

Capital Projects & Infrastructure

Modular construction: From projects to products

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June 2019



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In brief

For decades, construction has lagged other sectors in productivity performance. Now there is an opportunity for a step change: shifting many aspects of building activity away from traditional onsite projects to offsite manufacturing-style production. While modular (or prefabricated) construction is not a new concept, it is attracting a fresh wave of interest and investment on the back of changes in the technological and economic environment. This research quantifies the potential benefits, explores the challenges, and looks at whether, this time, modular construction will have a more widespread and sustainable impact. Among our findings:

- As one of the largest sectors globally, a profound shift in construction can have major impact. Recent modular projects have already established a solid track record of accelerating project timelines by 20–50 percent. The approach also has the potential to yield significant cost savings, although that is still more the exception than the norm today. Our analysis suggests that leading real estate players that are prepared to make the shift and optimize for scale will be able to realize more than 20 percent in construction cost savings, particularly as everyone involved moves up the learning curve. Under moderate assumptions of penetration, the market value for modular in new real-estate construction alone could reach \$130 billion in Europe and the United States by 2030.
- Prefabricated housing has achieved a sustainable foothold in only a few places, including Scandinavia and Japan. It has been in and out of favor in markets such as the United States and the United Kingdom since the post-war era. Yet there is reason to believe the current revival could be different. The industry is adopting new materials as well as digital technologies that enhance design capabilities and variability, improve precision and productivity in manufacturing, and facilitate logistics. Countering the old reputation of prefabricated housing as an ugly, cheap, poor-quality option, some builders are focusing on sustainability, aesthetics, and the higher end of the market.
- Multiple factors determine whether a given market is likely to embrace modular construction. The two biggest determinants are real estate demand and the availability and relative costs of skilled construction labor. In places such as the US West Coast, the southern part of the United Kingdom, Australia's East Coast, and Germany's major cities, labor shortages and large-scale unmet demand for housing intersect, making this model particularly relevant.
- Capturing the full cost and productivity benefits of modular construction is not a straightforward proposition. It requires carefully optimizing the choice of materials; finding the right solution between 2D panels, 3D modules, and hybrid designs; and mastering challenges in design, manufacturing, technology, logistics, and assembly. It also depends on whether builders operate in a market where they can achieve scale and repeatability. Public owners and regulators can facilitate a shift in the industry structure, too.
- In many countries, modular construction is still very much an outlier. But there are strong signs of what could be a genuine broad-scale disruption in the making. It is already drawing in new competitors—and it will most likely create new winners and losers across the entire real estate and construction ecosystem.

Modular construction's time may have finally come

The benefits

Modular construction can speed construction by as much as

50%

In the right environment and trade-offs, it can cut costs by

20%

The opportunity

Modular construction could claim

\$130B

of the market by 2030 in U.S./Europe at moderate penetration, delivering annual cost savings of

\$22B

This would help fill a

\$1.6T

productivity gap identified in 2017

Driving demand

Labor and housing shortages are the biggest predictors of where modular construction can gain traction



e.g. Australia, UK, Singapore, U.S. West Coast

All industry participants will need to make big changes



Modular manufacturers: Scale and optimize



Developers: Productize and partner



Materials suppliers: Prepare for a shift in products and go-to-market; or enter the space



Public sector: Bundle pipelines and update building codes



Engineering & construction firms: Preempt commoditization



Investors: Seek to understand new opportunities

Preface & acknowledgements

This work builds on previous analysis of the construction industry's productivity challenges and the levers that can help deliver it. It focuses on the impact that modular construction can have on the real-estate industry. However, this is just one of the areas which can be impacted, and the disruptive elements discussed here apply throughout the construction industry.

This research was led for McKinsey by Jan Mischke, a McKinsey Global Institute (MGI) partner based in Zurich; Nick Bertram, an associate partner in London; Gernot Strube, a senior partner in Munich; Jonathan Woetzel, a senior partner and MGI director in Shanghai; Steffen Fuchs, a senior partner in Dallas; and Robert Palter, a senior partner in Toronto. The project team was led by Barty Pleydell-Bouverie and comprised Hege Larsen, James McGeorge, Josh Southern and Priyanka Kamra, all based in London, and Bernardo Lara in Costa Rica.

Many McKinsey colleagues provided helpful input and advice, including Sergey Asvadurov, Jose Luis Blanco, Dominique Christ, Marion Duriez, Stephan Eibl, Christophe Francois, Nicklas Garemo,

Lasmar Hadj Belgacem, Tony Hansen, Ivan Jelic, Tomasz Jurkanis, Praveen Matta, Andrey Mironenko, Maria João Ribeirinho, Gauthier de Robillard, David Rockhill, Mukund Sridhar, Erik Sjödin, and Paul Zoghbi.

