescriptive building code, the several parties participated in the following manner:

1. Parliament defined the overall societal goals to be fulfilled by the code through legislation.
2. Ministries developed ordinances based on that legislation.
3. Boverket and its predecessor agencies defined operative or performance requirements, verification methods, and examples of acceptable solutions before 1989.

With the shift to the performance code in 1995, acceptable prescriptive solutions were maintained. Still, they were no longer obligatory for compliance, with the industry able to provide alternative solutions if they fulfilled the performance criteria. In practice, most conventional builders continued to use acceptable solutions as if they were obligatory, with performance criteria being used by more innovative subsectors of the housing sector, especially wood-based offsite construction.

Sweden Offsite Construction Acceleration | Years 6–10 (1996–2000)

Starting in 1994, the shift to performance code encouraged the industry to develop new standards to take advantage of this regulatory reform. Under the previous prescriptive code, wood construction was limited to two stories in height. This inherent limit no longer existed under the performance code, but without a new referential standard, compliance with performance criteria was considered on a project-by-project basis. To take advantage of this regulatory reform, Sweden's forestry sector supported the development of a series of new referential standards that were used by the offsite construction sector to economically design, engineer, fabricate, and install increasingly taller wooden structures. Several existing offsite construction companies, including Lindbäcks Bygg and Derome, took advantage of these new standards to expand their product range from detached low-rise to semi-attached and even mid-rise housing. As in Japan, this new national innovation system also encouraged innovative companies from other parts of the Swedish economy to enter the offsite construction sector. For example, Skanska, Sweden's leading onsite builder that had experimented with offsite construction during the Million Homes Program and became a leader in onsite industrialization, developed a joint venture with Ikea, the multinational conglomerate furniture company. The Skanska-Ikea partnership, named BoKlok, leveraged Ikea's manufacturing and direct sales knowledge combined with Skanska's construction management and onsite industrialization experience to develop a unique housing product, a condominium scaled and priced as a starter home.

Multistory offsite construction began to grow in 2000. By 2000, several companies were able to bring new multistory wood-based offsite construction systems onto the market, only a few years after performance code was adopted.

Easy Harmonization with Eurocode and CPR between 2010 and 2011. In 2010, the EU actively encouraged the harmonization of national building codes with the newly adopted Eurocode. With Sweden's existing performance code already used for more than a decade, harmonization with Eurocode was relatively simple. By 2011, CPR became widely used throughout the European market, with Sweden again benefiting from access to innovative products and new markets for its own companies. In addition to the established and dominant form of wood-based offsite construction, around this time, timber frame and mass timber systems began to grow in use, supported by the supranational regulatory reforms.

Overview Of the Current Industry and Framework

Sweden's housing policy has directly and indirectly supported the acceleration of offsite construction since the 1930s. Although the Million Homes Program directly focused on the acceleration of offsite construction, the finalization of a national innovation system, with performance criteria at its core, fully formed the country's world-class offsite construction for the housing sector. The effect is evidenced through four broad metrics:

1. **Wood-based offsite construction dominates detached and semi-detached housing in Sweden.** Sweden's regulatory reforms, and those of the EU, completed offsite construction consolidation and near-total domination of the detached and semi-detached housing market.
2. **Wood-based offsite construction has grown from 0 to 20 percent of Sweden's large multistory sector.** The creation of a national innovation system transitioning to a performance code that balances life safety, innovation, and affordability has encouraged Sweden's existing detached-housing-focused offsite industry and companies from other sectors of the economy to push the boundaries of multistory housing utilizing offsite construction.
3. **Second largest prefabricated wood building market, by value, in Europe.** In addition to market share, Sweden's offsite construction companies make a significant contribution to the country's overall economy, with prefabricated wood buildings—turnkey offsite construction housing products—being Sweden's number one building product. Only Germany's offsite industry creates more value, while Germany is looking to Sweden to help increase domestic consumption of its prefabricated wood buildings in the detached market and enable the construction of multistory housing.
4. **Offsite construction has a definitive labor productivity advantage over onsite construction nationally.** A 2017 McKinsey report tied the high cost of construction with low labor productivity and suggested that a shift to a "manufacturing style production system" would improve productivity and reduce cost (Barbosa et al., 2017). In 2023, a report on Sweden's offsite construction industry definitively provided the first evidence at a national scale that this hypothesis was true (Stehn and Jimenez, 2024).

The report demonstrates the following:

1. "Industrialized house builders" are more productive than conventional home builders at a company level, project level, and in absolute and growth terms during an 8-year period.[77]
2. Labor productivity was 10 percent higher on average than in construction overall.
3. Industrialized home builder productivity measures halfway between conventional construction and the manufacturing sector.
4. At a project level, industrialized house building displayed an average cost productivity growth of 19 percent for an employed prefabrication degree of about 45 percent, denoting highly enhanced panels or volumetric modules.

[77] Industrialized home builders are builders that utilize offsite construction and practice industrialized onsite construction and design for manufacturing and assembly and closely coordinate all three activities for productivity improvements, including efficiency, optimization, and value creation through vertical integration. Refer to the Introduction section for additional information.

Although several European countries have made significant strides in accelerating offsite construction, particularly in the detached and semidetached housing sector, Sweden is still the frontrunner in innovation and market share. Like other Scandinavian countries, Ireland, Germany, and Austria all harmonize their regulatory frameworks with Eurocode and anticipate similar results regarding the acceleration of offsite construction and expansion to multistory housing.

Sweden is now piloting or preparing a series of new initiatives to evolve their national innovation system by:

1. **Further Increasing Affordability—Housing System Certification for Public Housing Projects.** Albeit much less acute than that of the United States, Sweden is experiencing its own housing affordability crisis (Eurostat, 2021).[78] One new program currently being piloted involves housing system certification for industrialized home builders that are interested in delivering housing to Sweden's public housing agencies. Public housing agencies are tasked with reinvesting funds from existing facilities to create new housing to maintain affordability and access. More recently, Sveriges Allmännytta | Public Housing Sweden, the association of Sweden's municipal public housing agencies, has developed a housing system certification process (SABO, n.d.).[79] Companies that pass certification can be awarded projects at a fixed cost without the usual public tender process. One of the largest and most innovative industrialized home builders, Lindbäcks Bygg, has already undergone this transition, avoiding the typical design-bid-build process that is more suited to onsite construction.
2. **Further Developing the National Innovation System in Anticipation of Eurocode 2.0.** In anticipation of the 2027 updated standards and overall framework of Eurocode, Boverket has already introduced two key changes to Sweden's regulatory framework. First, acceptable solutions will no longer be provided, meaning that a prescriptive pathway will not exist. Second, the building sector will follow the manufacturing sector in shifting from a conventional permitting and inspection process to a system of quality control, like Japan. Boverket anticipates that placing more responsibility on Sweden's already innovative offsite construction industry, and construction more broadly, will accelerate a "cultural" transformation toward an HTHS.
3. **Increasing Building Performance and Maintaining Housing Supply and Affordability in the EU and Sweden.** In 2020, the EU passed several pieces of legislation geared toward improving overall housing supply, performance, and affordability. In Sweden's national strategy, wood-based offsite construction is a central part of achieving these goals. Boverket is charged with further accelerating the expansion of market share in the multistory housing sector well above 20 percent. Several other members of the EU are essentially adopting Sweden's approach to achieving housing performance, resource efficiency, and affordability.

In summary, Sweden provides an important case study of key lessons that can be applied to the U.S. context of government-led action to foster an NIS by accelerating offsite construction. Sweden started with early R&D focused on wood-based offsite construction, low-interest forestry sector industrialization loans, code advancements, and tenure equity between 1930 and

[78] In Sweden, 17 percent of households are cost-burdened, less than the EU average of 19 percent and much less than the U.S. average of 26 percent. However, this level is considered unacceptably high by Swedish standards.
[79] Sveriges Allmännytta | Public Housing Sweden represents Sweden's municipally owned housing companies and long-term private housing companies. Members include 300 companies holding more than 950,000 housing units throughout Sweden.

1950. The most significant government-led efforts that affected housing affordability in Sweden were realized by the Million Homes Program and the development and adoption of the performance code and system certification between the 1960s and 2000 that fostered a robust wood-based offsite housing industry by aggregating market demand. Boverket, a public-private government company that oversees performance-based standards to this day, is leveraging the performance code to foster an HTHS to achieve greater affordability and meet EU-wide targets focused on economic and resource efficiency. A key lesson of Sweden's creation of an NIS is that it was intentionally planned, developed, and cultivated through robust partnerships between government, industry, and applied research universities. Sweden is a prime example of government-led action that has accelerated generational offsite construction housing supply, affordability, resource efficiency, and building performance.

The following section transitions from case studies of established sectors to the United Kingdom, an evolving example of government-led action in accelerating offsite construction.

