Single-Family Off-Site Construction

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About NEEP / MEEA

NEEP was founded in 1996 as a non-profit whose mission is to serve the Northeast and Mid-Atlantic to accelerate regional collaboration to promote advanced energy efficiency and related solutions in home, buildings, industry, and communities. Our vision is that the region’s homes, buildings, and communities are transformed into efficient, affordable, low-carbon resilient places to live, work, and play.

MEEA is a nonprofit membership organization with 160+ members, including utilities, research institutions, state and local governments, and energy efficiency-related businesses. As the key resource and champion for energy efficiency in the Midwest. MEEA helps a diverse range of stakeholders understand and implement cost-effective energy efficiency strategies that provide economic and environmental benefits.

Disclaimer: NEEP verified the data used for this brief to the best of our ability. This paper reflects the opinion and judgments of the NEEP staff and does not necessarily reflect those of NEEP Board members, NEEP Sponsors, or project participants and funders.

Introduction

Buildings create 39% of annual global greenhouse gas emissions.[1] In the United States in 2019, this number was approximately 30%.[2] According to the Intergovernmental Panel on Climate Change, unless reductions in greenhouse gas emissions are severely reduced, the global temperature rise will exceed 2.0 degrees Celsius within this century. In order for states and communities to reach their climate goals, buildings must make their way to net-zero. This goal can be targeted through increased energy efficiency, and one way to achieve this is through off-site construction.

A shortage of construction workers and rising materials costs contributes to an affordable housing crisis in the United States. The U.S. Department of Energy's Building Technologies Office is dedicated to R&D that will contribute to the ability to deliver solutions at scale. The Advanced Building Construction Initiative invests in new technologies such as off-site construction to address the affordable housing crisis, while also committing to efforts that will reduce greenhouse gas emissions, both by retrofitting existing structures, and building better, more energy efficient new buildings.

Off-site construction is defined as construction of a building in which various parts are fabricated in a factory and transported to a prepared site for final assembly and installation. This method is in contrast to traditional site-built, also known as stick-built, construction in which the building materials are brought to the building site and erected on location. There are four primary categories of off-site construction: modular, panelized, precut, and manufactured (HUD housing). This report will focus on single-family off-site construction.

Based on 2019 data, there were 124 million U.S. households, and 68 percent of them lived in single-family homes.[3] Single-family residential is a fairly unique typology, while multi-family residential shares some characteristics with other larger scale construction projects, such as commercial construction. In 2020, approximately three percent of U.S. construction was built using off-site construction,[4] and the construction sector in the U.S. was about $1.36 trillion.[5] There is real room for growth in use of off-site construction. Use of prefabricated roof trusses is already at 64% in new homes, and 15% of those surveyed planned to use them more often.[6] The biggest barriers to adoption of off-site construction are inertia in the building sector and lack of contractor familiarity and experience, although many other barriers exist.[7] Primary barriers can be addressed with better educational opportunities for builders, architects, lenders, and homeowners. In October 2021, NEEP and MEEA jointly hosted a webinar on off-site construction, with panelists from the International Code Council (ICC), National Institute for Building Sciences (NIBS), NIBS Off-site Construction Council (OSCC), Modular Building Institute (MBI) and Advanced Building Construction (ABC) Collaborative.[8]

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[1] Architecture 2030. "Why the Building Sector?" Architecture 2030. 2021. https://architecture2030.org/why-the-building-sector/.
[2] Cleary, K. et al. 2021. "Federal Climate Policy 106: The Buildings Sector." Resources for the Future, April. https://www.rff.org/publications/explainers/federal-climate-policy-106-the-buildings-sector/.
[3] Center for Sustainable Systems, University of Michigan. 2021. "Residential Buildings Factsheet." Available at: https://css.umich.edu/factsheets/residential-buildings-factsheet.
[4] US Census Bureau. 2021. "2020 Characteristics of New Housing." https://www.census.gov/construction/chars.
[5] Statista. 2021. "Topic: U.S. Construction Industry." August. https://www.statista.com/topics/974/construction/.
[6] Home Innovation Research Labs. "When & Where Offsite Construction Technologies Will Emerge." Home Innovation Research Labs. October 2019. https://www.homeinnovation.com/trends_and_reports/trends/when_and_where_offsite_construction_technologies_will_emerge
[7] Razkenari, M. et al. "Perceptions of Offsite Construction in the United States: An Investigation of Current Practices." *Journal of Building Engineering* 29 (May 1, 2020): 101-138, https://doi.org/10.1016/j.jobe.2019.101138.
[8] Egelkamp et al., "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?," https://www.mwalliance.org/events/residential-site-construction-where-has-it-been-and-where-it-going.

Off-site construction is a natural fit for sustainability, due to precision cutting which allows for tighter fits between materials, and therefore tighter seals. Modular housing is delivered with insulation already installed, and this is often true with panelized systems as well. Off-site construction is also cost effective. Materials are cut and used in a factory environment, so there is less waste, as leftover materials can be re-used for other projects. The work site is secure, preventing theft. It is also protected from the weather in a controlled climate, preventing moisture infiltration and future mold problems, and material degradation. Because most of the work occurs in the factory, the building site can be prepared simultaneously with the fabrication of multiple building parts, speeding up the timeframe. This time savings is cited by those in the construction field as the single most important factor in favor of choosing off-site construction.[9] This also contributes to less overall site disruption, with benefits ranging from less pollution from construction vehicles to less contamination in stormwater runoff from the site. For this reason, modular and panelized construction is particularly well-suited to greenfield sites or urban infill sites.

All off-site construction (with the exception of some aspects of manufactured housing) must comply with state and local building and energy codes. Modular housing is made up of modules which include structural components, walls, floors, windows, doors, insulation, plumbing, electrical, and sometimes finishes. They are sized to meet transportation requirements, constructed in factories, transported, and installed on site. Panelized construction is built as structural panels, meaning often entire wall and floor assemblies with insulation installed at the factory. Panelized construction may or may not include mechanical, electrical, or plumbing system components. Precut construction consists of building components such as dimensional or engineered lumber which are factory cut to design specifications, transported, and assembled on-site. These types of off-site construction methods will be discussed in this brief.

