

Off-site Construction in an On-site Regulatory World: Streamlining the Path to Decarbonized Homes

Ian Blanding, Pacific Northwest National Laboratory

Ryan Colker, International Code Council

Diana Fisler and Alyssa Watson, ADL Ventures

Lucas Toffoli, RMI

Abstract

Numerous industry actors view off-site and industrialized construction as a primary solution to help alleviate the housing affordability and availability crisis while enhancing energy efficiency and greenhouse gas reductions at scale. Modernized off-site practices promise reduced construction times, improved quality control, safer working conditions, and economies of scale — reducing the cost and risk to construct decarbonized and high-performance homes. Interest in off-site construction is growing as the building industry addresses multiple societal and industry challenges, from the availability of workers to affordable housing to sustainability. According to a Home Innovation survey (HIRL 2021), a significant percentage of home builders expect to increase the use of off-site construction in the next 5 years. This may be in part due to housing availability trends. Demand is growing while supply — including skilled labor, materials, and property — is decreasing. However, barriers to widespread use of industrialized construction remain, with regulatory hurdles including a patchwork of building codes, inconsistent state and local enforcement programs, restrictive zoning ordinances, and misunderstandings around the compliance pathway for various processes and approaches. This creates a market where repeatability and economies of scale — key success factors — become more difficult to achieve.

This paper will explore these barriers and the structural solutions in process. These include industry education and off-site construction standards development — as well as future opportunities to streamline the off-site construction process and ensure a more affordable, energy-efficient, and decarbonized housing stock.

Introduction

By 2050, the world's population is expected to grow by 2 billion people, almost 70% of the global population will live in city centers, and the global building stock is expected to double. This massive rise in construction comes with a one-third increase in global material use, which is expected to double overall by 2060 (WGBC 2021). The boom in construction activity and material use will put an ever-increasing and unsustainable demand on the environment if historic construction practices persist. In the U.S. and globally, the construction industry continues to lag in productivity gains, having only averaged a 1% increase over the last two decades, as compared to a 3.6% increase in the manufacturing sector (Barbosa et. al 2017). According to this same report, construction labor productivity shrunk in the U.S. while it increased in countries like Germany, Belgium, Australia, Sweden, and many others from 1995 to 2015. Productivity and advancements must also account for the increase in frequency and intensity of climate-induced disasters, rebuilding previously devastated communities, and retrofitting existing stock to withstand future climate uncertainties for public safety, health, and security. Coupled with the immediate need to reduce greenhouse gas emissions and integrate resilience measures into the built environment, the next generation of construction needs to focus on sustainability and zero-energy solutions to prepare for the future. The current state of the construction industry will not

enable us to achieve these goals; a faster, cost-effective, cleaner and less carbon-intensive approach must be implemented at an unprecedented speed and scale.

Industrialized construction (IC) refers to the application of modern manufacturing practices to optimize construction. It commonly involves off-site construction and prefabrication (such as modular or panelized methods), repeatable elements, mass production or mass customization of building components, digital tools, and integrated workflows. IC often builds on advancements in technology and practices. This paper will focus on the regulatory framework of off-site construction practices in a factory setting — a subset of IC.

Off-site construction as a practice is often touted for its ability to reduce build times, lower costs, improve quality and performance, reduce environmental impact, create safer working environments, and increase overall construction productivity (Dodge 2020). Despite these many positive attributes, off-site construction currently represents a fraction of the overall construction industry. In 2020, just 3% of single-family homes and 1% of multifamily buildings were constructed using off-site practices (Skillington 2021). There are many reasons why this is the case, with typical challenges being related to the structure of real-estate capital and financing, manufacturing availability, design processes, fragmented building regulations, lack of industry education, and unfavorable perceptions by owners (Dodge 2020).

However, according to a recent report, changes to the construction industry, including increased use of off-site practices, need to happen sooner rather than later. *A combination of sustainability requirements, cost pressure, skills scarcity, new materials, industrial approaches, digitalization, and a new breed of player looks set to transform the value chain. The shifts ahead include productization and specialization, increased value-chain control, and greater customer centricity and branding* (Ribeirinho et. al 2020).

Addressing the challenges mentioned above is paramount in order for the off-site industry to grow more freely and produce the many potential social and environmental benefits it can support. This paper seeks to better elucidate the structure of building regulations — from building codes to zoning — and specific regulatory challenges impacting the off-site industry in the U.S. Additionally, this paper will provide insight into how off-site is regulated in Japan, Sweden, and Germany, three countries with relatively high rates of off-site construction, and identify best practices and future opportunities to streamline off-site regulatory processes and enable faster off-site market growth.