3.3 UNITED KINGDOM CASE STUDY

The United States, Japan, and Sweden all implemented significant offsite acceleration programs during the 1960s and 1970s that have continued to define their respective industries and frameworks. However, the UK has followed a different trajectory according to the research (Gibb, 1999; Pickavance, 2022; Batako et al., 2022; Luorio, 2024). Like several other European countries heavily damaged during World War II, the UK employed several government-led acceleration actions to address housing shortages.[80] An immediate postwar program utilized mobile-home-like detached structures as a form of emergency housing, producing 41,000 temporary units. This program was replaced c. 1948 by market demand coordination of Britain's council housing to accelerate a local offsite construction capacity, primarily precast concrete construction. Precast dominated public housing in the UK for the subsequent 20 years. In 1967, the most significant UK government investment in housing occurred through local authorities constructing public housing. These actions proved inadequate, resulting in only a modest housing supply increase. The maximum number of new units per 1,000 inhabitants reached equaled 7.7, less than what France and the Soviet Union had achieved and significantly less than Japan, Sweden, and the United States (Hashemi, 2013).

In 1968, several highly publicized incidents involving both the mobile-home-like buildings of the immediate postwar period and the larger precast structures resulted in increasingly negative public perception of offsite construction.[81] That fallout, coupled with the economic recession of the late 1960s and early 1970s, caused government initiatives and offsite construction technologies to be suspended. Although government-subsidized and municipal housing constituted most of the new housing starts between 1949 and 1980, thereafter, the UK housing sector was primarily driven by private investment. Until around 1970, offsite construction was relatively dormant until a resurgent interest in industrializing housing emerged through

[80] As with Sweden, the roots of offsite construction began even earlier. Around 1920, government reports called for alternative methods of construction to satisfy housing supply demand in a socioeconomic context of a lack of available labor and material supply chain. The Homes Fit for Heroes Programme in 1921 produced 30,000 steel and concrete prefabricated homes that yielded poor-quality results and required extensive repairs attributed to the lack of experience, planning, and management for the onsite work.

[81] Following a tragic gas explosion on an upper floor of a precast systems building tower in London, critics claimed that the designers, builders, and code officials did not take proper precautions regarding certification, testing, and continuous improvement of the system. At the same time, precast buildings from the 1940s started cracking and leaking.

lightweight wood-framing kits transferred to the UK from North America and Sweden.[82] Wood-based panelized construction was an ideal solution for the growing private speculative developer market. This form of offsite construction has continued to slowly increase in market uptake in England through the 1990s and 2000s but has not resulted in significant market share (Howes, 2002). However, since the introduction of wood kits to the British Isles, Scotland has developed a robust wood-based offsite sector by continuously fostering an NIS.

The slow housing supply increase and offsite construction adoption during the past few decades have led the UK to revisit government-led offsite construction acceleration during the past 20 years. These efforts are still in progress but have already affected several other government-led offsite construction acceleration efforts, particularly in the English-speaking world. This section reviews the recent government actions in the UK to address housing supply through offsite construction and compares approaches in England with Scotland to extract key lessons learned that are applicable to the U.S. context.

Motivations For Government-Led Actions to Accelerate Offsite Construction (c. 1998)

Many of the motivations for UK government-led actions to accelerate offsite construction in the recent past can be traced to three government-sponsored sequential reports that brought government and industry together. Latham (1994) called out the ineffective, fragmented, and inhumane construction industry. This report was followed by Eagan (1998), appropriately titled *Rethinking Construction*, which identified five key drivers of change toward an integrated delivery, including offsite construction. Eagan's contribution was highly influential in developed economies around offsite construction housing topics and the need for more integration of construction delivery.

Farmer (2016) is the most recent report and addresses low labor productivity and available labor, which showed no improvement, much like the UK's postwar efforts. Farmer challenged the construction industry to "modernise or die" and use a more holistic approach to housing delivery that integrated design, engineering, assembly, and finishing as a complete value chain. Farmer termed it the *modern methods of construction* (*MMC)*. Farmer recommended that industry and government invest in R&D and innovation by changing commissioning trends from traditional to premanufactured approaches. This recommendation spurred the UK government to action once again to invest in offsite housing. Since the release of the report in 2016, many UK funding schemes, pilot projects, research organizations, and universities have oriented their efforts toward solving productivity, cost overruns, and lack of labor supply issues through studying and applying industrialization of onsite and offsite operations of development. Moreover, the UK government has made major capital investments in offsite manufacturing companies and factories.

Several important regulatory reforms support the offsite construction or MMC acceleration actions:

Performance-Based Building Code. The Building Act 1984 (Scotland) was the first UK building code that introduced functional performance standards. Later that year, England and Wales followed suit. The transition away from prescriptive code came because of the risk perception associated with noncompliance to the impending Eurocode. Furthermore, the UK government and construction industry recognized that the prescriptive system offered little

[82] It is worth noting that light wood-frame construction arrived in Japan around the same time.

flexibility and accountability. Although a prescriptive "approved documents" pathway still exists, designers and builders are increasingly using alternative solutions that meet 18 designated building functions. These solutions place the responsibility for performance on building professionals to protect the health, safety, and welfare of the public. Scotland updated its performance code with Building (Scotland) Regulations 2004. The latest version in England and Wales is Building Regulations 2010. Both efforts are to simplify the compliance requirements.

Performance-Based Criteria for Standards and Assemblies—the British Agreement System. Following the French Agreement program, on which HUD's Operation Breakthrough was based, the British agreement system was developed and operates today to provide a performance-based certification route for building products and assemblies. The British Board of Agrément (BBA) is a nongovernmental organization providing a construction products certification service that approves compliance with relevant standards. In 2001, BBA represented the UK in the European Organization for Technical Assessment to be able to issue European Technical Assessments for performance-based criteria. BBA also performs product and assembly testing as well as permitting and inspection, although it is not the only accredited entity to do so, and has issued more than 6,000 certificates. Since 2013, the legal requirement has been for European Technical Assessment compliance with the EU standard Conformité Européenne (CE) under CPR. Although no longer an EU member, harmonizing a system certification program with an overarching performance-based building code allows the UK to operate considerably more agilely in adopting and adapting to offsite construction technologies in the EU market.

The results from the British functional-based system of Building Regulations 2010, Building (Scotland) Regulations 2004, and the BBA system certification have led to a proliferation of imaginative design and MMC factory-produced solutions. The transition to performance code has involved extensive education for building industry professionals and particularly building control officers. Code officials indicate that performance code is a liability for the jurisdiction, but housing designers and builders cite flexibility as the added benefit. As the performance code was brought on at the same time the housing market was becoming more privatized, developers were incentivized to find solutions that accelerated the evolution and promulgation of performance code and has led to an increase in acceptance and uptake of offsite construction.

Building Information Modeling (BIM) Standards. In 2010, concurrently with the update to the England and Wales Building Regulations, the UK government set out to establish a BIM vision to grow digitalization of the built environment sector. Subsequently, the government mandated BIM adoption in 2016 across all projects procured by central government departments requiring private consultants and service providers to comply through award criteria.[83] The UK BIM Alliance was established the same year, with BIM processes outlined that became the ISO 19650 standard, published in 2018. With the British Standards Institution and the Centre for Digital Built Britain, the UK BIM Alliance created the UK BIM Framework in 2019. The UK BIM Alliance changed its name to Nima in 2022. Offsite construction industry stakeholders, including architects, engineers, manufacturers, and constructors, have benefited greatly from the UK government leading the development and adoption of BIM standards for accelerating the industry. Although BIM standards for offsite construction started in airport, healthcare, and

[83] Concurrent with the UK efforts in BIM, NIBS established Levels of Development for BIM standards in the United States. Like the UK, the U.S. Government adopted these standards through award criteria that required all consultants to use BIM for the planning, design, construction, and operations of federal buildings. The policy had a waterfall effect on the rest of the construction industry quickly migrating to BIM tools and processes in their practices.

institutional facility delivery, the impact affected all construction, including housing delivery (Nima, 2024; IMI, n.d.).

Case Study: Modern Methods Of Construction Framework (1998–Present)

By July 2017, most of the findings from the Farmer Report (2016) were endorsed by the UK government. Compounded by the evolution of performance code, system certification, and adoption of BIM standards, a series of offsite construction for housing actions were developed and implemented, as the following outlines.

UK Offsite Construction Acceleration | Years 1–2 (2018–19)

Governmentwide Award Criteria for Offsite Construction: The MMC Framework. Following the Farmer Report and the precedent set by the UK BIM Alliance, one of the first government-led acceleration actions by the Ministry of Housing, Communities and Local Government included the development and dissemination of a common set of award criteria for all nationally funded projects that utilized MMC (Farmer, 2022). The two key metrics used for these award criteria are categories and value of MMC.

1. Categories of MMC that describe offsite construction types include:
    - Category 1: Premanufacturing (3D Primary Structural Systems)
    - Category 2: Premanufacturing (2D Primary Structural Systems)
    - Category 3: Premanufacturing components (non-systematized primary structures)
    - Category 4: Additive manufacturing (structural and nonstructural)
    - Category 5: Premanufacturing (nonstructural assemblies and sub-assemblies)
    - Category 6: Traditional building-products-led site labor reduction and productivity improvements
    - Category 7: Site-process-led site labor reduction, productivity, and assurance improvements
2. Premanufactured Value (PMV): the amount of monetary value of a given project that is manufactured off site in a factory environment.

The MMC framework was developed in 2018 and published in 2019, governing all nationally funded offsite construction projects since. The framework has also influenced the general terminology and culture of construction in the UK and elsewhere.