Manufactured housing is also known as mobile housing, and unlike other methods of construction, these homes are built on a permanent chassis. The U.S. Department of Housing and Urban Development (HUD) has established federal standards for these homes, which may preempt state and local laws if they do not conform. Due to the significant differences between this and other off-site construction, and because HUD is preparing its own report on manufactured housing, this brief does not address the HUD category.

Buildings are an important part of the solution to the global problems created by climate change. If we can build structures with more energy efficient envelopes, we will cut down on the amount of energy expended to heat and cool our homes. There are benefits of off-site construction, but there are many barriers as well. This brief examines why off-site construction has not taken on a larger share of the residential single-home market, and ways to increase the use of off-site construction in the U.S.

[9] Razkenari et al. “Perceptions of Offsite Construction in the United States.”

Current use of Single-Family Off-Site Construction in United States

Residential construction is divided into single-family and multifamily housing. Single-family housing consists of a structure that houses only one household. Multifamily housing may be as small as a two-family house, or it may be as extensive as a large apartment building that holds hundreds of units which share common spaces.

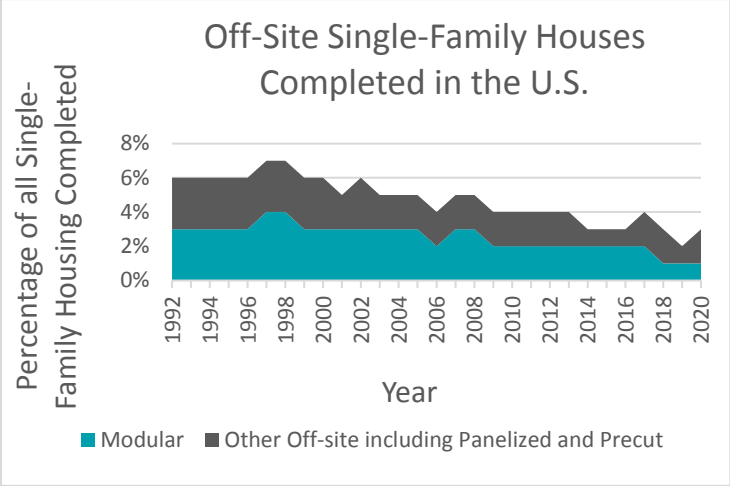

Figure 1: Data from the U.S. Census Bureau, 2020 Characteristics of New Housing

Off-site construction has been losing single-family market share over the last 20 years (see Figure 1). Over that time, the number of houses completed using modular methods has been roughly equal to the number of houses completed using panelized and precut methods.[10] The use of off-site construction varies geographically, with the Northeast completing the most housing of this type (see Figure 2).[11]

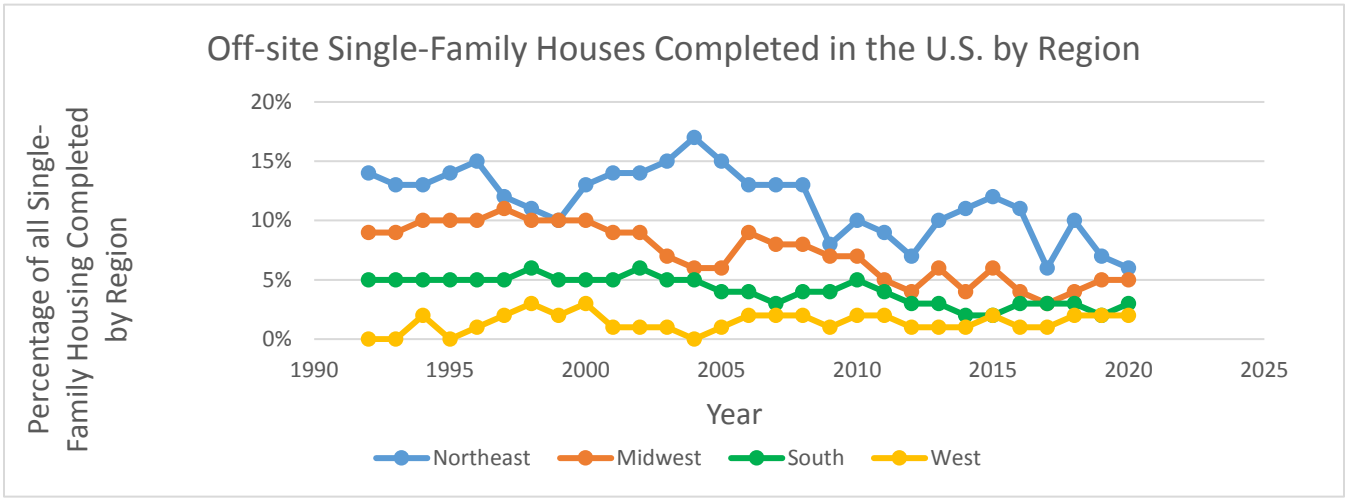

Figure 2: Data from the U.S. Census Bureau, 2020 Characteristics of New Housing

Polling data from a NEEP/MEEA off-site construction webinar shows that participants were most likely to have utilized off-site construction for residential construction, and for single-family residential in particular. A majority

[10] US Census Bureau. "2020 Characteristics of New Housing."
[11] US Census Bureau.

of participants were from city or state government (16 percent) or non-profits (24 percent), so the smaller number of respondents was due to the relatively smaller number of builder respondents (five percent).[12]

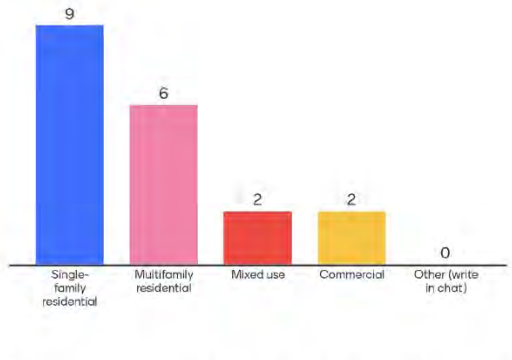

Figure 3: Polling results from NEEP/MEEA webinar October 4, 2021

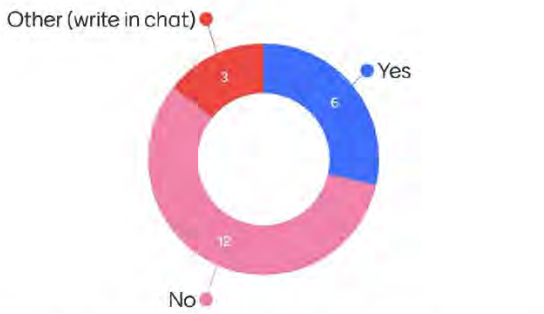

Figure 4: Polling results from NEEP/MEEA webinar October 4, 2021

Types and Benefits of Off-Site Construction

The overall project schedule of an off-site project is more efficient because while the site is being prepared and the foundation built, the modules, panels, or precut lumber pieces are being prepared in the factory. As a result, the schedule can be shortened by 20-50 percent.[13]