Building Decarbonization Potential

President Biden’s vision of a net-zero carbon economy by 2050 can only be fully realized with structural changes to the way we construct and retrofit our buildings. Across the entire value chain, construction and buildings account for approximately 37% of greenhouse gas (GHG) emissions globally, which include the GHG intensity associated with material manufacturing, the construction process and continued building operation, and decommissioning (GlobalABC 2021). Additionally, buildings are one of the highest users of freshwater during construction and operation, global construction waste is expected to reach 2.2 billion tons per year by 2025 (TMR 2018), and the construction process can pollute the environment through material manufacturing, job site runoff, and other sources. If implemented effectively, industrialized and off-site construction practices can introduce important changes necessary to address both embodied and operational carbon of buildings in a holistic and cost-effective manner. Through continued advancements in low-carbon building materials and streamlining processes from building design and energy modeling to the mass production of prefabricated low-carbon and highly efficient

building systems, the carbon intensity of both the construction process and long-term building operation can be dramatically reduced.

To help increase the pace at which industrialization of the construction industry occurs, the U.S. Department of Energy's (DOE's) Building Technologies Office (BTO) launched the Advanced Building Construction (ABC) Initiative in 2019. The focus of this initiative is to accelerate the decarbonization of the U.S. residential and commercial building sectors at the speed and scale needed to achieve a zero-carbon economy by 2050 and address the long-term affordability crisis in this country through industrialized construction practices. Faster, more replicable, affordable, and appealing solutions are critical to increasing the low uptake of high-performance, low-carbon building renovation and construction practices and solutions (Goldstein, Turnbull, and Higgins 2018).

The ABC Initiative specifically supports decarbonizing the building stock by developing, demonstrating, commercializing, and deploying innovations that lead to low-carbon buildings that are also high-performance, affordable to developers and consumers, faster and easier to construct, and provide added value for consumers — such as resilience, indoor air quality, reduced maintenance, and improved comfort.

Off-Site Manufacturers

The decarbonization potential of the off-site construction industry is evident in the growing number of off-site manufacturers offering net-zero energy homes, reduced operational and embodied carbon, passive house certified buildings, and homes that exceed national model energy code requirements.

Two examples of zero-energy off-site manufacturers come from California, a state with a robust off-site code compliance program and progressive energy codes. In 2019, Plant Prefab took decarbonization goals upon itself and became the first off-site manufacturer to pledge to become carbon neutral by 2028. Guided by six core principles of a circular, net-zero cradle-to-cradle manufacturing process (zero energy, water, emissions, waste, carbon, and ignorance), Plant Prefab has achieved monumental strides towards a decarbonized construction process. Plant Prefab's LivingHomes are designed to be self-sufficient and exceed California's increasingly stringent minimum energy code requirements, with the newest model surpassing California's Title 24 energy standards by 51% (Plant Prefab 2019). Plant Prefab goes a step further to reduce emissions and recycle construction waste in a cradle-to-cradle cycle that is analyzed for emissions that are then offset by the company.

Mighty Buildings is another company leading the zero-energy manufacturing wave alongside Plant Prefab. Mighty Buildings, an off-site manufacturer of 3-D printed homes and accessory dwelling units in California, takes a similar approach to transparency. Mighty Buildings' manufacturing process eliminates 95% of construction waste and utilizes recyclable materials. According to company estimates, one Mighty House eliminates the CO₂ emissions of driving 5,026 miles, twice the distance from Atlanta to San Francisco as compared to constructing a conventional home (Mighty Buildings 2022).

One off-site manufacturer has focused on automation and software to reduce waste, address code barriers, and streamline the construction process. Autovol, an Idaho-based robotic volumetric manufacturer, utilizes its partner company, Prefab Logic, to navigate code compliance pre-emptively through design. Prefab Logic aggregates local building code regulations to inform module design. This upstream effort then becomes the blueprint for

Autovol’s robotic manufacturing line, allowing Autovol to manufacture jurisdictional compliant modules for any state for any project (Autovol 2021).

These companies are prime examples of the paradigm shift needed in the construction industry to meet the housing demand in an environmentally conscious manner. However, they also understand that in order for their innovative approach to be accepted in the marketplace, they need to educate both consumers and practitioners. As we will discuss throughout, off-site construction faces additional regulatory barriers, including a patchwork of building codes, inconsistent state and local enforcement programs, restrictive zoning ordinances, and misunderstandings around the compliance pathway for various processes and approaches.

Regulatory Framework and Barriers

Building codes serve as the primary mechanism for assuring public safety, sustainability, and resilience in the built environment. In the U.S., the adoption and enforcement of these codes largely fall to state and local governments. The processes for adoption and the extent of enforcement can vary widely from state to state. Some states adopt codes that apply across the state and are enforced at the local level. Others establish a minimum code that local jurisdictions must adopt (or exceed) if the locality adopts a code. In other states, the adoption of codes is left solely to the local jurisdiction. There are also variations in how frequently codes are updated. This framework leads to a patchwork of building codes across individual states and the country as a whole, which is manageable — and, in some cases, preferable — to local builders and designers but creates confusion and uncertainty among off-site manufacturers providing products across multiple jurisdictions or the whole country.