Critics of PMV indicate that the framework favors the level of enhancement or finish prior to the premanufactured subassemblies leave the factory without consideration for the level of enhancement needed for a particular project (i.e., design, scope, stakeholders, distance from factory to site, and other parameters). In addition, the concern is that PMV considers construction scope value but places less emphasis on the total project value of offsite construction. For example, PMV does not take into consideration the value that is created in Industrialized Home Delivery through the holistic integration of offsite construction by vertically aligning the supply chain, employing turnkey delivery, or emphasizing collaborative offsite construction delivery teams.[84]

Government-Led Demand Aggregation: Homes England. Developed in tandem with the MMC framework, a new government agency, Homes England, was established in 2018 with the

[84] These MMC framework and PMV concerns were documented during a MOD X research trip to the UK in December 2022.

mission of accelerating housing supply. This mission included the adoption of MMC, particularly categories with high PMV, by coordinating market demand and offering direct financing to innovative companies to create an HTHS. Falling under the Ministry of Housing, Communities and Local Government (equivalent of HUD), Homes England was established to directly support new market entrants and small- and medium-sized enterprises that are starting offsite manufacturing businesses. One of the organization's key performance indicators is the "share of supported completions using MMC" (Jezeph, 2022).

UK Offsite Construction Acceleration | Years 3–5 (2020–22)

Despite several serious internal and external crises, including BREXIT and the recent global pandemic, the UK government continued to support government-led acceleration of MMC. The research team led a delegation of U.S. and international offsite construction experts and industry representatives to the UK in December 2022, witnessing firsthand the effect of common award criteria and Homes England's direct support of several offsite construction home builders, including L&G Homes, Ilke Homes, and Tide Construction/Vision Modular.

UK Offsite Construction Acceleration | Years 6–7 (2023–24)

In 2023, several of the leading offsite construction companies supported by government-led acceleration actions, including L&G and Ilke Homes, went into administration prior to shutting down operations prompting a reassessment of the Homes England program through testimonials to the House of Lords. L&G Homes was a subsidiary of Legal and General, a pension fund company that invested £1.4 trillion pounds of capital via investors and the UK government's direct monetary support into an offsite manufacturing and turnkey operation for mass timber and structural steel modular construction. Five years later, it was no longer an operational business. Ilke Homes was established in 2017, touting durability and net-zero energy and receiving £60 million pounds from Homes England. This light-gauge steel offsite solution had the capacity to produce 10,000 homes per year but also ceased operations 3 years later. Significant government resources were invested into offsite manufacturing companies in England for the purpose of creating supply capacity and capability via fostering a high-tech sector that, although too soon to reach a verdict, has not yielded scalable and positive results to date.[85]

Case Study: Comparative Overview of Homes England and Built Environment-Smarter Transformation (BE-ST)

The UK is a political entity that includes four constituent countries, including England and Scotland. England has recently attempted to establish and accelerate an offsite construction industry to address its persistent housing affordability crisis and shrinking labor pool, with mixed results. On the other hand, Scotland has approached similar overall goals of housing supply with different actions for a longer period. Offsite construction in England and Wales is estimated at 20–30 percent of the total new housing construction, whereas in Scotland, offsite construction, and more specifically wood-based panelized and modular construction, constitutes 70–75 percent of the new housing market share (Hairstans and Sanna, 2017).

Introduction of North American timber frame construction. Around the time of the global energy crisis and subsequent recession, several countries, including Japan, Australia, New Zealand, England, and Scotland, introduced North American timber frame construction as a low-

[85] Company failures have been widely made public via the press media.

cost alternative to established modes of mass housing construction. In all these countries, the structural elements were prefabricated off site before being assembled on site. In England, poor technical design and execution led to "sick buildings" that, in turn, led to a backlash against wood construction and prefabrication that has influenced public perception to this day. In Scotland, a somewhat declined but still intact tradition of timber building, as well as a more skilled labor pool, resulted in better quality and affordability. By the 1980s, a small but significant timber frame offsite industry emerged in Scotland, looking to Scandinavia and especially Sweden, for technical support and an import supply chain of quality lumber. Today, housing construction in Scotland is synonymous with offsite panelization (open and closed) and volumetric modular in light wood frame.

Support for home-grown timber and mass timber construction. Several factors can be attributed to the success of Scotland's industrialized wood housing industry. The first is geography, as Scotland has more rain than southern England, making manufacturing assemblies indoors more valuable to project delivery. Furthermore, Scotland has been much more proactive in the adoption of biogenic, rapidly renewable, affordable, and more insulating materials for construction. However, perhaps the greatest success factor is Scotland's innovation and partnership culture. Since the mid-2000s, Edinburgh Napier University, in partnership with the construction industry and the government departments Scottish Enterprise and Scottish Forestry, has steadily been researching the viability of local timber resources grown in the Highlands for use in housing construction. Although it is generally considered a low-quality wood compared with that found in Scandinavia or Canada, using local timber has advantages for material cost, job creation, and natural resource efficiency. This applied research has been performed in direct support of offsite housing companies to test technical and economic resource compatibility in light wood frame panelized and mass timber technologies.[86]

Indirect acceleration through affordable housing demand aggregation. Small- and medium-sized enterprises constitute 95 percent of the construction industry companies in Scotland. However, most of the offsite construction in Scotland is performed by larger, well-capitalized enterprises. The Scottish government has made a concerted effort to promote additional companies entering and sustaining operations in the offsite construction industry to grow supply capacity. This has yet to be achieved by offering investment capital. Instead, incentives for offsite construction have been provided indirectly via forms of demand aggregation.

Campbell Construction Group (CCG) is one of the companies in Glasgow that has participated heavily in partnership R&D for offsite construction in housing with the Scottish government and universities. CCG started a subsidiary company called CCG Offsite Manufacture. In the early 2000s, the Scottish government made a public bid for turnkey housing to support HTHS and accelerate the housing supply. The project promised a pipeline of three affordable housing developments with award criteria for companies that provided industrialized and rationalized solutions. CCG, a medium-sized general contracting company at the time, responded with a plan to start up a closed-panel manufacturing operation to service the construction. After winning the tender, CCG in turn increased the overall capacity of its construction business to deliver housing projects and reduce cycle time through this simple, indirect government-led action in demand aggregation (Murray, 2022).

[86] The researchers have been collaborating with the Scottish offsite construction industry for the past decade through Edinburgh Napier University and BE-ST (formerly Construction Scotland Innovation Center).

Offsite Solutions Scotland and Built Environment-Smarter Transformation (BE-ST): The Nexus of Scotland's National Innovation System (NIS). Scotland has excelled in offsite construction acceleration through fostering collaboration between industry, academia, government, and related nonprofit entities, essential to a thriving NIS. Three developments that built on one another during the past 10 years have been instrumental to this evolution:

1. **Offsite Hub (Scotland).** Based on the research work at Edinburgh Napier University, the UK Commission for Employment and Skills in 2014 funded the development of a timber offsite hub as one of a few innovation hubs throughout the country. Led by the university and in collaboration with two timber offsite companies, CCG and Stewart Milne Timber Systems, the team established an Offsite Hub (Scotland) to address workforce training and effective knowledge transfer. This partnership constituted the core three organizations. Additional levels of knowledge partner membership commensurate with participation were also offered to join the hub (Hairstans and Smith, 2018; Youtie and Shapira, 2008).
2. **Offsite Solutions Scotland.** Co-organized by the Scottish government, small- and medium-sized offsite housing companies in Scotland—including CCG, Stewart Milne Timber Systems, Scotframe, Oregon Timber, and five others—formed a joint venture in 2017 to bid on large housing tenders in the UK that no one company could deliver alone. They called this business venture Offsite Solutions Scotland. In addition to winning projects, the partnership aggregated demand and shared knowledge about innovations in offsite delivery as the overall high-technology offsite sector capacity grew.
3. **Built Environment-Smarter Transformation (BE-ST):** Led by the Scottish Funding Council, a conglomerate of universities, and industry members, BE-ST (formerly Construction Scotland Innovation Centre) was established in 2014 and rebranded in 2019 with the combined mission of Offsite Hub (Scotland) and Offsite Solutions Scotland. BE-ST is funded by public and private funds in a 2:1 ratio. The board consists of government, industry, and academic representation. BE-ST's mission is to address societal needs in the built environment, and its scope includes innovation that intersects with the needs of nurturing an NIS as follows:[87]
    - Bringing new products, businesses, and services to market.
    - Providing training and skills to grow for students and professionals.
    - Offering a prototyping and testing facility for industry-based R&D called the Innovation Factory.
    - Connecting university research with the applied industry needs.
    - Creating career connections between entities in the construction sector.
    - Hosting events in the conference space.
    - Supporting companies' digital transformation.
    - Consulting on technical solutions for advanced building construction and MMC.