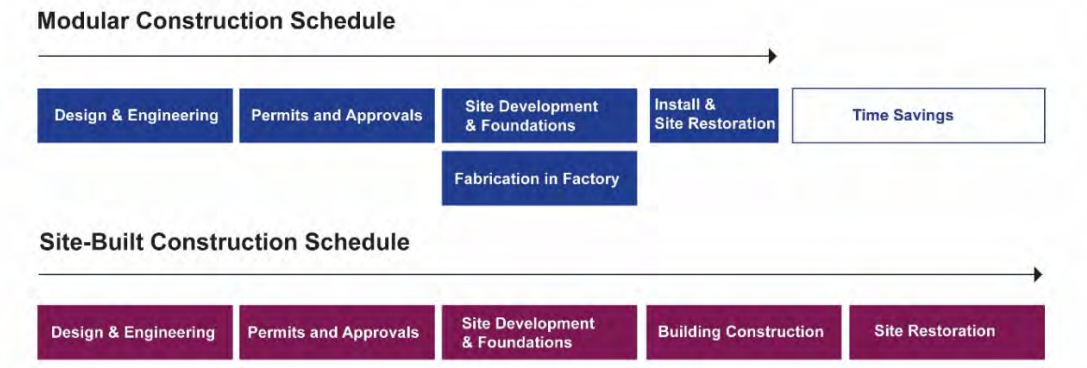

Figure 5: Adapted from Modular Building Institute, http://www.modular.org/htmlpage.aspx?name=why_modular

[12] Egelkamp, C. et al. 2021. "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?," October. https://www.mwalliance.org/events/residential-site-construction-where-has-it-been-and-where-it-going.
[13] Bertram, N. et. al. 2019. "Modular Construction: From Projects to Products." McKinsey & Company. June. https://www.mckinsey.com/business-functions/operations/our-insights/modular-construction-from-projects-to-products

Precut Dimensional Lumber/Engineered Lumber

Precut packages of dimensional, or traditional, lumber date back to the early 20th century, when Sears, Roebuck and Co. sold mail-order houses. Precut lumber companies today use sophisticated software to determine sizing, cut lumber to within 1/16" of an inch, and label each unique piece of lumber, keyed to each other and to the construction drawings. When building a wall, the stud locations are already printed on the bottom plate, eliminating the measuring step.[14] A typical traditional job requires 600 cuts on-site.[15] Precut lumber packages arrive on-site in sorted, sequenced bundles, saving time during framing, and allowing for smaller crews. In a recent study that compared a precut jobsite with a traditional jobsite, the precut house was framed 20 percent faster.[16] Utilizing precut packages produces less waste, saving on materials and money. The lumber comes in the exact sizes needed for construction. By comparison, for a stick-built project, estimators typically order more than needed. In the comparison study above, the dumpsters needed for waste were reduced from three to one.[17]

Engineered lumber, as opposed to dimensional lumber, consists of wood products such as I-joists, laminated veneer lumber, and glue laminated timber. Weyerhaeuser, a North American manufacturer of these products, offers a NextPhase® Site Solutions program (a precut endeavor) to train professional lumber yards in its proprietary 3-D software, which interacts with typical Building Information Modeling (BIM) software used by architects such as Autodesk Revit. Builders provide construction drawings in digital form, which are examined by the software. Lumber yards then use computer numerical control (CNC) capabilities to precut the engineered lumber to a tolerance of 1/16", and also to precut holes through the lumber as needed for electrical and plumbing.[18] Weyerhaeuser has factories in rural areas, but by partnering with professional lumber yards, it is able to decentralize the precut service and bring it closer to the consumer. NextPhase® Site Solutions technology is designed to provide precut engineered lumber, but it also offers an off-site solution producing floor panels (cassettes), or a combination of both. Over 50 percent of the program is used for single-family residential construction, with a slight bias towards the eastern part of North America.[19] The material savings by precutting engineered lumber is between 5-7 percent.[20] Dimensional lumber projects save more material by precutting as a result of the overage in the orders mentioned above. Because engineered lumber already tends to have materials savings built in, the savings are slightly lower. In terms of energy efficiency, precision cut pieces will fit tighter. As a result the constructability improves and tighter seals between building materials are produced. A precut engineered lumber package compared to a traditional stick-built home will install 50-60 percent faster.[21]

Panelized Systems

In a panelized system, the walls, roof, and/or floors are manufactured off-site. As with other off-site construction types, panelized systems minimized material waste and save time by building at the factory simultaneous with on-site preparation.

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[14] LaLiberte, M. 2021. "Precut Framing Field Test: Does This Off-Site Solution Earn Its Keep?" Professional Builder. March. https://www.probuilder.com/precut-framing-benefits-field-test.
[15] Beirne, M. 2019. "2019 Housing Giants Report: Easy Does It." Professional Builder. May. https://www.probuilder.com/2019-housing-giants-alternatives-traditional-building.
[16] LaLiberte. "Precut Framing Field Test."
[17] LaLiberte.
[18] Jeremy Dummer and Sarah Fulcher. Interview. October 13, 2021.
[19] Dummer and Fulcher.
[20] Dummer and Fulcher.
[21] Dummer and Fulcher.

Trusses

Many builders are familiar with off-site construction through roof trusses, as 64 percent of roof trusses are built in a factory.[22] In a similar vein, builders may install floor trusses that were built off-site, though this is less common.

Floor Cassettes

Floor cassettes are pre-fabricated floor assemblies in which the floor joists are joined together at the ends. The joists are built out of dimensional or engineered lumber. The subfloor is fastened to the top of the joists off-site, creating a rigid construction. The cassette is lifted into place on-site by crane.