In jurisdictions that adopt codes, most U.S. states and communities choose the International Codes (I-Codes) developed by the International Code Council (ICC) as the basis for their codes. The I-Codes are model codes developed through a consensus process that brings together expertise from across the building industry. While many jurisdictions amend the I-Codes for their particular circumstances, the national-level process supports consistency, affording designers, manufacturers, and others some degree of efficiency across jurisdictions.

The model codes are updated every three years to capture lessons learned from post-disaster assessments and from research and new technologies and practices entering the marketplace. However, even with frequent updates, it is impossible and impractical to cover every new technology and process explicitly in the code. Therefore, the codes typically include pathways for “alternative means and methods” or performance-based compliance methods.

Off-Site Construction Programs

Most codes are written from the perspective of site-built construction, yet off-site construction still must comply with the code in place at the final job site. Additionally, the traditional inspection process for construction is based on the notion that an inspector can visit the job site at regular intervals and see the building at various stages in the construction process. This assumption can create challenges for off-site construction projects.

Several strategies have emerged for addressing these challenges. While some states have established programs to regulate the off-site components of projects, state programs differ from one another in processes, regulatory agencies, and requirements. ICC and the Modular Buildings Institute (MBI) have developed standards to help verify an off-site construction project’s compliance with applicable codes while also retaining the inherent efficiencies in the off-site construction process. Off-site construction components may also use product approval

mechanisms including product evaluations that are contained within the codes. We will cover each of these mechanisms in further detail below.

Thirty-nine states regulate off-site construction at the state level. This means that the off-site construction elements of a project are reviewed and inspected under the auspices of a state off-site construction building program (sometimes called industrialized buildings, factory-built buildings, prefabricated buildings, or some other similar term). Each office has different rules on the types of off-site construction (volumetric or non-volumetric) and construction segment (residential, commercial, or both) it covers, whether it allows third-party plan review and/or inspection, and whether inspections can be done through remote virtual inspections (RVI). In these states, all on-site elements of the project and the assembly of the off-site construction components at the job site are the responsibility of the local authority having jurisdiction (AHJ).

In states without statewide programs, the regulation of off-site construction falls solely on the local jurisdiction. This can be a challenge as local governments often do not have the necessary expertise to administer off-site projects or the resources to develop it. Off-site construction manufacturers can be hundreds or even thousands of miles from the final job site and are often outside the jurisdiction of local code officials. In many cases, the jurisdiction can work with a third-party provider to do plan review and inspection, but the process needs to be established on a project-by-project basis.

Salt Lake City, Utah is in a state without a statewide program, but like most of the country, is dealing with an affordable housing crisis. The city government saw off-site construction as a tool to help address this, however, existing city ordinances required all inspections to be conducted by city inspectors while also not allowing inspectors to leave the jurisdiction. This had the effect of restricting the use of off-site construction in the city. The City Council adopted ICC/MBI Standards 1200 and 1205 in March 2021 to support a consistent process for off-site construction projects that leverages the expertise of third-party inspection agencies.

While the Standards have been primarily used to inspect and approve the construction of prefabricated accessory dwelling units (ADUs), the city has already seen a substantial increase in housing: in less than a year, 30 ADUs have been completed, 17 are in inspection processes, 11 plans are under review, and 34 permits are pending. Salt Lake City is also actively engaging with off-site manufacturers to plan an affordable housing development of 50 units for low-income individuals and families.

Off-site Construction Standards

Many of the benefits inherent in off-site construction come from the efficiencies gained in replicability. As indicated above, the regulatory approach to off-site construction can vary considerably. Considering off-site construction requirements early in the project can help realize the greatest benefits. Recognizing the value standards could play in furthering the use of off-site construction, ICC and MBI came together in late 2019 to start the development of two new standards — Standard 1200 to cover planning, design, fabrication, and assembly of off-site construction and Standard 1205 to address regulatory compliance and inspection. The Standards were completed in September 2021.

Standard 1200 outlines the policies and procedures for architects, engineers, manufacturers and assemblers of off-site construction, setting the stage for an effective regulatory review. The standard speaks to the roles and responsibilities of each party, the application of labels and decals, and the setup and content of quality assurance programs. These

requirements dovetail with Standard 1205, which covers the role of code officials and third-party plan review and inspection agencies. The standards also include definitions for many off-site construction terms — aiming to reduce confusion.