Effect of Scotland's Offsite Construction Acceleration Efforts. England has attempted to rapidly accelerate the creation of an MMC PMV Category 1 highly premanufactured volumetric modular offsite construction sector, with mixed results. Conversely, Scotland has gradually nurtured a more enhanced Category 2 and Category 3 offsite construction sector of open and

[87] BE-ST hosted a MOD X knowledge exchange visit to Scotland in December 2022. For additional information about BE-ST as an offsite construction for housing hub, visit https://www.be-st.build/.

closed timber panels, as well as a small but growing locally sourced mass timber subsector. In addition, the example of England's government action demonstrates that aggregating demand through direct capital investment is one way to spur acceleration efforts in offsite construction. However, once the investment is complete or the market shifts, it is difficult for offsite companies to sustain and recover. Scotland is an example of indirect aggregated demand by government-incentivized pipeline through project award criteria. This action created positive competition that fostered a high-tech sector in industrialized timber systems and housing delivery. Scotland has also been effective at partnering between offsite housing delivery companies to compete with traditional construction to deliver housing supply at scale and meet key societal goals of affordability and the efficient use of local resources. Finally, the example of BE-ST demonstrates the potential of fostering an NIS whereby industry, academia, government, and NGOs converge to create value for one another, train the next generation of offsite workforce, and exchange knowledge. Although the development of a 75-percent market share in wood-based industrialized housing in Scotland has taken many decades to develop, this sustainable growth has shown great resilience through recent recessions and political transitions.

Part B of the Action Plan report has outlined the most significant government-led offsite construction acceleration efforts over time in the United States, Japan, and Sweden and evolving actions in the UK. The comparative lessons from each country case study will be evaluated in the following section. These lessons provided the basis for the actions recommended to HUD as a means by which to accelerate offsite construction in the United States in Part A of the report.

B.4 KEY LESSONS FOR EFFECTIVE GOVERNMENT ACTIONS TO ACCELERATE OFFSITE CONSTRUCTION IN THE UNITED STATES AND ABROAD

The findings from the country case studies are summarized in the following section. These lessons are compared and combined to form overall conclusions that serve as the basis for the Action Plan recommendations for accelerating offsite construction in Part A of the report.

4.1 KEY LESSONS BY COUNTRY CASE STUDY

Key Lessons From the United States

From a review of the Housing and Urban Development Act of 1968, the Housing and Community Development Act of 1974, the state industrialized building programs, Operation Breakthrough, and HUD's Manufactured Housing Program, the following lessons can be concluded:

1. Rapid housing supply acceleration can be achieved through clear long-term goals and demand aggregation programs. Offsite construction thrives within this context, helping increase overall supply.
2. Conversely, abandoning long-term goals and demand aggregation programs prematurely prevents housing supply and affordability from improving and can lead to a decline in industry capacity, competency, and capability (3Cs) for decades.
3. Even well-planned long-term goals supported by demand aggregation programs will struggle to generate rapid housing supply acceleration without some form of regulatory reform in the short term, nor will they ensure the creation of a stable HTHS and NIS in the long term.

4. Without establishing an HTHS and NIS, costly government-led acceleration actions will be required every time a housing affordability crisis or a new societal challenge occurs.
5. Regulatory reform in the form of market harmonization at a national scale and a shift from prescriptive- to performance-based specifications can deliver housing affordability and improved quality. However, without an HTHS and NIS that can gradually evolve to be independent of direct government-led programs and actions, these benefits will be limited in terms of effect and ability to address future challenges.

Key Lessons From Japan

From a review of Japan's housing system certification program and ultimate shift to performance code, the following lessons can be concluded:

1. Regulatory reform and demand aggregation can rapidly accelerate housing supply, but without also encouraging the creation of a knowledge-based high-tech sector and self-sufficient NIS, housing quality can decline, and the industry will require future government-led acceleration efforts.
2. Modest but consistent demand aggregation in the form of targeted incentives and subsidies, combined with regulatory harmonization and streamlined permitting and inspections, can be more cost-effective in terms of public investment than direct procurement or subsidization of offsite construction.
3. Although housing production and delivery offer unique challenges and opportunities, the knowledge transfer of a "manufacturing mindset" from other sectors of the economy can play a significant role in creating an HTHS and NIS. This knowledge transfer is essential in supporting the shift from project-based to platform-based housing delivery.
4. Despite focusing government-led acceleration efforts on creating vertically integrated industrialized offsite construction companies, many of Japan's regulatory reforms and demand aggregation programs have broadly benefited conventional construction. Instead of assuming that the entire sector will shift from conventional project-based onsite construction to platform-based vertically integrated offsite construction, Japan provides an example of a heterogeneous sector in which innovations can move relatively quickly from innovators and early adopters to early majority and late majority companies.
5. Although Japan considers approximately 15 percent of its current housing production as industrialized offsite construction or prefabricated homes, by international standards, more than 50 percent of all housing production would be defined as offsite construction by the criteria of any other context. As such, Japan is a unique example of a context in which the housing sector has fully completed the "technology adoption life cycle" theorized in innovation studies (Rogers, 1967, 2010).
6. Japan has balanced a profound understanding of the barriers and opportunities of its context with genuine interest, comprehension, and effective translation of best practices from around the world.
7. Performance-based housing system certification has proven to be a successful intermediary strategy in transitioning from a prescriptive- to a performance-based regulatory environment.
8. Japan's NIS and HTHS, which utilizes a platform-based approach, have enabled the country to respond rapidly and economically to new crises and societal goals, such as disaster

resilience, aging in place, zero energy, and circularity, without the need for major government-led acceleration actions on par with those taken in the 1960s and 1970s.

Key Lessons From Sweden

From a review of the Million Homes Program and the transition to a performance-based regulatory framework, both within Sweden and more broadly as a member of the EU, the following lessons can be concluded:

1. Regulatory reform in the form of harmonization at a national scale, combined with demand aggregation in the form of direct and indirect procurement of offsite construction, can rapidly increase housing supply and improve housing affordability. However, this approach does not always ensure a self-sufficient HTHS without the development of an NIS.
2. Instead, a self-sufficient HTHS and NIS require a structural shift from prescriptive- to performance-based regulations for buildings and building products.
3. Even with a self-sufficient HTHS and NIS, housing supply for the lowest-income members of society will require some form of subsidy. Those subsidies will have a maximum effect within the context of innovation.
4. An HTHS and NIS not only support the rapid increase of housing supply, but they can also support the transition of a company's focus from one set of services or products to another with relative ease. In Sweden, for example, industrialized offsite construction first dominated the detached and semi-detached housing market before expanding into the multistory housing market. Although the room for future growth is significant, Sweden's multistory housing market share of nearly 20 percent is the highest in the EU and one of the highest in the world.
5. As in Japan, although housing production and delivery offer unique challenges and opportunities, the knowledge transfer of a "manufacturing mindset" from other sectors of the economy can play a significant role in creating an HTHS and NIS. This knowledge transfer is essential in supporting the shift from project-based to platform-based housing delivery.
6. Sweden's early adoption of a performance-based regulatory framework has allowed a country with a smaller population than several states in the United States to serve as a model and enjoy a competitive advantage within the EU, a supranational entity of 27 member states, whose population and GDP are comparable in scale with those of the United States.
7. Following the publication of the McKinsey Global Institute's study of the construction sector's lagging behind labor productivity compared with nearly every other sector of the global economy in 2017, several countries have seen offsite construction technology as a solution (Barbosa et al., 2017). Sweden is the first country to have demonstrated significant improvements in labor productivity compared with conventional construction through a combination of the use of offsite construction technology and a reform of the design, delivery, and regulation of the construction sector.
8. Sweden's mature housing innovation system and HTHS, working within a performance-based building design and building materials specification environment for decades, have proven to be ideally suited for responding to the ambitious resource efficiency targets set by the EU. In fact, in anticipation of these goals, Sweden is in the process of eliminating all vestiges of its prescriptive-based regulatory environment, starting in June 2025.

Key Lessons From the United Kingdom

Whereas the analysis of Japan and Sweden analyzes more mature offsite industries and frameworks, the case study of the UK was selected because its government-led acceleration is currently underway. Due to the political structure of the UK, two of its nations, England and Scotland, provide very different examples of government-led action and effect. The following lessons can be concluded:

1. Clear and consistent national award criteria can be a cost-effective instrument for government-led offsite acceleration (UK-wide).
2. An HTHS cannot be created *overnight* through demand aggregation, including direct procurement, coordinated procurement, or even generous subsidies (England). In contrast, long-term goals, regulatory reform, and demand aggregation in the form of initial government pipeline security for the short term can positively sustain the evolution of existing construction companies to high-tech companies (Scotland).
3. Once established, an NIS can sustain housing affordability, higher building performance, resource efficiency, supply chain independence, and an HTHS without an ongoing major government-led intervention of investment (Scotland).
4. The formation of an NIS is the result of sustained efforts by industry, academia, government, and NGOs working together toward shared societal goals (e.g., affordability, supply, and workforce development), and active willingness to exchange knowledge through formal and informal partnerships (Scotland).

4.2 KEY LESSONS OVERALL

Accelerating Offsite Construction *Can* Rapidly Increase Housing Supply. In all three of the contexts where long-term offsite construction acceleration occurred (United States, Japan, and Sweden), housing supply increased significantly:

- In the United States, 6.5 new housing units per one thousand inhabitants were delivered in 1968, the year preceding offsite construction acceleration, whereas 9.9 units were delivered in 1973, the last year of acceleration. When mobile home production is included (not included in published statistics), 8.2 units were delivered in 1968 and 12.6 units in 1973. By comparison, the U.S. supply has been approximately one-third of that peak in recent years (U.S. Census Bureau, 2024).
- In Japan, 5.1 new housing units per one thousand inhabitants were delivered in 1961, the year preceding offsite construction acceleration, with deliveries more than tripling by 1973. Even in recent years, Japan's new unit production is nearly triple that of the United States (Statistics Bureau of Japan, 2024).
- In Sweden, 10.7 new housing units per one thousand inhabitants were delivered in 1963, whereas 13.7 were delivered in 1970 and 12 in 1973, the last full year of the acceleration program. Sweden's supply declined dramatically between 1974 and 2000 to an all-time low of 1.5 new units, but it has been growing since, with 6.18 new units in 2023, significantly more than in the United States (Statistics Sweden, 2023).
- The increase in supply can be partially attributed to the increase in the use of offsite construction and partially to the positive effect of regulatory reforms and demand aggregation on housing production and delivery, more broadly, on site and off site.