Precast Panels

Precast concrete panels can be used as foundation walls or above grade walls. They are precast in the factory to dimensional specifications, and they arrive at the site fully insulated, often with holes for electrical. They are erected on-site with a crane.

Manufactured Wall Panels

Wall panels take the precision cutting and materials savings of the precut lumber package and assemble dimensional or engineered lumber in the factory. Exterior panels can include insulation, vapor barrier, sheathing, siding, windows, and exterior doors. Interior wall panels are also possible, with openings installed in the factory.

Structural Insulated Panels

Structural Insulated panels (SIPs) are usually fabricated from ½" oriented strand board (OSB) sheathing on both sides, and 5-1/2" foam insulation on the inside. The outer portion of the panel can be a variety of materials, including metal or concrete. The structural part of the name arises out of the fact that SIPs form load-bearing walls, removing the need to stick-build exterior walls. They reduce heat transfer due to their insulated core, making them ideal for sustainability goals. Most SIPs are used in residential or low-rise commercial projects, and they are popular for renovations and retrofits due to their relatively light weight. They can often be moved by people or by forklift, rather than by crane. Despite their light weight, they perform well in seismic zones.[23] Panelized systems can be built faster on-site than precut packages, with more of the labor shifted to the factory.

Figure 6: SIPs on-site installation, photo by C. Wu, NEEP

Figure 7: SIPs on-site installation, photo by C. Wu, NEEP

[22] Holt, E. 2020. "Modular and Panelized Construction: A Study on Costs and Housing Affordability Impacts." University of Denver, National Association of Home Builders. October.

[23] Home Innovation Research Labs. "When & Where Offsite Construction Technologies Will Emerge." Home Innovation Research Labs. October 2019.

SIPs construction is estimated to make up perhaps one percent of the residential single-family housing market.[24] Houses constructed with SIPs are more energy efficient for a few reasons. The SIPs are filled solid with EPS (expanded polystyrene) foam insulation, achieving as much as R-24. The higher the R value, the more the insulation prevents heat from moving in or out of the home. Since SIPs are structural in their composition of OSB and foam insulation, there are no thermal bridges created by structural lumber as occurs with stick-built on-site construction. Many stick-built homes are filled with batt insulation, and the 16" on center occurrence of the structural lumber gives the blended wall a lower effective R-value in comparison to SIPs. Because of the nature of their construction, continuous insulation is inherent to the fabrication of the SIPs. Continuous insulation helps keep heat in or out of a house, as it reduces thermal bridging.

A blower door test measures building tightness and can alert homeowners of leaks in the home. The fewer air changes per hour, the less leakage there is in the home, preventing heat loss. A SIPs built home is capable of achieving approximately one air change per hour,[25] exceeding the new code requirements in progressive jurisdictions such as New York state of three air changes per hour, and well exceeding far weaker code requirements in other jurisdictions. For example, the Anacortes Triple Zero Home achieved just over 1.0 air changes per hour (ACH50), while a SIPs built house in Menlo, California achieved 0.2 air changes per hour (ACH50).[26] Because of the energy savings as a result of exceptional insulation, both money and energy can be saved on the HVAC (heating, ventilation, air conditioning) package.

The only part of a SIPs built home that is truly fabricated off-site are the exterior walls, and possibly the roof panels if those were also designed as SIPs. Interior walls are stick-built, and the panels typically have chasses built into the foam for electrical to be run on-site. The structural integrity is not compromised if small cuts need to be made into the OSB and foam for electrical conduit. Plumbing is typically avoided on exterior walls so as to avoid installation issues.

Metal panels are less commonly used in single-family construction, though they are more frequently used in multi-family. The metal panels are usually less structural and often rely on the building structure for support. One reason they are less frequently used for single-family is that they are harder to cut.

Modular Construction

Of the three types of off-site construction discussed, modular construction is perhaps the type most people think of when off-site construction is mentioned. The modules include walls, floors, windows, and doors. Most of the electrical, plumbing, and heating is installed in the factory and then connected together on-site. Wall finishes such as drywall are included. Floor finishes can either be applied partially in the factory and partially off-site, or entirely on-site. The final exterior finish of the house (cladding) is usually installed on-site, though factory installation is possible. Mechanical systems in modular buildings are often decentralized to avoid deep ductwork. The modules are timed to arrive on-site when the foundation is ready, and a crane moves them to their final location.

[24] Trevor Huffard. Interview. October 14, 2021.
[25] Huffard.
[26] Premier SIPs. "Using SIPs to Build High-Performance Homes: Lower ACH and HERS for Maximum Efficiency," Premier SIPs (blog), March 6, 2020, https://www.premiersips.com/using-sips-to-build-high-performance-homes-lower-ach-and-hers-for-maximum-efficiency.

Wood is commonly used for single-family modular. The ceiling to floor connection is very deep, and the modules may require temporary bracing for shipping.[27] Steel modular has a number of advantages, including higher fire resistance, and a more rigid structure. The ceiling to floor connection is shallower than with wood. Also, while wood structures often leave out millwork, appliances and heavy finishes to be installed on-site, steel modules usually install these at the factory.[28] However, steel modules usually have lower wall assembly R-values, and higher embodied carbon.

There has been a labor shortage in the construction industry for some time. According to the U.S. Labor Bureau, there were 434,000 vacant construction jobs in 2019.[29] Approximately 1.2 million workers lost their jobs during the collapse of the housing market from 2007-2009.[30] In addition, the current construction workforce is aging. The lack of skilled labor has had an effect on the affordability of homes. One solution is modular construction, because it increases construction efficiency. A new workforce must be trained to fill the labor shortage. The factory creates far greater control over the worksite, and the work requirements often do not exceed the use of a six-foot ladder under rigorous safety conditions.[31] Factory assembly of modular houses lends itself to training of a greater pool of people to take these roles. Manufacturers should reach out to a more diverse workforce, including older workers, women, and Black, Indigenous, and people of color (BIPOC).

When a general contractor builds a house on-site he or she must organize the schedules of many subcontractors, such as masons, carpenters, plumbers, and electricians. When a general contractor hires a modular manufacturer as one of his or her subcontractors, the scheduling of all of those trades is worked out by the manufacturer in the factory. This can be seen as a positive or a negative by the builder, who may either see efficiencies, or a lack of control.