Currently, work is underway on ICC/MBI Standard 1210 to cover mechanical, electrical and plumbing systems, energy efficiency, and water conservation in off-site construction. This standard will help further enhance the sustainability of off-site construction by identifying where specific characteristics can be leveraged to improve energy or water savings. For instance, air sealing of volumetric modules can be achieved effectively and then tested in the factory before arriving at the jobsite. Additionally, the connections of building systems between off-site components are an important part of the process and a potential point of failure. Finally, mechanical pods (e.g., packaged HVAC and sometimes water heating systems) or multi-trade racking (e.g., metal rack with packaged HVAC, electrical, water infrastructure) have emerged as off-site construction strategies.

International Approaches to Building Codes and Off-Site Construction

From an international perspective, Sweden, Japan, and Germany have a more established off-site construction sector than the U.S. In these countries, off-site construction practices makeup between 10 and 20% of the market and, for certain building types, comprise much more — as much as 90% in the case of Sweden’s single-family-residential segment (Steinhardt and Manley 2016). Structural, social, and political differences between these countries and the U.S. in terms of land availability, owner preferences, and policies and incentives may have matured the off-site construction industry in these countries. An often-forgotten aspect is an analysis of how regulatory frameworks are structured to enable, or at least not discourage, off-site construction. Although this paper is not intended to provide a detailed assessment of building regulations across these countries, the discussion that follows introduces how their regulations are structured in the context of off-site construction.

Out of these three countries, Germany is the most similar to the U.S. in terms of its building code development and implementation framework. In Germany, although a national Model Building Ordinance exists, it is primarily a recommendation to the states; each of the 16 federal states develops a legally binding Building Ordinance that is tailored to its climate and construction practices. Building codes in Japan, on the other hand, are more centrally regulated. Japan’s National Building Standard and Fire Service Laws ensure structural, health, and fire safety in buildings, with localized seismic zone requirements. Japan does allow jurisdictions some flexibility to enforce supplemental requirements and “promotional laws” such as energy conservation (Tomohiro 2013). In Sweden, national rules are established through the Planning and Building Code, Building Ordinance, and the Boverkets Building Regulations (BBR) or National Board of Housing and Building regulations, which are updated regularly to ensure minimum acceptable levels of performance for ventilation, fire protection systems, electricity consumption, and accessibility. In addition to BBR, some EU construction standards will apply (Hansson 2017).

As in the U.S., building code plan review, permitting, and inspections occur at the state or local level in Germany, Sweden, and Japan. The structure in place in Germany and Sweden is nearly identical to that of the U.S., whereas Japan is unique. Japan extensively uses third-party inspectors and designated inspection bodies with varying degrees of authority, from specific districts to countrywide authority. Japan implemented the use of private inspectors in 1999 to help address complaints of slow approvals. This program grew quickly: private inspectors

inspected approximately 2% of buildings in 1999 but 85% by 2013 (ERI 2014). It is probable that the more centralized and standardized set of building regulations in Japan and Sweden, and the expanded use of private inspectors in Japan, reduce complexities and approval times with building code requirements for off-site construction.

Another enabler in these countries may be type approval. Type approval is a process whereby a particular building system, component, or even entire unit type and manufacturing process can receive certification that it fulfills relevant building regulations and can cut through off-site regulatory hurdles (Hansson 2017).

In Japan, “Type Approval” and “Specific Provisions of Approval of Manufacturers” were introduced in the building code in 2000 to streamline the approval process of manufactured building products such as prefabricated components, where materials and assembly are consistent during the manufacturing process. Designated approval bodies are certified by the Ministry of Housing to provide these approvals and ensure products and manufacturers meet the specifications of the building codes. Once building components are approved, an on-site building inspector need only to confirm that a given installed component is of an approved type (Tomohiro 2013). Although Germany removed type-approval legislation specific to modular multifamily building components across the country in 2000, there were recent discussions about this legislation (Hansson 2017). Hamburg and North-Rhine Westphalia are currently the only two states in the country still allowing it, but if it were reintroduced nationally, all states would be required to accept it. The way type approval worked in Germany was as follows: 1) Approval was granted for a specific type of building or system, 2) Approval was granted for 5 years with a possible 5-year extension, 3) Type approval was accepted across all states, 4) Developers needed to apply for a building permit, but components covered under type approval were not scrutinized again during the building permit process (Hansson 2017).

Sweden does allow type approval in the BBR, but it is unclear if an approved prefabricated assembly would also need to be inspected for local building code compliance. Sweden, like Germany, is interested in creating a framework to streamline the approval process for off-site construction methods with type approval as one of those options (Hansson 2017). In the U.S., the concept of type approval is most similar to the product evaluation process.

Product Evaluation in the U.S.