Accelerating Offsite Construction *Can* Increase Housing Affordability and Accessibility for the End User. In all three countries, offsite construction housing supply efforts did coincide with increased accessibility and affordability, but the direct effect is more difficult to gauge. In most programs, direct cost savings to the offsite construction companies were less of a priority than affordability for the end user.

In terms of direct cost to the end user, the most successful government-led acceleration program is HUD's Manufactured Housing Program, which improved the quality and safety of an existing form of housing production and delivery while maintaining a near 50-percent cost reduction compared with similar onsite construction during the past half-century.

In terms of increased supply leading to higher affordability overall, Sweden's Million Homes Program, in which approximately 50 percent of the units (1 million) were produced off site, all utilized some form of industrialization and managed to stabilize housing costs within 5 years of the program's existence.

In Japan, the direct impact on affordability is more difficult to gauge than the effect on quality and resilience.

Accelerating Offsite Construction *Can* Improve Overall Housing Quality Economically. In the United States, Japan, and Sweden, some evidence exists that accelerating offsite construction can improve overall housing quality.

In the United States, a lack of government-led action led the largest subsector of offsite construction, the mobile home industry, to essentially self-regulate, setting an industrywide standard in 1960 that did not adequately address quality and life safety. In 1974, Congress empowered HUD to develop a government standard for the industry, transforming it into the manufactured housing industry and significantly improving quality and life safety while maintaining affordability.

In Japan, initial industry growth starting in the mid-1950s, coupled with government-led acceleration action, did increase housing supply and offsite construction market share, but it did not adequately ensure improved quality and resilience until the introduction of more advanced housing system certification in 1973. Since 2000, prefabricated houses have often been appraised as higher quality and higher resilience than their conventional counterparts.

In Sweden, some of the multistory housing delivered using offsite construction during the Million Homes Program proved to be of lower quality. However, significant quality issues have not been a factor in recent decades, and end users have even accepted mid- and highrise wood-based construction, almost entirely produced using offsite construction, despite earlier concerns about fire safety and overall quality.

Regulatory Reform and Demand Aggregation are *Prerequisites* for Offsite Construction Acceleration. The first national building codes appeared after World War II in countries focused on accelerating industrialization and offsite construction. As construction has become more industrialized in these countries, migrating production operations off site to a factory, these existing regulatory frameworks have required reform, following changes that are similar to regulations that govern other manufacturing-based industries. In the cases of Japan and Sweden, offsite acceleration and housing supply increases were preceded by regulatory reform through

the harmonization of building codes nationwide. Initially, this was in the form of the Building Standards Act in 1950 in Japan and the Byggnadsstadgan in 1960 in Sweden.[88]

In the United States, regulatory reform was conducted in tandem with initial offsite acceleration actions, starting with the introduction of state industrialized building programs in California and Washington State in 1969, and followed by the more experimental regulatory reform pilots in eight states as part of Operation Breakthrough. In 1976, the most significant regulatory harmonization action, the introduction of the national HUD Code, ensured the rapid recovery, transformation, and sustained operation of the former mobile home industry, now the manufactured housing industry. Therefore, the research indicates that a shift from a variety of discrete and unique local regulatory frameworks to a harmonized national and even supranational regulatory framework has positive effects on offsite construction evolution and housing supply more broadly. National regulatory frameworks either utilize preemption by the national government over local authorities or encourage the adoption of national regulations through various incentives, such as improved mortgage or insurance terms for the end user or developer.

In all three of the countries with longstanding offsite construction programs, the shift from prescriptive- to performance-based specifications for building products and structures also proved effective. In Sweden, some performance-based specifications were introduced into the existing building code in 1968, with a full transition to this form of regulation occurring in 1995. In Japan, performance-based specifications were first introduced through the 1975 housing system certification program, with full adoption of performance-based building codes occurring in 2000. In the United States, performance-based regulations were first experimented with as part of Operation Breakthrough between 1969 and 1973, before being adapted to the HUD Code between 1974 and 1976. More recently, the UK adopted performance-based building regulations during its membership in the EU. In many cases, this shift toward performance-based regulations required an intermediary step, the performance-based certification of assemblies or entire housing systems. System certification can be defined within a confined scope, such as HUD-funded projects, or broader to include all federally funded housing projects, motivating the industry to evolve toward using performance-based certification for offsite construction over time.

The other important form of government-led action to accelerate offsite construction from this research is market demand aggregation. Aggregating market demand involves government-led action to coordinate and unify housing demand to create a more stable pipeline for offsite manufacturing. In the United States, the Housing and Urban Development Act of 1968 provided several means for supporting demand aggregation. As part of Operation Breakthrough, one of HUD's key roles was to work with state and local governments and nongovernmental end-user groups to coordinate housing demand around the program's pilot sites, thereby ensuring an adequate pipeline. Sweden's Million Homes Program was a massive demand aggregation action. In Japan, direct and coordinated programs focused on demand aggregation during the 1950s and 1960s that gave way to more indirect demand aggregation in the form of award criteria for mortgages and mortgage rate reductions from the 1970s to the present day. In the UK, Homes England currently functions as a demand aggregation entity.

[88] Japan adopted a unified national building code in 1950, and Sweden adopted one in 1960. Before the postwar period, building regulations tended to be localized in most countries, as HUD concluded in a 1968 study of government-led offsite construction acceleration efforts.

Demand aggregation was necessary to evolve the existing industry, encourage new sector entrants, attract external investment, and justify internal debt investment. Those interviewed for this international comparative study corroborated this fact repeatedly. The research findings indicate that government action to aggregate demand can be realized with several tactics, including direct procurement through government-owned housing, indirect procurement through government-led coordination of housing procurement by other entities, and aligning governmentwide award criteria. Research from the country case studies reveals that regulatory reform supports demand aggregation, allowing offsite manufacturers to increase standardization of process and product-to-service jurisdictions in different geographic locations.

A High-Technology Housing Sector (HTHS) *and* a National Innovation System (NIS) Ensure That an Offsite Construction Sector Can Function Without Significant Government-Led Action and Ongoing Future Investment. In addition to achieving a rapid increase in housing supply, concerted demand aggregation and regulatory reform have resulted in the effective development of an HTHS and NIS in these international contexts. The research demonstrates that the creation of a functional HTHS and NIS can achieve housing supply and affordability goals *and* critical societal goals without the need for costly structural or ongoing government investment. The HTHSs presented in the case studies comprise entities that can continuously improve their capacity, competency, and capability (3Cs) through deploying manufacturing principles in the service of housing delivery.

In these countries, some government-led action is still necessary today to ensure affordability and access to housing during economic downturns or in response to new societal challenges. However, government initiatives have not required programs like Japan's Pilot Program or Sweden's Million Homes Program to create and reinforce their domestic offsite construction industries. Entities like Japan's BCJ or Sweden's Boverket serve as innovation hubs for continual dialogue between national and local government, industry, academia, and the nongovernmental sector for sustained offsite construction for housing evolution. Although smaller in terms of scale, Scotland's BE-ST has served a similar role. The Housing and Communities Development Act of 1974 envisioned a similar role for the National Institute of Building Sciences (NIBS). Therefore, the researchers recommend, as outlined in Part A of this report, the reinstatement of NIBS to serve in this capacity to foster a U.S. NIS to realize and sustain an offsite construction industry that can deliver on societal housing goals.

4.3 CONCLUSION

As the HUD study of government-led acceleration efforts prior to the development of Operation Breakthrough succinctly explained, the **"large-scale application of industrialized building systems … is not limited by technological, design or cost factors, but only by institutional constraints"** (Patman et al., 1968: 121). Because of the complex nature of affecting institutional reform at varying scales from local jurisdictions to national programs, the research findings alone are not a guarantee of future success. Rather, the findings based on case study precedent provide the strongest foundation available on which to develop effective and scalable actions to accelerate offsite construction. The lessons that HUD's offsite construction efforts provided in the past led to the functioning NIS and HTHS frameworks in Japan and Sweden and are informing the current actions in the UK. As such, the key lessons provide empirically derived evidence for defining future government-led offsite construction acceleration efforts. The specific tactics that have worked in other contexts and even in other periods of U.S. history may

not be easily translated into practice today. However, these case studies do provide a roadmap for how institutional reform can be effectively implemented.