One of the main advantages of modular construction is predictability of both schedule and cost. Joseph Tanney, FAIA is a principal architect at Resolution: 4 Architecture, based in New York City. He designs his houses to make maximum use of the efficiencies of modular, but always requests site-built bids as well. In over 20 years, and well over 100 homes sited all over the country, only twice has the site-built bid come in at less than the modular bid.[32] Tanney uses innovative procedures to capitalize on the advantages of the factory. For instance, he specifies an insulation process where the exterior wall cavities are sprayed in the factory a few inches deep, then the remainder is filled with batt insulation. The result is an R-25 wall (with a comparable all spray foam wall at R-30 and a comparable all batt wall at R-13). The advantage of the process is that the spray foam doesn't have to be shaved down flush with the wall, creating waste and requiring factory clean-up. However, the initial spray seals the exterior wall, in a way that is impossible with an all batt wall. A custom modular house takes 16 months from start of design to completion of site installation, while a comparable site-built house would take 18-24+ months.[33]

[27] Brown, A. "Fabulous Pre-Fab: Applying Modular Construction to Multifamily Residential Projects in Washington, DC." Available at: https://hickokcole.com/wp-content/uploads/2016/08/FABULOUS-PRE-FAB_PRESENTATION-sm-2.pdf.
[28] Brown.
[29] Holt. "Modular and Panelized Construction: A Study on Costs and Housing Affordability Impacts."
[30] Holt.
[31] Hardiman, T. 2021. "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?" October. https://www.mwalliance.org/events/residential-site-construction-where-has-it-been-and-where-it-going.
[32] Joseph Tanney, FAIA. Interview. October 14, 2021.
[33] Tanney.

Barriers to Off-Site Construction

Off-site construction has been fighting off a stigma that associates the method primarily with single-story, temporary applications.[34] It is often thought of as producing low quality, cookie-cutter houses. In the past, modules were often overly repetitive in order to achieve economies of scale. As outlined above, today's off-site construction is centered on quality and often delivers projects that are indistinguishable from site-built houses.

Financing a single family project that is built with modular methods may be more difficult than with traditional stick-built construction. Lenders are used to releasing money as the project progresses, and they can see the house rising out of the ground. With off-site construction, more money is drawn upfront, due to simultaneous site preparation, material purchase, and factory assembly.[35] In addition, for more money at the outset, there is less to see on-site, as the "house" is in the factory.

For SIPs panels, a 50 percent deposit is typical before fabrication is started. For many builders this disrupts the regular flow of day-to-day business. In addition, some builders, particularly those that don't build homes at high volume, don't value their time well, so the time savings from installing panels isn't accounted for in the calculation of whether to choose this off-site construction method.[36]

Framers accustomed to site-built houses do not always pass on the labor savings of panelized houses to the general contractor. This cancels out the higher cost of the precut package. There are several reasons why the framers do not pass on savings. Sometimes it is because panelized projects are new to them. But the reason can simply be that framers are accustomed to pricing lumber installation by the square foot, and therefore they don't count the labor savings of the panel installation. These issues are also tied to the labor shortage, which puts framers in a better bargaining position. In fact, house framers can reduce their crew by two people, and still build faster when building with precut or panelized packages.[37]

Depending on the geographical location of a project (and associated labor costs), SIPs homes, which are filled with foam insulation, can be more expensive than stick-built homes, which may be filled with batt insulation. When this occurs, it is due to the cost of the rigid foam used in SIPs panels. However, as discussed above, these SIPs homes can be far more energy efficient. They are also roughly comparable in cost to a stick-built home insulated with spray foam.

Builders who work with modular factories state that there is not enough capacity, and that there are long wait times to get their project to the factory floor. Modular factories are often clustered together, leaving some areas without much coverage.[38] Since modules have to be transported, distance between site and factory is a cost and energy issue. The maximum radius from the factory for shipping in a cost-effective manner works out to around 300 miles.[39] Transportation of the modules also requires that they be designed with some redundancy, so that the end result is a double wall where modules join, creating material waste. However, this is offset by the greater material savings overall of building the modules in a factory environment. The modules do have to be craned into place, which is not possible on all sites.

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[34] Salama, T. et al. 2018. "Modular Industry Characteristics and Barriers to Its Increased Market Share." *Modular and Offsite Construction (MOC) Summit Proceedings* (March 22, 2018) https://doi.org/10.29173/mocs34.
[35] Hardiman, T. 2021. "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?"
[36] Jack Armstrong. Interview. October 22, 2021.
[37] Holt. "Modular and Panelized Construction: A Study on Costs and Housing Affordability Impacts."
[38] Hardiman, T. 2021. "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?"
[39] Holt. "Modular and Panelized Construction: A Study on Costs and Housing Affordability Impacts."

A general contractor newly transitioning to using modular construction may fear a scope gap. The contractor may not be sure that every activity is covered. For instance modules arrive on-site and are installed onto the previously constructed foundation. The contractor may fear that activities he or she thought were installed by the factory are in fact intended to be installed on-site. This may be especially true for elements that are installed both off-site and on-site, such as interior or exterior finishes. Effective communication and careful planning can alleviate these fears.

NEEP and MEEA conducted the Prefabricated Construction and Remote Virtual Inspection Technical Advisory Group (TAG) survey. The TAG consists of industry experts from non-profits, utilities, architecture firms, research organizations, manufacturers/contractors, code and inspection offices, state energy offices, and trade associations. The survey showed that the biggest barrier to the growth of off-site construction in single-family housing is regulatory issues posed by codes and different permitting, inspection, and zoning processes.[40]

Survey respondents also discussed a lack of knowledge amongst both consumers and municipalities.[41] Inertia in the building industry has also been cited by stakeholders. The barrier to increased adoption of off-site construction most selected during a poll in the NEEP/MEEA webinar was "unwillingness to change to different construction method."[42]

In both 2014 and 2018, the National Institute of Buildings Sciences surveyed industry professionals and found that the following issues were among the "moderate to significant" barriers: design and construction culture, industry knowledge and skills, and regulation and codes.[43]