New and innovative products can often have a difficult time entering the marketplace. Code officials, designers, contractors, owners, and other stakeholders may be unsure of the product's efficacy or whether it complies with building codes. Product evaluation fills this gap. Organizations like the ICC Evaluation Service (ICC-ES), Underwriters Laboratories (UL), Intertek and others provide product evaluation services for many types of building products including those considered under off-site construction (For example, ICC-ES evaluates structural building products from shipping containers and sandwich panels including SIPs).

Product evaluation is a process whereby an accredited and trusted third party reviews the testing or engineering analysis of a product against codes, standards, or other criteria to assure compliance. Once the analysis is completed and the product is determined to meet a specific requirement, an evaluation report is issued. This evaluation report can provide assurance to the building industry that a recognized authority has reviewed the product, opening larger avenues for the product to be specified and installed with minimal hindrances. Periodic audits are performed to ensure products continue to comply with the scope of the original evaluation.

Where specific standards or criteria for a product have not yet been developed or code provisions are not sufficiently clear, an Acceptance Criteria can be created. Without a recognized product evaluation process, testing and verification falls to individual jurisdictions. With potentially different requirements in each jurisdiction, product manufacturers may need to conduct multiple tests, adding expense, delay, uncertainty, and inconvenience to the widespread deployment of a product.

Plan Review and Inspection or Product Evaluation?

Since off-site construction can be a new process for many in the building industry, navigating the different processes for receiving approval can be complicated. Below are a few considerations that can inform the decision of whether to go through a statewide program or through a product evaluation pathway.

- Products that are open construction (i.e., can be easily inspected at the final job site, including key parts and connections, without disassembly, damage, or destruction) are generally conducive to product evaluation.
- Products that are closed construction (i.e., that cannot be inspected at the installation site without disassembly, damage, or destruction) are generally covered by state-wide off-site programs. However, if a product is commoditized or is produced in large quantities with limited variation, a product evaluation report may be implemented.
- In some cases, a hybrid approach may be necessary. For instance, in the case of repurposing shipping containers, ICC-ES has acceptance criteria for the structural aspects but, when the container is intended to be used as part of a building, plan review and inspection may be required.

Zoning Regulations

Zoning regulations are the DNA of the built environment: as a regulatory tool by which a community is divided into separate districts based on activity and use, zoning regulations determine how neighborhoods function. Comparable to the fragmentation of the building code landscape, zoning regulations differ on multiple scales ranging from individual pieces of land to cities, municipalities, and states. Permissible zoning frameworks are typically determined at the state level, while local governments hold the authority to develop and enforce specific zoning ordinances.

Traditional Zoning Regulations

Zoning has been traditionally differentiated by a few key aspects of intended use, including activity, the intensity and density of activity, and the shape of activity. Euclidean (also known as exclusionary) zoning is the predominant zoning framework in the U.S. Euclidean zoning typically separates land plots into four distinct categories based on approved land use (often with further sub-categories within each of these): single-family residential, multi-family residential, commercial, and industrial. This type of zoning permits or prohibits activities on designated land lots to enforce the separation of activities — for example, prohibiting industrial activities next to residential lots to limit residents' exposure to pollution. While Euclidean zoning offered many benefits to industrializing cities, the practice has created persisting negative environmental and social effects for modern cities — including exacerbating housing shortages and introducing additional regulatory barriers for advanced building construction practices (French 2019).

Due to Euclidean zoning regulations, nearly 75% of residentially zoned land in the U.S. is restricted to detached single-family homes. Single-family detached residential lots account for some 80% of residentially zoned land in Seattle, Washington, and a staggering 94% in San Jose, California (Badger and Bui 2019). The historic use of Euclidean zoning has promoted urban and suburban sprawl, decentralization, and has exacerbated housing shortages in many U.S. cities by creating patterns of development with extended and inefficient infrastructure systems (French 2019). As the number of people living in cities continues to increase, the rigidity of Euclidean zoning restricts the ability of communities to adapt to changing circumstances and address modern problems.

While exclusionary and restrictive zoning regulations apply to all aspects of building construction, off-site construction faces additional regulatory barriers due to zoning regulations. Zoning regulations tend to be most restrictive in densely populated metropolitan areas, where housing demand is high. Urban infill projects could benefit from the time and cost savings offered by the standardization of off-site construction practices (Pullen 2022). However, infill projects can be easily ensnared in complex local zoning constraints around irregular lot geometry, height, setback and complicated requirements for on-site installation of off-site construction assemblies (Pullen 2022). These zoning constraints interfere with off-site construction's standardization and ability to realize widespread adoption, weakening its potential to help meet housing needs effectively. In 2017, Michigan's Supreme Court ruled to remove a partially prefabricated home from its final site for being in violation of the neighborhood's zoning regulations on the basis of consisting of prefabricated modular components (Hirzel 2019). While the court overturned the decision in 2019, it was far too late for that project — restrictive zoning laws remain a frequently overlooked barrier for off-site construction.