Because of the importance of regulatory reform in all the country case studies researched, government-led action is deemed essential, but national governments have not acted alone. A vital element identified across all offsite construction case studies is **key strategic partnerships**. The study revealed through literature, interviews, and observations that the intentional and strategic integration of government, industry, academia, and related nonprofit entities through structures of mutual benefit can expedite the maturation of an NIS and related elements. A common lesson the case studies support is that stakeholders are aligned to societal goals harmonizing and compounding individual efforts to achieve greater outcomes of supply, affordability, and quality of housing. Moreover, national governments and corresponding political will often played a key role in directing and encouraging partnerships to align efforts in offsite construction policy, finance, and technology.

In the United States, HUD has a long history of providing a broad coalition leadership role through effective government-led actions that accelerate offsite construction to address the ongoing housing affordability and supply crisis. In Japan and Sweden, HUD's peer agencies, working in collaboration with an entity similar to NIBS, have been at the center of national innovation systems designed to support HTHSs with minimal ongoing future government-led action and investment.

The case studies of Sweden and Scotland also provide an important lesson for HUD. Local and regional governments can develop offsite acceleration efforts that larger political entities can later adopt. In the case of Sweden, the European Commission, presiding as the EU's governing body, has often pointed to the country's success as a model for other member states to reference. Sweden continues to be a regulatory reform trailblazer and is currently planning an aggressive performance code launch in the summer of 2025 modeling policies that other member states will adopt in the future. Scotland, one of four nations in the UK, serves a similar role in that country and has influenced the development of Ireland's ambitious Action Plan, the *Roadmap for Increased Adoption of Modern Methods of Construction in Public Housing Delivery* (Government of Ireland, 2023).[89] As HUD and federal agency strategic partners consider which acceleration actions to prioritize and implement to increase national housing supply, the researchers are currently collaborating with several state and city partners in the United States to develop Regional Offsite Action Plans. Akin to efforts in Sweden and Scotland, this research effort anticipates and supports United States federal action to address regulatory reform and demand aggregation to foster an HTHS and NIS that can sustain an affordable and resilient housing supply into the future.

[89] Although not included in the report, Ireland's Action Plan is highly relevant for future U.S. offsite acceleration efforts. Developed through a collaboration between the Department of Housing, Local Government and Heritage, HUD's peer agency in Ireland, and the Department of Enterprise, Trade and Employment, which views offsite construction as an important economic development driver, the plan combines ambitious goals with pragmatic instruments to realize these goals. A significant delegation of Irish policymakers participated in the MOD X research trip to Sweden in June 2023, sharing knowledge and experiences with HUD and other participating U.S. offsite experts.

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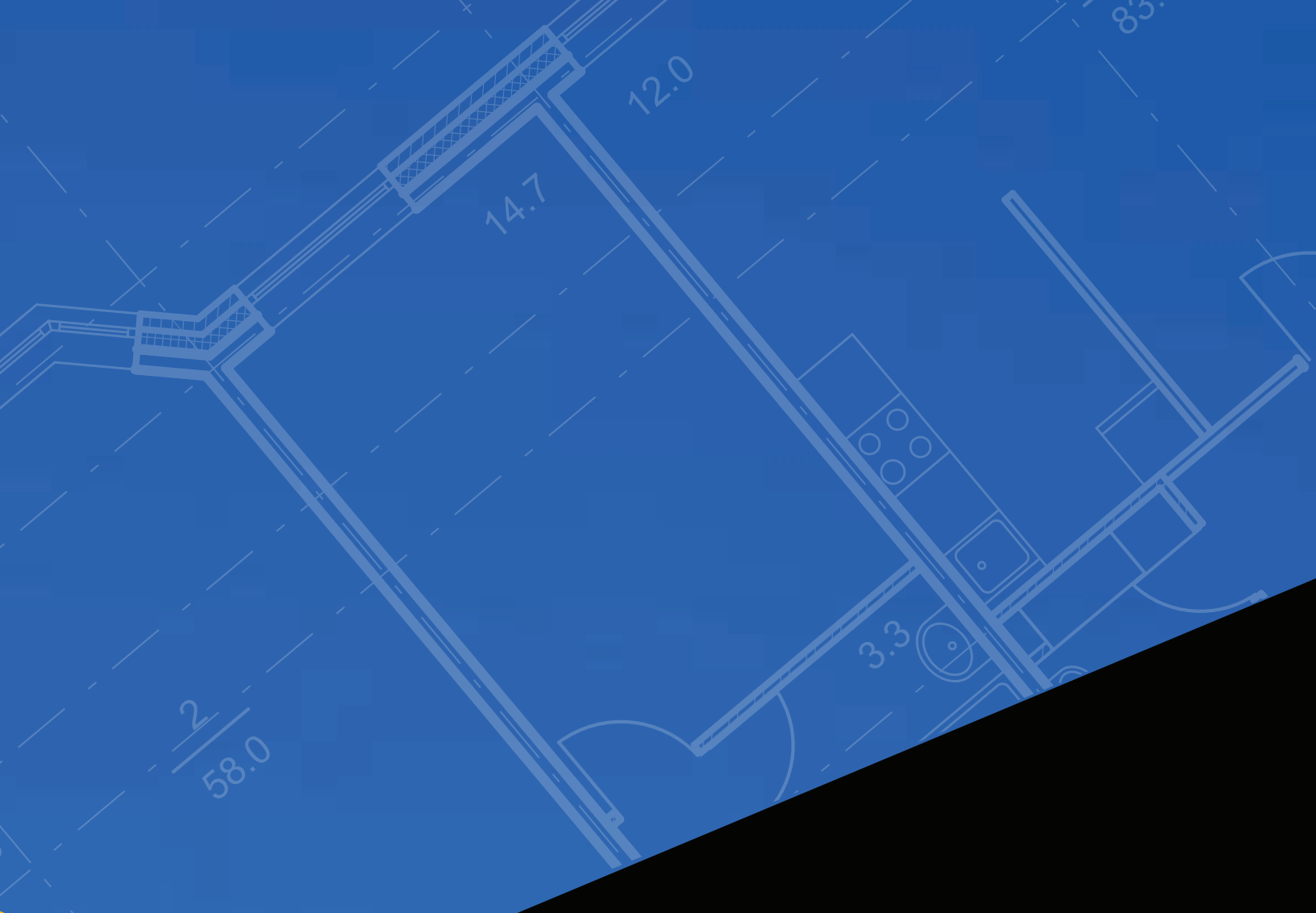
APPENDIX: PROJECT PARTNER ROLES AND CONTRIBUTIONS