Organized Labor and Off-site Construction

More often than not, trade unions have opposed the use of off-site construction on job sites. This usually stems from an issue with modular construction for multifamily housing and commercial buildings, rather than single-family residential. A discussion of off-site construction would be incomplete without addressing organized labor issues. Use of off-site construction in some urban markets can lead to conflict. For example, when developer Forest City Ratner decided to build a multifamily building in Brooklyn using modular construction, unions protested and the Plumbing Foundation filed a lawsuit.[44] In San Francisco, trade unions protested the use of modular construction to build supportive housing for the homeless.[45] Off-site construction is traditionally seen as moving jobs out of the job site's immediate area and to a factory location where wages are lower. However, some unions and factories have been meeting in the middle. The Northern California Carpenters Regional Council (NCCRC) represents 37,500 members and contracted with two modular factories in California. The agreement included member training in electrical, plumbing, and carpentry in modular factories.[46] The NCCRC

[40] Northeast Energy Efficiency Partnerships and Midwest Energy Efficiency Alliance. "Prefabricated Construction: Guidance, Technical Assistance, and Virtual Inspections: Prefabricated Construction and Remote Virtual Inspections Project Technical Advisory Group Survey Synopsis." March 2021.
[41] Northeast Energy Efficiency Partnerships and Midwest Energy Efficiency Alliance.
[42] Egelkamp, C. et al. "NEEP/MEEA Webinar."
[43] National Institute of Building Sciences. "Report of the Results of the 2018 Off-Site Construction Industry Survey," (2019), Available at: https://www.nibs.org/reports/report-results-2018-site-construction-industry-survey.
[44] Blau, R. 2013. "Bruce Ratner's Modular Tower Violates City Building Rules: Suit." *NY Daily News*. July 10. https://www.nydailynews.com/new-york/brooklyn/bruce-ratner-pre-fab-tower-illegal-suit-article-1.1394910.
[45] Dineen, J. 2020. "San Francisco, Trade Unions at Odds over Modular Construction - Even for Homeless Projects." *San Francisco Chronicle*, November 27. https://www.sfchronicle.com/bayarea/article/San-Francisco-trade-unions-at-odds-over-modular-15755264.php.
[46] Modular Building Institute. 2018. "Carpenters' Union Embraces Factory Built Housing to Address Labor Needs in Northern California." *Modular Advantage Magazine*. November. http://www.modular.org/documents/Modular_Advantage/MA_Q4-2018-small.pdf

uses 35 full-time staff members to recruit women and minorities.[47] There may be more opportunities in the future for organized labor to partner with new or existing factories, and create jobs in the process.

Interaction With Other Advanced Technologies

One of the barriers mentioned earlier is the relative inflexibility of the fabrication process in the factory. Since fabrication occurs simultaneously with on-site preparation, the design for the house must be set earlier. Building Information Modeling (BIM) software such as Revit can be used with other advanced technologies to increase flexibility. These technologies include computer numeric control (CNC), robotics, and 3-D printing.[48] The ability to produce as-built drawings by digitally scanning the product/module allows the factory to improve quality control.

Greenhouse Gas Emissions and Energy Efficiency Potential

As previously mentioned, in 2019, buildings produced approximately 30 percent of greenhouse gas emissions in the United States.[49] Included in that percentage is 12.5 percent from fossil fuel use for heating, cooking, and cooling.[50] The rest was generated by electricity use. The embodied carbon in buildings is represented by the carbon dioxide equivalent produced in their construction and the fabrication and transportation of the materials within them. This embodied carbon contributes another 11 percent of greenhouse gas emissions.[51]

Energy efficiency in buildings can be seen as a first approach to reducing greenhouse gas emissions. For instance, when designing a new home, or retrofitting an older home, it does not make sense to size the mechanical system until the designers/contractors have improved the home's insulation and tightness as much as (cost-effectively) possible. An example of long-term savings is the application of insulation. In the case of SIPs construction, insulation is inherently continuous in its design. In the case of modular construction, since insulation is applied in the factory, this allows for better coordination to achieve continuous installation. Since even a small gap in insulation leads to a thermal bridge, resulting in heat loss either in or out of the enclosure, this has significant consequences over the life of the building. However, foam insulation has much higher embodied carbon than fiberglass or cellulose insulation.

The process of constructing buildings emits carbon dioxide (CO_2). While we do not have data on CO_2 emissions for single-family residential construction, a study on multifamily residential construction provides us with some information. The study calculated CO_2 emissions including but not limited to such activities as vehicle use for material delivery and crew movement, construction vehicles, excavation and foundation walls, framing activity, and winter heating of both the construction site and the factory.[52] The on-site construction took 10.75 months and generated 530.1 metric tons of CO_2 emissions (of this 98.9 was from the construction process proper), while the modular construction of the same design generated took 6.75 months and generated 303.6 metric tons of CO_2 emissions (of this 56.3 metric tons was from the construction process).[53] Therefore, for this multi-family

[47] Modular Building Institute. "Carpenters' Union Embraces Factory Built Housing."
[48] Salama, T. et al. 2018. "Modular Industry Characteristics and Barriers to Its Increased Market Share."
[49] Cleary, K. et al. 2021. "Federal Climate Policy 106: The Buildings Sector." Resources for the Future, April. https://www.rff.org/publications/explainers/federal-climate-policy-106-the-buildings-sector/.
[50] Cleary, K. et al.
[51] Architecture 2030. "Why the Building Sector?" Architecture 2030. 2021. https://architecture2030.org/why-the-building-sector/.
[52] Al-Hussein, M. et al. 2009. "North Ridge CO2 Analysis Report Comparison between Modular and On-Site Construction." September. https://www.modular.org/IMAGES/foundation/NorthRidgeCO2Report.pdf.
[53] Al-Hussein, M. et al.

building example, the savings on CO_2 emissions by using a modular method of construction was 226.6 metric tons, or 43 percent.

Standards and Codes

Building standards are written to describe an agreed upon method of constructing. They can be adopted in an industry as best practice or incorporated into regulatory requirements. If a standard is not adopted by a local jurisdiction, it is not enforceable. In Canada, CSA A277 standardizes the certification of prefabricated buildings, including modules and panels for buildings.[54] In the U.S., the requirements for off-site construction vary from state to state. Two new standards developed by the International Code Council and Modular Building Institute are intended to help address these inconsistencies. Once again, the standards do not include HUD manufactured housing.