In addition to zoning restrictions on land use, homeowner associations (HOAs) and private covenants can create another set of barriers for off-site construction (Owens 2020). Restrictive covenants are legal tools that are attached to real property deeds and used to permit or prohibit land use activities by owners or neighborhoods. Covenants have commonly been used to prohibit HUD-regulated manufactured housing from neighborhoods on the basis of these being built off-site and claims improper placement, which can decrease the value of neighborhoods (Geary 2013). However, in many instances, the covenants have been applied to restrict modular or other prefabricated houses. Covenants allow for the continued restricted use of modular construction in many areas, primarily in the American South (Geary 2013). State policy and zoning ordinances can override restrictive covenant policies, which is further discussed in the policy recommendation section of this paper.

Zoning Reforms

In December 2018, Minneapolis' city council voted to eliminate single-family zoning to allow for up to three dwelling units on residential lots to help address the affordable housing shortage. California took a similar approach in 2021 with SB9, the Housing Opportunity and More Efficiency (HOME) Act, a statewide bill that now allows additional residential units on most single-family zoned lots. Early evidence from zoning reforms to allow for accessory dwelling units (ADUs) on residential lots suggests these contribute to an increase in overall affordable housing (Pullen 2022). An ADU or small infill home constructed off-site can be deployed and connected on-site within days, eliminating the neighborhood disruption created by lengthy site-built new construction practices.

In a similar vein to Minneapolis and California, Salt Lake City — in addition to adopting ICC/MBI 1200 and 1205 — reformed its single-family residential zoning ordinances in 2017 to allow ADUs to be added to single-family residential lots. The permitting of additional housing units has allowed Salt Lake City to begin to ease its affordable housing shortage. On the other side of the country, Boston is using zoning reforms to support its net-zero by 2050 climate goals by identifying strategies to strengthen green building zoning requirements to a net-zero carbon standard for new construction (BPDA 2022).

Although zoning regulations can introduce additional barriers, reforms to existing ordinances can incentivize affordable housing and sustainable construction practices, providing an inherent opportunity for off-site construction.

Recommendations

As discussed throughout, the regulatory framework for U.S. buildings creates challenges for off-site construction. The decentralized and fragmented nature of building codes and zoning ordinances throughout the country erodes the efficiencies of the off-site construction process, given the need to customize each product to fit local requirements. In order to scale this industry and unlock its ability to help meet the need for affordable, resilient, zero-carbon buildings, enabling standardization and mass production of building components is essential. The following set of recommendations organized in order of implementation difficulty is intended to help address some of the current building regulatory challenges and achieve a more streamlined approach to off-site construction inspection and approvals.

Education for Supply Chain and Demand Stakeholders

Even though off-site construction practices were introduced decades ago, their relatively small overall adoption means many in the construction industry remain unfamiliar with the design, construction, and inspection process for off-site products. This general lack of knowledge among code officials, designers, builders, engineers, and ultimately homeowners and developers, commonly leads to misperceptions and potential reluctance to use or accept off-site construction. A recent survey of off-site construction barriers found that the limited availability of prefabrication shops, a trained workforce to install the off-site components, and lack of interest in prefabricated elements from the client are top challenges to the industry (Dodge 2020). Combining these challenges with the anecdotal information of local building departments not fully understanding off-site inspection processes at the factory creates a tremendous opportunity for broadscale workforce and demand-side education and training programs.

Increased education and training of code officials on the various off-site construction processes, their approval, and the roles and responsibilities of parties in these processes (particularly third-party plan review and inspection agencies, state code officials and local officials) will be valuable for AHJs and the off-site industry alike — not to mention the communities that will benefit from readier availability of high-quality, high-performance housing. ICC is developing a suite of courses for code officials and others with existing courses providing an introduction to off-site construction and on using the ICC/MBI Standards already available.

Developing a set of educational resources on off-site construction and inspection processes applicable across the country would go a long way in avoiding confusion and potentially garnering more support and acceptance of this construction approach.

Supporting Consistency in Regulation and Approvals

Expanding the use of off-site construction and capturing the efficiencies inherent in the process requires ensuring every stage in the process is optimized — including the regulatory process. Factories shipping to multiple states currently must navigate the differing regulatory regimes of various states (and even of local agencies, where state programs do not exist). Further, when engaging local AHJs, the level of familiarity with off-site construction practices and their effective inspection and approval can vary significantly.

Consistency in how off-site construction is regulated and approved can further enable its use. For example, widespread adoption of the ICC/MBI standards could drive harmonization across states and localities.