Reference	Country	Organisation	Name	Key Partner	Exchange Delegate	Exchange Host	UK England Workshop	UK Scotland Workshop	Japan Workshop	Sweden Workshop	U.S. Workshop	Peer Reviewer
1.00	**UK - England**											
1.01	UK - England	Homes England	Edward Joseph	☑	☑	☑	☑	☑	☑	☑	☑	☑
1.02	UK - England	Homes England	Paul McGivern	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.03	UK - England	Homes England	Joey Chopra	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.04	UK - England	Homes England	Callum Smith	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.05	UK - England	Department for Levelling Up, Housing and Communities (DLUHC)	Jake Prust	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.06	UK - England	Department for Levelling Up, Housing and Communities (DLUHC)	Jake Boomhauer	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.07	UK - England	Department for Levelling Up, Housing and Communities (DLUHC)	Dan Thornton	☐	☐	☑	☑	☐	☐	☐	☐	☐
1.08	UK - England	L&Q Homes	Mike Dempsey	☐	☐	☑	☐	☐	☐	☐	☐	☐
1.09	UK - England	Bio Homes	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
1.10	UK - England	Vision Modular (Tide Construction	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
1.11	UK - England	Gast Consultancy	Mark Farmer	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.12	UK - England	Gast Consultancy	Jeff Endean	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.13	UK - England	Offsite Alliance/Modularize	Gaynor Tennant	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.14	UK - England	Offsite Alliance/Modularize	Matthew Egan	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.15	UK - England	BRE	Gwyn Roberts	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.16	UK - England	BRE	Eloise Francis	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.17	UK - England	BRE	Jane Goddard	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.18	UK - England	Make Modular	Steve Cole	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.19	UK - England	Make Modular	James Brun	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.20	UK - England	Building Better	Trina Chakravarti	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.21	UK - England	ESS Modular/Spatial Initiative	Emily King	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.22	UK - England	Hawkins Brown	Nigel Ostime	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.23	UK - England	Henry Riley LLP	Dan MacPherson	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.24	UK - England	Mott MacDonald	Will Mollvoy	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.25	UK - England	Trowers & Hamlins	Katie Saunders	☐	☐	☐	☑	☐	☐	☐	☐	☐
1.26	UK - England	TRADA	Tabitha Binding	☐	☑	☐	☑	☐	☐	☐	☐	☐
1.27	UK - England	Volumetric Building Companies	Andy Smith	☐	☑	☐	☑	☑	☐	☐	☐	☐
1.28	UK - England	England Department for Education	Beverly Quinn	☐	☐	☐	☑	☑	☐	☐	☐	☐
2.00	**UK - Scotland**											
2.01	UK - Scotland	Edinburgh Napier University| Centre for Advanced Timber Technology	Robert Hairstans	☑	☑	☐	☑	☑	☐	☑	☑	☐
2.02	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Stephen Good	☑	☑	☑	☐	☑	☐	☐	☑	☐
2.03	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Douglas Morrison	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.04	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Helen Maguire	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.05	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Kay Kennan	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.06	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Lynsey Brydson	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.07	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Mark Milne	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.08	UK - Scotland	BE-ST	Scotland Construction Innovation Centre	Sam Hart	☑	☐	☑	☐	☑	☐	☐	☐	☐
2.09	UK - Scotland	Stora Enso UK	Edinburgh Napier University	Mila Duncheva	☑	☑	☑	☑	☑	☐	☐	☐	☐
2.10	UK - Scotland	Fettes College	School		☐	☐	☑	☐	☐	☐	☐	☐	☐
2.11	UK - Scotland	MAKAR	Natural Homes Healthy Living	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
2.12	UK - Scotland	James Jones & Sons	Company		☐	☐	☑	☐	☐	☐	☐	☐	☐
2.13	UK - Scotland	OCD Construction + Manufacturing Group	David Crawford	☑	☐	☑	☐	☐	☐	☐	☐	☐
2.14	UK - Scotland	OCD Offsite Manufacturing (OSM)	Callum Murray	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.15	UK - Scotland	MAKAR	Neil Sutherland	☐	☐	☑	☐	☑	☐	☐	☐	☐
2.16	UK - Scotland	Ecosystems Technologies	Matt Stevenson	☑	☐	☐	☐	☑	☐	☐	☐	☐
2.17	UK - Scotland	Ecosystems Technologies	Gill Henry	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.18	UK - Scotland	Donaldson Timber	Alex Goodfellow	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.19	UK - Scotland	Donaldson Timber	Frank O'Reilly	☐	☑	☐	☐	☐	☐	☑	☐	☐
2.20	UK - Scotland	Gentor	Andy Leitch	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.21	UK - Scotland	Saint-Gobain Ecophon	Colin Campbell	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.22	UK - Scotland	Norscot Joinery Ltd	Callum Grant	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.23	UK - Scotland	South Lanarkshire College	David Innes	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.24	UK - Scotland	The Wee House Co.	Jennifer Higgins	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.25	UK - Scotland	University of Glasgow	Ken Gibb	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.26	UK - Scotland	Edinburgh Napier University| Built Environment Group	Kirsty Connell-Skinner	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.27	UK - Scotland	Robertson Timber	Nicola Jackson	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.28	UK - Scotland	South Lanarkshire College	Nicola Murray	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.29	UK - Scotland	Mass Timber Academy	Peter Wilson	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.30	UK - Scotland	Gala Homes	Robin Dodyk	☐	☐	☐	☐	☑	☐	☐	☐	☐
2.31	UK - Scotland	Scottish Futures Trust	Ryan Gosser	☐	☐	☐	☐	☑	☐	☐	☐	☐
3.00	**Japan**											
3.01	Japan	Ministry of Land, Infrastructure, Transport & Tourism (MLIT)	Government	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.02	Japan	Prefabricated Construction Suppliers and Manufacturers Association	Government	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.03	Japan	Building Center of Japan (BCJ)	Kimihiro Hashimoto	☑	☐	☑	☐	☐	☑	☐	☐	☐
3.04	Japan	Building Center of Japan (BCJ)	Noriaki Sasaki	☑	☐	☑	☐	☐	☑	☐	☐	☐
3.05	Japan	Japan Housing Finance (JHF) Agency	Government	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.06	Japan	University of Tokyo	Shuichi Matsumura	☑	☐	☑	☐	☐	☑	☐	☐	☐
3.07	Japan	University of Tokyo	Tomoyuki Gondo	☑	☑	☑	☐	☐	☑	☑	☑	☐
3.08	Japan	University of Tokyo	Motohiro Ishii	☐	☑	☑	☐	☐	☑	☐	☐	☐

Reference	Country	Organization	Name	Key Partner	Exchange Delegate	Exchange Host	UK England Workshop	UK Scotland Workshop	Japan Workshop	Sweden Workshop	U.S. Workshop	Peer Reviewer
3.09	Japan	Housing Stage Shinjuku – Prefab Model Home Exhibition	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
3.10	Japan	Daiwa House	Company	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.11	Japan	Alba Homes	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
3.12	Japan	Shimizu Corporation	Company	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.13	Japan	Sekisui House	Company	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.14	Japan	Sekisui House	Junichiro Takagi	☐	☑	☑	☐	☐	☑	☐	☑	☐
3.15	Japan	Sekisui House	Masaya Iwamoto	☐	☐	☑	☐	☐	☑	☐	☑	☐
3.16	Japan	Sekisui Chemical | Sekisui Heim	Company	☐	☐	☑	☐	☐	☑	☐	☐	☐
3.17	Japan	Sekisui Chemical | Sekisui Heim	Yasuhiro Shinto	☑	☐	☑	☐	☐	☑	☐	☑	☐
3.18	Japan	Sekisui Chemical | Sekisui Heim	Tetsuji Ando	☐	☑	☐	☐	☐	☐	☐	☑	☐
3.19	Japan	Sekisui Chemical | Sekisui Heim	Daiki Yamashita	☐	☑	☐	☐	☐	☐	☐	☑	☐
3.20	Japan	Sekisui Chemical | Sekisui Heim	Taku Sasaki	☐	☑	☐	☐	☐	☐	☐	☑	☐
3.21	Japan	Sekisui Chemical | Sekisui Heim	Masaya Iwamoto	☐	☑	☐	☐	☐	☐	☐	☑	☐
4.00	**Sweden**											
4.01	Sweden	Volumetric Building Companies | Lindbäcks Bygg AB	Helena Lidblöw	☑	☑	☑	☐	☐	☐	☑	☑	☑
4.02	Sweden	Swedish Wood Council | Sveriges Träbyggnadskansli	Susanna Rudenstam	☑	☑	☑	☐	☐	☐	☑	☑	☐
4.03	Sweden	BoKlok | Skanska & IKEA	Jorker Lessing	☑	☐	☐	☐	☐	☐	☑	☐	☐
4.04	Sweden	Västerbotten County	Helene Hellmark Knutsson	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.05	Sweden	Skellefteå Municipality	Lars Hedqvist	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.06	Sweden	Wood-City Skellefteå	Evelina Fahlesson	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.07	Sweden	The Wood Hotel | Sara Kulturhus	Anna Hedman	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.08	Sweden	Wood Innovation Cluster	Association	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.09	Sweden	Wood Industry North | Träbransch Norr | Luleå University of Technology	Lena Drugge	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.10	Sweden	Wood Technology | Träteknik | Luleå University of Technology	University	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.11	Sweden	Tree Center North | TräCentrum Norr	Bror Sundqvist	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.12	Sweden	Research Institutes of Sweden | RISE	Rickard Falkman	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.13	Sweden	Tree Unity | Träenigheten	Association	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.14	Sweden	Holmen | Martinsons	Company	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.15	Sweden	Lindbäcks Bygg AB	Stefan Lindbäck	☐	☐	☑	☐	☐	☐	☑	☐	☐
4.16	Sweden	White Architects	Oskar Norelius	☐	☐	☑	☐	☐	☐	☑	☐	☐
4.17	Sweden	SkellefteKraft	Patrik Sundberg	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.18	Sweden	Trähäbriken Project | Hammarby Sjöstad	Company	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.19	Sweden	Arvet | Strandparken Housing	Sandra Frank	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.20	Sweden	Folkhem | Cedar Houses	Company	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.21	Sweden	Sweden Ministry of Infrastructure and Housing	Government	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.22	Sweden	Swedish National Board of Housing, Building and Planning	Government	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.23	Sweden	Sweden-U.S. Green Transition Initiative (GTI)	Linda Andrén	☐	☐	☑	☐	☐	☐	☑	☐	☐
4.24	Sweden	Confederation of Swedish Enterprise	Government	☐	☐	☐	☐	☐	☐	☐	☐	☐
4.25	Sweden	Swedish Environmental Protection Agency | Naturvårdsverket	Simon Lindström	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.26	Sweden	Sweden Knowledge Foundation	Gabriel Granström	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.27	Sweden	Swedish Agency for Innovation Systems | Vinnova	Anna Ottenhall	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.28	Sweden	Swedish Municipal Housing Association | Sveriges Allmännytta	Sofia Hanssötter	☐	☑	☐	☐	☐	☐	☑	☑	☐
4.29	Sweden	Linnaeus University	Jimmy Johansson	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.30	Sweden	Linnaeus University	Åsa Rydell-Blo	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.31	Sweden	Växjö Linnaeus Science Park	Fredrik Lindblad	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.32	Sweden	Nordic Innovation House	Stina Berglund	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.33	Sweden	WoodCity Sweden	Jessica Backer	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.34	Sweden	Pod Comp	Peter Lundmark	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.35	Sweden	Randek	Paul Uhr	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.36	Sweden	MOKO	Patrik Jenson	☐	☐	☑	☐	☐	☐	☐	☐	☐
4.37	Sweden	The Labyrinth	Alf Karlsson	☐	☐	☑	☐	☐	☐	☑	☐	☐
4.38	Sweden	Bowrket	Lena Hagert Pfanäs	☐	☐	☐	☐	☐	☐	☑	☐	☐
4.39	Sweden	Bowrket	Oskar Larsson Ivanov	☐	☐	☐	☐	☐	☐	☑	☑	☐
4.40	Sweden	Bowrket	Tomas Carlsson	☐	☑	☐	☐	☐	☐	☑	☐	☐
4.41	Sweden	Swedish Energy Agency | Energimyndigheten	Veronica Eade	☐	☐	☐	☐	☐	☐	☑	☐	☐
5.00	**Ireland**											
5.01	Ireland	Department of Housing, Local Government and Heritage	Éadaoin Ní Fhearghail	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.02	Ireland	Department of Housing, Local Government and Heritage	Gareth Williams	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.03	Ireland	Department of Enterprise, Trade and Employment	Coline McHugh	☐	☑	☐	☐	☐	☐	☑	☑	☐
5.04	Ireland	Department of Enterprise, Trade and Employment	Manus O'Donnell	☐	☑	☐	☐	☐	☐	☐	☑	☐
5.05	Ireland	Forest Service, Department of Agriculture, Food and the Marine	Richard Walsh	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.06	Ireland	Coillte	Desmond O'Toole	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.07	Ireland	Irish Green Building Council	Alan Connolly	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.08	Ireland	Office of Public Works	Andrew Devenport	☐	☑	☐	☐	☐	☐	☑	☐	☐
5.09	Ireland	Enterprise Ireland | High Tech Construction & Housing	Tom Maguire	☐	☑	☐	☐	☐	☐	☑	☐	☐
6.00	**United States**											
6.01	United States	International Code Council (ICC)	David Tompos	☑	☑	☐	☑	☑	☑	☑	☑	☑
6.02	United States	International Code Council (ICC)	Ryan Colker	☑	☑	☐	☑	☑	☑	☑	☑	☑
6.03	United States	Terner Center for Housing Innovation | University of California Berkeley	Carol Galante	☑	☐	☐	☐	☐	☐	☐	☐	☐
6.04	United States	Terner Center for Housing Innovation | University of California Berkeley	Tyler Pullen	☐	☑	☐	☑	☑	☑	☑	☑	☐