Off-site construction must meet all codes that apply to the state/jurisdiction of its final location. As a result, housing components built for one state may not comply with regulations in another state. This complicates the business model for factories, and disrupts attempts at economies of scale. The International Code Council (ICC) writes model codes which are adopted, often with amendments, by states and local jurisdictions. The ICC/MBI Standards 1200 and 1205 are designed to work with building codes to facilitate the safe and effective use of off-site construction. ICC/MBI 1200 addresses planning, designing, fabricating, transporting, and assembling building elements. ICC/MBI 1205 addresses permitting, in-plant and on-site final inspections, and third-party inspections. The standards define off-site construction as "a modular building, modular component or panelized system which is designed and constructed in compliance with this standard and is wholly or in substantial part fabricated or assembled in manufacturing plants for installation - or assembly and installation - on a separate building site and has been manufactured in such a manner that all parts or processes cannot be inspected at the installation site without disassembly, damage to, or destruction thereof."[55] Because of the closed construction nature of off-site construction, inspections must occur at both the factory and the final project site.[56] Currently in the United States, states vary in their use of state, local, or third-party plan review and state, local, or third-party inspection.

[54] Modular Building Institute. "Breaking Down the 'Modular Building Code.'" Modular Building Institute. Accessed October 11, 2021. https://www.modular.org/HtmlPage.aspx?name=MA-oi-modular-building-codes.
[55] Colker, R. "NEEP/MEEA Webinar: Residential Off-Site Construction: Where Has It Been, and Where Is It Going?" October. https://www.mwalliance.org/events/residential-site-construction-where-has-it-been-and-where-it-going.
[56] Brown. "Fabulous Pre-Fab: Applying Modular Construction to Multifamily Residential Projects in Washington, DC."

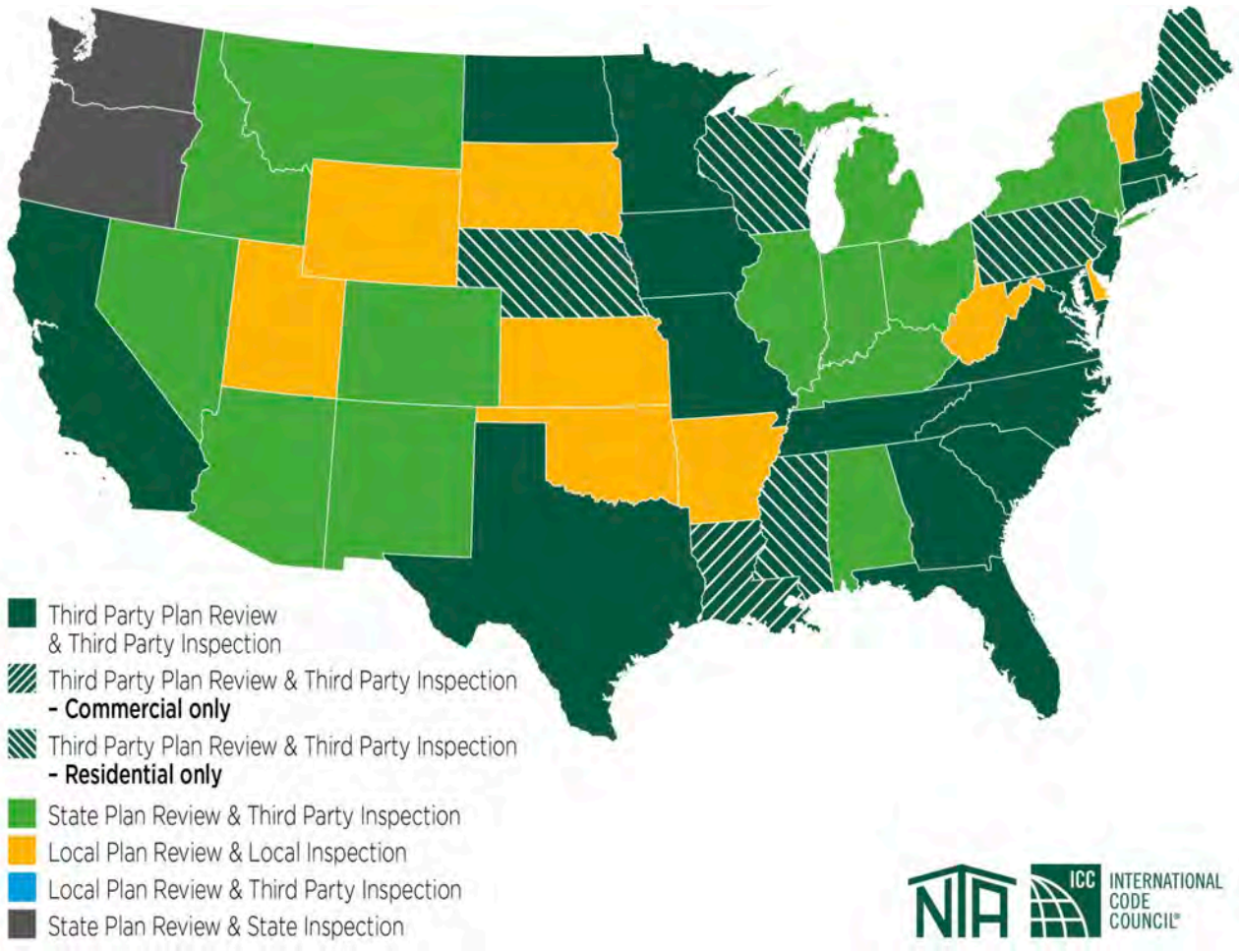

Figure 8: State Regulation of Off-site Construction, as of October 4, 2021, International Code Council, NTA

As previously discussed, differing codes across disparate jurisdictions has been the biggest barrier to growth of the off-site construction industry. Prior to the release of the new ICC/MBI 1200 and 1205, there was no industry-wide standard. Even if adoption takes some time, the fact that there is now a model code is already an improvement.