Remote Virtual Inspections

During the COVID-19 pandemic, remote virtual inspections (RVI) became a necessary building inspections tool to ensure the safety of building inspectors and builders without compromising the delivery of needed housing. At its simplest, “RVI is a form of inspections that use visual or electronic aids to allow an inspector or team of inspectors to observe certain types of construction, products and/or materials from a distance” (ICC 2020). Best practices on the use of remote virtual inspections are already available and growing. The ICC has produced a Recommended Practices for RVI document, is working with the DOE to produce protocols for using remote inspections with the IECC, and is developing a standard for virtual inspection of energy and water attributes with the Residential Energy Services Network (RESNET).

According to a recent survey of code officials and manufacturers, RVI is being offered as an inspection option in 42% of responding jurisdictions, with most of the responses clustering in the West and Southern regions of the U.S (Egelkamp and Riley 2021). Although respondents in this survey had some projects pertaining to on-site construction practices, RVI has also been implemented successfully during the inspection of off-site manufacturing plants. One example of this was the inspection of a modular citizenM hotel being constructed in Washington, D.C., by an off-site manufacturing firm in Poland. The District’s Department of Consumer and Regulatory Affairs (DCRA) approved procedures developed by the third-party inspection firm ICC-NTA to perform all inspections entirely virtually (Colker 2021).

This is just one example of RVI supporting off-site inspection processes and, to create a streamlined and replicable model, additional research, field demonstrations, and more sophisticated technologies will need to be developed. If RVI technology such as strategically placed video cameras, telepresence robot inspectors, and integrated sensors and computer programs to automatically identify material use and flag non-compliance can be considered during the initial design of a manufacturing plant, RVI could reduce inspection costs and streamline the inspection process. Through the adoption of ICC/MBI 1200 and 1205, jurisdictions have the authority to allow the use of RVI in an off-site manufacturing plant so, as this standard is adopted across the U.S., the use of RVI in this setting may grow and new technologies could emerge.

Code and Standards Adoptions

The adoption of codes across the U.S. varies widely. The Federal Emergency Management Agency (FEMA) reports that about two-thirds of the country has not adopted modern, hazard-resistant codes. Further, 30 percent of the nation's construction activity is in communities without codes or with codes preceding the turn of the century (FEMA 2020). While

the model codes are updated every three years to capture new research and technologies, jurisdictions using older codes do not capture these improvements. New products and processes can generally be used in these jurisdictions, but approvals may need to be done inefficiently on a project-by-project basis.

This diversity of codes can also hinder manufacturers and designers who need to navigate different requirements depending on the project or market. The off-site construction industry is particularly challenged as efficiencies in the process can be eroded by navigating each jurisdiction's requirements. The ICC/MBI standards are intended to help address some of these inconsistencies but are limited in their impact until adopted at the state or local level.

Additionally, with respect to energy efficiency and GHG reductions, the International Energy Conservation Code (IECC) has made significant improvements. According to DOE, the residential provisions in the 2021 edition should yield a 9.4% improvement in energy savings and an 8.6% reduction in GHG emissions over the 2018 edition (DOE 2021) and represents approximately a 40% improvement in energy efficiency for residential and commercial buildings compared to the 2006 edition. Improvements in the residential and commercial provisions of the IECC since 2009 will provide over 350 million metric tons (MMT) of CO₂ savings for residential buildings and 340 MMT for commercial buildings, totaling nearly 700 MMT of savings.

ICC, along with a dozen organizations that include trade groups, regional energy efficiency organizations, and energy efficiency advocates, launched the Code on a Mission campaign to get about one-third of the U.S. population covered by a code that meets or exceeds the 2021 IECC by the end of 2023. Adopting the latest codes and standards across the country can create much needed consistency for the off-site industry — and important gains in meeting critical climate goals.

Stretch Energy Codes

A stretch or “reach” code is a set of building standards or compliance requirements, more aggressive than the base code, that can be a voluntary alternative or locally mandated. In the U.S., these codes have typically been implemented to help achieve energy or climate goals, provide an option for a city to move faster than the base state code, create a program framework for energy utilities, and prepare or push the construction industry for future base code requirements.

Massachusetts developed and adopted a statewide stretch code option for jurisdictions in 2009, becoming the first state to create a standardized set of requirements other than the base code that jurisdictions can legally adopt and implement. The stretch code has become a popular policy lever for individual jurisdictions to enable deeper energy and carbon emissions savings in the built environment: to date, 296 of 312 municipalities in the state are enforcing it. Other states, such as New York, Maine, California, and Vermont, have developed a statewide stretch energy code available to jurisdictions. Stretch energy codes can also be developed at the local level to create an optional compliance pathway for developers.