For their input and insightful discussions with us, many thanks go to Bruno Balbinot, Ambar; John Buongiorno, the Axis Group; Cesar Ramirez-Martinell, Barcelona Housing Systems; Graham Cleland, Berkley Group; Mats Williamson, NRC Group; Jerome Smalley, BluePrint Robotics; Stefan Bögl, Max Bögl; Marcus Hedman, BoKlok; Jamie Johnstone, Bryden Wood; Nate Willey, Cortland Partners; Jan-Hendrik Goldbeck, Goldbeck; Joseph Schottland, Innovatus; Stephen Jeffrey, Mace; Tom Hardiman, Modular Building Institute; Frédéric Augier, Nexity; Randy Miller, RAD Urban; Natalie Somekh; Mark Skender and Todd Andrik, Skender; Ryan E. Smith, School of Design & Construction, Washington State University; Paul Larkin and Barry O'Neill, WE-Link; and Rainer Bareiss, Züblin.

We are grateful for all the input we have received, but the final report is ours, and all errors are our own.

Modular construction: From projects to products

In 2017, the McKinsey Global Institute and McKinsey's Capital Projects & Infrastructure Practice published research analyzing the construction sector's stagnant productivity growth and outlining ways to jump-start it. The report put forward seven strategies to improve productivity by up to 60 percent. Collectively, they could generate \$1.6 trillion in value—enough to fund roughly half of the world's infrastructure spending.¹

Our work also pointed to an even bigger long-term opportunity: shifting to a modular construction model based on more efficient manufacturing-style production systems and pre-fabricated components. While this has been tried before in various guises, it has never achieved full scale, nor demonstrated the revolutionary productivity gains it should be capable of.

There is mounting evidence that this disruption is now happening. Many of our construction, real-estate, and infrastructure clients are already adopting a more industrialized model, or developing strategies on how they can do so. Similarly, in a recent report on modern methods of construction in the United Kingdom,² 40 percent of home builders surveyed said that they were already investing in manufacturing facilities or intended to do so in the near future. Earlier this year, Katterra, a US modular construction supplier, announced a round of funding from Softbank that took its estimated overall value above \$4 billion.

These are promising signs of a trend that we believe has staying power and growth potential. This report delves deeper into the concepts of production systems and modular construction as they apply to the real-estate market. We examine the potential benefits, best practices, what it will take for wider adoption, and potential ecosystem disruptions emanating from the shift.

Modular construction could scale to an industry that represents more than \$100 billion in US and European real estate, delivering \$20 billion in annual savings

Modular construction, when optimized and capably delivered, can demonstrate a series of benefits over traditional construction for appropriate projects. We examine these in more detail later, but briefly they include:

- i. Reduced build cost and overall lifetime cost of the building—while these are not always demonstrated, we will discuss ways to unlock such savings
- ii. Accelerated build schedules

¹ *Reinventing construction: A route to higher productivity*, McKinsey Global Institute and McKinsey's Capital Projects & Infrastructure Practice, February 2017, McKinsey.com.

² *Modern methods of construction: Who's doing what?*, NHBC Foundation & Cast, November 2018, nhbcfoundation.org.

- iii. Greater certainty on both build times and costs
- iv. Improved quality of the building, including better energy or seismic performance

Modular construction is particularly in demand for players and building types where these benefits play a key role.

\$22b

Potential annual
cost savings

The trade-offs involved favor modular construction in particular when the type of structure has a degree of repeatability, a unit size that suits land transport, and a value density where the savings of shifting activities to the plant outweigh logistics cost. Any building being manufactured needs to be designed for the manufacturing process and hence constrain the number of different variations required. For example, affordable housing, student housing, and hotels are highly standardized and repeatable. This doesn't mean that all of these buildings now need to be the same—understanding the level of customization desired by the end customer and what can be built into the manufacturing process is a key element of developing the modular solution. In terms of unit size, narrow hotel rooms, for instance, are easier to pre-produce than wide lobby halls. And bathrooms with a high built value are more feasible for modularization than simple structures.

Applying these trade-offs to different real-estate segments to estimate likely penetration, we find that the market could reach more than \$130 billion by 2030 for the new-build market in Europe and

Box 1

Impact of modular beyond real estate

In other areas of the construction industry beyond real estate, modular construction is also having an impact, or demonstrating the potential for significant impact. We have estimated that modular construction could gain a market share of up to 10 percent in an upper scenario of infrastructure and industrial spend, and deliver cost savings in the order of 10 percent.