Additionally, the International Code Council is currently developing ICC 1210 -202X, which will be a standard for mechanical, electrical, plumbing systems, energy efficiency and water conservation in off-site construction.[57]

[57] International Code Council. "ICC Off-Site and Modular Construction Standards Committee." International Code Council. Accessed on October 27, 2021. https://www.iccsafe.org/products-and-services/standards/is-osmc/.

Case Study: City of Milwaukee

Municipalities can help lead the way by investing in off-site construction and workforce development. One example is Milwaukee, Wisconsin. Faced with energy burden (the percentage of gross household income spent on energy costs) and housing affordability problems, Director of Environmental Sustainability Erick Shambarger described a two-fold solution: housing costs have to be lowered, and incomes have to be raised. To address these problems, the city released a request for information in July 2021 to establish a public-private partnership to build an off-site construction factory that will create jobs and provide workforce training. Seven manufacturers responded, and a request for proposals is planned in the near future.

Milwaukee has allocated $1 million from American Rescue Plan Act (ARPA) funds to support the project. At this time, the city is open to organized labor or meaningful family-supporting job requirements for the facility, provided a willing factory partner can be identified. So far, unions have been receptive to the idea. The factory will manufacture structural elements (prefabricated walls and foundations) or modules.[1] The desired partnership is at least one developer and one manufacturer together with the city, building affordable housing on city-owned vacant infill lots.[2] There is a gap in the Midwest, with factories of the type described located primarily on the east and west coasts.[3]

The city has received a planning grant from the U.S. Environmental Protection Agency and is pursuing additional grants through the U.S. Economic Development Administration and state of Wisconsin. The energy efficiency standard targeted is Passive House Institute U.S. (PHIUS). Energy burden is disproportionate for incomes less than 50 percent of area median income (AMI). Therefore, it makes sense to aim to provide energy efficient housing to those who can least afford high energy bills.

The houses are conceived of as “mass customization,” to allow for economies of scale while avoiding a cookie-cutter result. The houses should cost $150,000 - $175,000 to construct, with gap financing to make up the difference in affordability.[4] The project is aimed at single-family and two-family housing. Two-family houses can be a way to help homeowners build wealth while creating more housing in a neighborhood. The Milwaukee project addresses many of the issues discussed in this brief: combatting climate change, providing jobs and training, and financing. Hopefully, other municipalities will watch this project closely for results.

[1] City of Milwaukee. 2021. “Public-Private Manufacturing Partnership to Support Equitable Housing, Economic Development, and Climate Action.” City of Milwaukee. July. https://city.milwaukee.gov/ImageLibrary/BBC/images/Housing-Plan/RFIforMilwaukeeManufacturingPartnership.pdf.
[2] Erick Shambarger. Interview. October 19, 2021.
[3] City of Milwaukee. “Public-Private Manufacturing Partnership to Support Equitable Housing, Economic Development, and Climate Action.”
[4] Shambarger.

Future Opportunities

Workforce Development

Another model for innovation can be found in the Incumbent Worker Training Program (IWTP) of Louisiana. The program utilizes state funds to reimburse employers who train their workers in approved learning activities.[58] The idea is to continue to train the workforce and prevent unemployment. The program is funded by a charge assessed to employers together with unemployment tax contributions.[59] This is an example of government support of workforce development that perhaps could be applied to training the energy efficiency workforce.

Education

Better education should be available to builders, architects, building department and code officials, as well as homeowners about off-site construction. This includes information about benefits such as increased energy efficiency, accelerated schedule, reduced waste, reduced labor needs during our current labor shortage, and workforce training opportunities for new jobs in factories. Education can be provided through articles, blogs, webinars, videos, and continuing education for licensed professionals. Education can be sponsored by jurisdictions, manufacturers, design magazines, and trade associations. While outreach should be made to all, prime target audiences include builders, architects, and homeowners who are already predisposed towards high performing houses or are interested in sustainability issues.

Adopting ICC/MBI 1200 and 1205

Jurisdictions can now adopt ICC/MBI 1200 and 1205, incorporating the standards into the International Building Code (IBC) Section 429 and the International Residential Code (IRC) Section 301.1.5.60. Adopting the codes would ensure local and factory inspection requirements are met and regulatory compliance is maintained. In particular, energy efficiency is an area where off-site construction can be explicitly controlled and documented, and adopting this code improves the possibility of achieving compliance with energy codes, something that is sometimes overlooked in on-site construction[61]. Adopting ICC/MBI 1200 and 1205 would align inspection processes across all jurisdictions that implement it. Leading the way, Salt Lake City, Utah adopted both standards into their code as of March 2021.

Conclusion

Off-site construction is capable of high quality, customizable, energy efficient single family homes. This method of construction is shaking off the negative stereotypes of the past, and is poised to increase its market share. According to a survey by Home Innovation Research Labs in 2019, homebuilders expected to use more off-site construction in the upcoming five years, especially roof trusses, factory-built open panel walls, and precut framing packages.[62] Greater public awareness and increased education is necessary for builders, architects,

[58] Louisiana Workforce Commission. "FAQ - Incumbent Worker Training Program - Customized Training - Louisiana Workforce Commission,"Louisiana Workforce Commission, Department of Labor. Accessed October 20, 2021. https://www2.laworks.net/FAQs/FAQ_IWTP_CustomizedTraining.asp.
[59] Louisiana Workforce Commission.
[60] Colker, R. "NEEP/MEEA Webinar"
[61] https://www.energycodes.gov/energy-efficiency-field-studies
[62] Home Innovation Research Labs. "When & Where Offsite Construction Technologies Will Emerge." Home Innovation Research Labs. October 2019. https://www.homeinnovation.com/trends_and_reports/trends/when_and_where_offsite_construction_technologies_will_emerge

homeowners, and local code officials. Off-site construction's many advantages include energy efficiency, reduced embodied carbon, time and material savings, and less disruption of project sites. In addition, there are opportunities for workforce development that specifically serve women and BIPOC.

The next step of off-site construction can be seen in the innovative thinking demonstrated by the city of Milwaukee. For many years, off-site construction has failed to gain market share of single family housing in the United States. With the increased emphasis on energy efficiency due to the climate crisis, now is the time for homeowners to step outside their comfort zone, for architects, builders, and manufacturers to evolve ways of working together that alleviate concerns and reach mutual goals, and for jurisdictions to incorporate stretch codes that reward energy efficiency.