From the perspective of off-site construction, stretch energy codes can help enable the growth of off-site construction and its benefits in several ways. A stretch code could be developed to incorporate an embodied or lifecycle carbon metric, in which case off-site construction's more efficient use of materials (including reduced waste) and facility in incorporating novel techniques and technologies could give it an advantage over conventional construction practices. More directly, a stretch code could be developed to incentivize the use of

off-site practices, either through an easier path to compliance, or a blanket requirement for buildings to be constructed in part using off-site construction practices. However, it could be argued that under the current approach to stretch codes — i.e., a general set of more efficient and sustainable construction requirements — off-site construction should have an advantage in meeting these enhanced requirements in an optimized way, and that off-site construction should compete on its merits rather than be explicitly favored.

Zoning and Laws to Override Restrictive Covenants

As previously discussed, private covenants can impede the use of off-site construction practices by categorically banning the use of any prefabricated building types, regardless of whether the final product is functionally identical to a site-built home. Clauses within some restrictive covenants group any prefabricated modular housing construction with manufactured housing together, with the net effect of discrimination directed toward modular homes as a residual effect of the restrictive covenants preventing manufactured housing (Geary 2013).

Restrictive covenants can be amended with the consent of landowners, overridden by zoning ordinances, or through local legislative action (French 2019). Achieving owner consent can be an effective mechanism for permitting off-site construction for a specific development but statewide reforms are needed to remove these arbitrary restrictions across all properties. As we have seen, the restriction of single-family residential zoning can be overruled by zoning reforms or statewide legislative action, allowing for accessory dwelling units to be permitted to increase available housing. In a similar manner, reforms that modify the off-site prohibition clause of many restrictive covenants could allow for permanent construction made with off-site practices, while still narrowly limiting manufactured housing on the basis of improper placement.

It is recommended that states and local jurisdictions review current zoning laws and private covenants and adopt reforms to remove requirements limiting the use of off-site construction.

Productization

Productization is the ability to review and approve a class of building components against regulatory requirements. Increased productization provides an additional opportunity to ease regulatory barriers for off-site construction, which can ensure a more affordable, energy-efficient, and decarbonized housing stock. Component productization could streamline code compliance requirements for both common and innovative building components manufactured off-site. The manufacturing processes and a representative sample set of a given building component would be inspected, tested, and approved for compliance with building codes. Component productization for code compliance would reduce the burden on local code inspectors, regulatory barriers for off-site manufacturers, and streamline the widespread adoption of advanced building technologies approved in this way. Given the high level of building code fragmentation across the U.S. and the additional burden of compliance for off-site construction, the productization of components serves as an additional pathway to streamline off-site construction code compliance.

Productization is not a new concept. Building components such as structural insulated panels (SIPs), appliances, and mechanical equipment have been productized for code compliance. As such, SIPs do not have to undergo individual code compliance pathways. Instead, the manufacturing facility and initial SIPs are inspected and approved to allow for future

specimens of approved components to be easily deployed in construction projects, avoiding the onerous off-site code compliance landscape.

For off-site manufacturers, productization would allow pre-approved building components to be readily installed on-site without permitting and compliance backlogs. Productization would also allow building components to seamlessly enter markets in multiple geographies — currently costly or practically impossible with building code fragmentation — enabling more widespread adoption of off-site construction and novel technologies. For code officials, productization can support confident certification of building code compliance while reducing the need for off-site and on-site inspections.

Conclusion

Off-site construction practices have the potential to dramatically reshape the construction industry by addressing some of its most pressing challenges: labor, cost, and environmental impact. Modernized off-site practices promise reduced construction times, improved quality control, safer working conditions, and economies of scale — reducing the cost and risk to construct decarbonized and high-performance homes. However, to grow off-site construction at the speed and scale needed to achieve housing affordability and climate goals, creating a regulatory environment that supports this type of innovation is critical. Although many regulatory barriers persist - such as building code fragmentation, inconsistent state and local inspection protocols, and restrictive land-use laws - a number of actionable steps to minimize regulatory challenges can be employed by national, state, and local stakeholders throughout the off-site and building regulatory industries.

Through research and discussion with stakeholders, we've identified seven key recommendations. These were described at length in the paper and include 1) education programs geared toward supply chain and demand stakeholders, 2) supporting consistency in state regulation and approvals (e.g., ICC/MBI Off-site Standards), 3) funding research and use of Remote Virtual Inspections, 4) supporting the adoption of the latest codes and standards, 5) developing and supporting state and local stretch energy codes, 6) identifying and addressing restrictive zoning and covenant laws, and 7) expanding the use of product development and productization. These activities have the potential to drive measurable efficiencies in the off-site segment, something desperately needed to increase its attractiveness to builders, designers, code officials, and consumers and continue to grow the market.

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