Reference	Country	Organization	Name	Key Partner	Exchange Delegate	Exchange Host	UK England Workshop	UK Scotland Workshop	Japan Workshop	Sweden Workshop	U.S. Workshop	Peer Reviewer
6.05	United States	The Colton Housing Group	Kent Colton	☑	☐	☐	☐	☐	☐	☐	☐	☐
6.06	United States	Joint Center for Housing Studies of Harvard University	Christopher Herbert	☑	☑	☐	☐	☐	☐	☑	☑	☐
6.07	United States	Construction Revolution	Mary Tingerthal	☑	☐	☐	☐	☐	☐	☑	☑	☐
6.08	United States	Schemata Workshop	Grace Kim	☑	☑	☐	☐	☐	☐	☐	☑	☐
6.09	United States	Modular Building Institute (MBI)	Tom Hardiman	☑	☐	☐	☐	☐	☐	☐	☑	☐
6.10	United States	Modular Building Institute (MBI)	Ralph Tavares	☐	☑	☐	☐	☐	☑	☐	☐	☐
6.11	United States	VEIC	Alison Donovan	☑	☐	☐	☐	☐	☐	☐	☐	☐
6.12	United States	MUSSON Factory	Brent Musson	☑	☐	☐	☐	☐	☐	☐	☐	☐
6.13	United States	Minneapolis Public Housing Authority | Aeon	Juan Torre	☑	☐	☐	☐	☐	☐	☐	☑	☐
6.14	United States	National Renewable Energy Lab (NREL) | U.S. Department of Energy (DOE)	Shanti Pless	☑	☐	☐	☐	☐	☐	☐	☐	☐
6.15	United States	Volumetric Building Companies	Sara Ann Logan	☐	☐	☑	☐	☐	☐	☐	☑	☐
6.16	United States	Virginia Department of Housing and Community Development	Cindy Davis	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.17	United States	U.S. Department of Housing & Urban Development (HUD)	Government	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.18	United States	U.S. Department of Housing & Urban Development (HUD)	Jagruti Rekhi	☐	☑	☐	☑	☑	☑	☐	☑	☐
6.19	United States	U.S. Department of Housing & Urban Development (HUD)	Mark Reardon	☐	☑	☐	☐	☐	☐	☑	☑	☐
6.20	United States	U.S. Department of Housing & Urban Development (HUD)	Solomon Greene	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.21	United States	U.S. Department of Housing & Urban Development (HUD)	Regina Gray	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.22	United States	U.S. Department of Housing & Urban Development (HUD)	Mike Blanford	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.23	United States	U.S. Department of Housing & Urban Development (HUD)	Dan Hardcastle	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.24	United States	U.S. Department of Housing & Urban Development (HUD)	Todd Richardson	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.25	United States	U.S. Department of Housing & Urban Development (HUD)	Tanaya Srini	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.26	United States	U.S. Department of Housing & Urban Development (HUD)	Alaina Stern	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.27	United States	U.S. Department of Housing & Urban Development (HUD)	Meron Habte	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.28	United States	U.S. Department of Housing & Urban Development (HUD)	Terese Payne	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.29	United States	U.S. Department of Housing & Urban Development (HUD)	Sarah Lee	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.30	United States	U.S. Department of Housing & Urban Development (HUD)	Carlyn Cullen	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.31	United States	U.S. Department of Housing & Urban Development (HUD)	Nicola Green-Colton	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.32	United States	U.S. Department of Housing & Urban Development (HUD)	Julie Gordon	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.33	United States	U.S. Department of Housing & Urban Development (HUD)	Cliff Kamegay	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.34	United States	U.S. Department of Housing & Urban Development (HUD)	David Fleishman	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.35	United States	U.S. Department of Housing & Urban Development (HUD)	Alexis Polosi	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.36	United States	U.S. Department of Housing & Urban Development (HUD)	Jennifer Turnham	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.37	United States	U.S. Department of Housing & Urban Development (HUD)	Claudia Monterrosa	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.38	United States	U.S. Department of Agriculture	Kevin Naranjo	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.39	United States	U.S. General Services Administration (GSA)	Matt Hoffman	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.40	United States	U.S. Department of Energy (DOE)	Jay Wrobel	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.41	United States	U.S. Department of the Treasury	Ellen Lurie Hoffman	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.42	United States	National Economic Council	Aaron Shroyer	☐	☐	☐	☐	☐	☐	☐	☑	☐
6.43	United States	Federal Emergency Management Agency (FEMA)	Jeffrey Dorko	☐	☑	☐	☐	☐	☐	☐	☑	☐
6.44	United States	Saint-Gobain | CertainTeed	Dennis Michaud	☐	☑	☑	☐	☐	☑	☑	☑	☐
6.45	United States	Saint-Gobain | CertainTeed	Christopher Reed	☐	☑	☑	☑	☑	☑	☑	☐	☐
6.46	United States	Rocky Mountain Institute	Lucas Taffoli	☐	☑	☐	☑	☑	☐	☑	☑	☐
6.47	United States	Synergy Inc | Synergy Modular	Justin Stewart	☐	☑	☐	☑	☑	☑	☑	☑	☐
6.48	United States	Port of Portland	Terese Carr	☐	☑	☐	☑	☑	☐	☐	☐	☐
6.49	United States	Port of Portland	Kenneth Anderton	☐	☑	☐	☑	☑	☐	☐	☐	☐
6.50	United States	Entelro | Offsite Tek	Garry McGaughey	☐	☑	☐	☑	☑	☐	☐	☐	☐
6.51	United States	Van Metre Homes	Christopher Fox	☐	☐	☑	☐	☐	☐	☐	☑	☐
6.52	United States	Ivory Innovations	Jenna Lovio	☐	☑	☐	☐	☐	☑	☑	☑	☐
6.53	United States	Ivory Homes	David Broadbent	☐	☑	☐	☑	☑	☐	☐	☐	☐
6.54	United States	Ivory Homes	James Jonsson	☐	☐	☐	☐	☐	☐	☐	☐	☐
6.55	United States	Whelan Advisory	Currey Cornelius	☐	☑	☐	☐	☐	☑	☐	☐	☐
6.56	United States	Connect Homes	Greg Leung	☐	☑	☐	☐	☐	☑	☐	☐	☐
6.57	United States	City of Boston Mayor's Office of Housing	Jessica Boatright	☐	☑	☐	☐	☐	☐	☑	☐	☐
6.58	United States	Timberlab	Erica Spinitos	☐	☑	☐	☐	☐	☐	☑	☐	☐
6.59	United States	Mercer Mass Timber | Mass Timber Systems	Todd Beyreuther	☑	☑	☐	☐	☐	☐	☑	☑	☐
6.60	United States	New York Times	Francesca Mari	☐	☑	☐	☐	☐	☐	☑	☐	☐
6.61	United States	City of Boston Mayor's Housing Innovation Lab	Paige Roose	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.62	United States	City of Boston Mayor's Office of Housing	Jay Lee	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.63	United States	City of Boston Mayor's Office of Housing	Karl Heckman	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.64	United States	City of Boston Mayor's Office of Housing	Jona Sulag	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.65	United States	Metropolitan Area Planning Council	Andrea Harris-Long	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.66	United States	MIT Center for Transportation and Logistics	Lauren Finegan	☐	☑	☐	☐	☐	☐	☐	☐	☐
6.67	United States	MIT Center for Transportation and Logistics	Jarrod Goentzel	☐	☑	☐	☐	☐	☐	☐	☐	☐



March 2026