In industrial structures, for instance, one pharmaceutical client has gained a competitive edge over its competition by designing “assemblies” that are repeatedly used across plants. In infrastructure,

several construction firms, in particular in PPP settings, design and build similar bridges across highways or railways to reduce costs and accelerate schedule. Quality and schedule certainty are the main motivations in other infrastructure cases: For the expansion at Heathrow Airport, the stated aspiration is to develop a series of offsite assembly areas to minimize the “hot and wet” works on site.

Still, the fragmentation of the industry is leaving value on the table. Even within an organization, project teams rework solutions to the same problems in silos. A structured portfolio approach within and even beyond organizations would reduce industry waste.

Exhibit 1

Modular construction in Europe and the United States could deliver annual savings of up to \$22 billion.

								High	Medium	Low
			Construction expenditure ² \$ ^a bn, 2017	Additional addressable volume ³	Market potential \$ bn	Savings potential ⁴	Savings volume \$ bn	Rationale		
								Repeatability ⁵	Unit size ⁶	Value density ⁷
Buildings ¹	Residential	Single family	376		30		5			
		Multi-family	277		45		6			
	Commercial	Office buildings	77		10		2			
		Hotels	40		10		2			
		Retail	42		5		1			
		Logistics/Warehouse	46		10		1			
	Public	Schools	59		15		3			
		Hospitals	41		5		1			
	Other buildings		70		5		1			
	Buildings total		1,027		135		22			

¹European countries included: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, UK.

²Includes only new building projects. Renovation/maintenance projects are less suitable for modular construction, but offer other productivity gain potential.

³Informed estimates. A full moon corresponds to a potential construction project value for (additional) modular construction of ~30%, a quarter moon thus to ~7.5%, in 2030.

⁴Informed estimates. A full moon corresponds to savings potential of ~20%, a quarter moon thus to ~5%, for each € of addressed construction expenditure.

⁵No unique layout requirements (either from regulation, or design expectations).

⁶Small unit size allows standard transportation.

⁷High complexity of units, high share of wet rooms, etc.

⁸Used 2017 average annual exchange rate to convert to \$ from Euroconstruct data in €.

Source: Euroconstruct; McGraw-Hill

the United States (Exhibit 1). The method could deliver savings of \$22 billion a year by 2030. Beyond real estate, there are also many opportunities to apply modular techniques to infrastructure and industrial structures (see Box 1: Impact of modular outside of real estate).

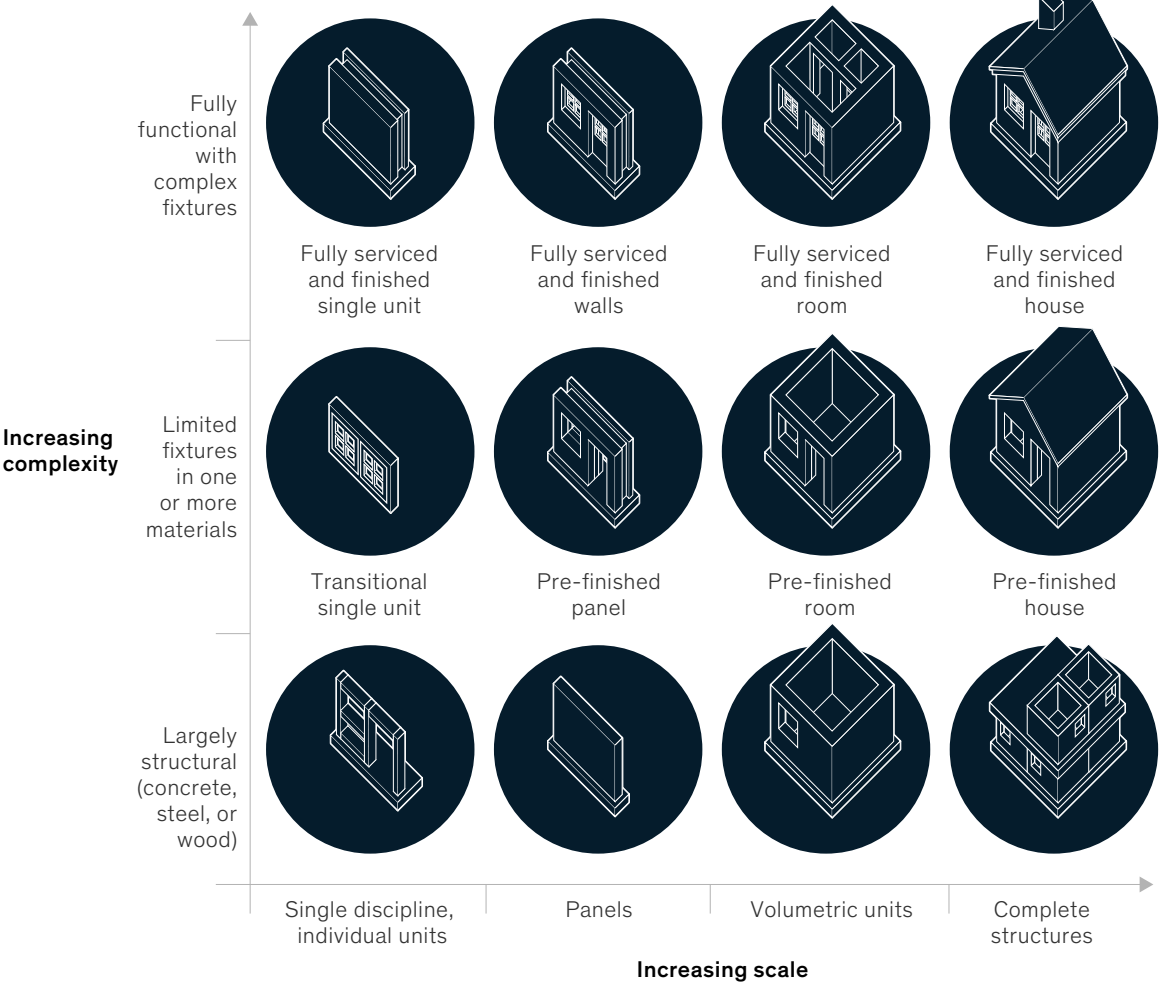
Modular construction encompasses a variety of methods

In broad terms, modular construction involves producing standardized components of a structure in an offsite factory, then assembling them onsite. Terms such as offsite construction, prefabrication, and modular construction are used interchangeably and cover a range of different approaches and systems (Exhibit 2). These systems vary depending on the complexity of the elements being brought together. The simplest are single elements that are clipped together using standard connections and interfaces.

Exhibit 2

Modular construction covers a broad set of approaches.

Complexity and scale of modular construction—comparison of approaches



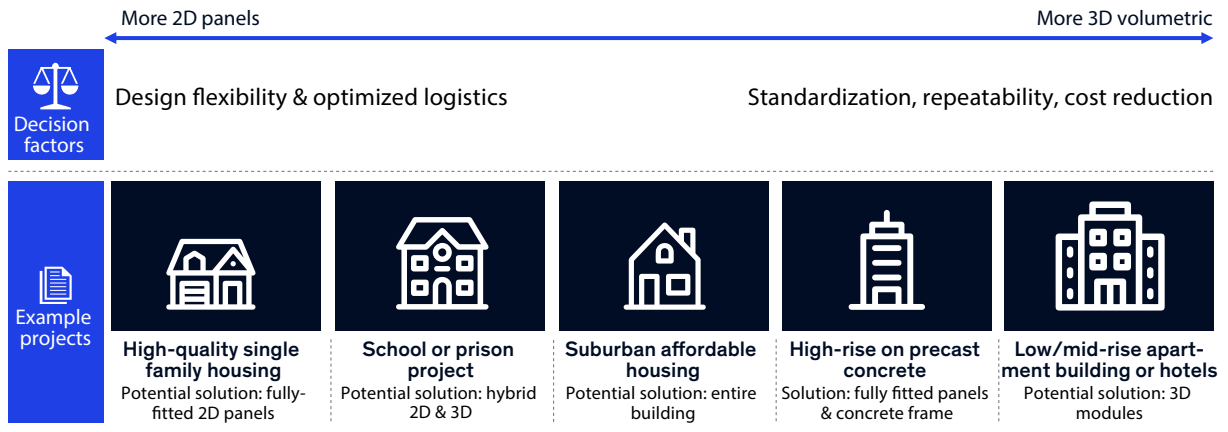
Source: Case studies; interviews; McKinsey Capital Projects & Infrastructure

Further along the spectrum are two-dimensional panels (which can be open or closed), while three-dimensional volumetric units with full fixtures are yet more complex. Wood, concrete, or steel can be used separately or in hybrid systems in various forms.

This report focuses on two major types of modular products: 2D elements that call for more assembly onsite; and 3D volumetric units, which are more fully fitted-out offsite. Each has its advantages and will be suitable for different parts of the real estate sector (Exhibit 3). These two approaches can also be

Exhibit 3

A project's specific requirements will determine the choice of modular system.



combined into a hybrid model. Although this is not an exhaustive look at the full range of modular approaches, we believe they illustrate the type of change that is on the horizon and the gains that are possible.

3D volumetric: Maximizing productivity benefits

3D volumetric solutions are fully fitted-out units, which could constitute a room, or part of a room, that can be assembled onsite like a series of Lego bricks. They are being developed in timber, steel, or concrete, with the first two materials being more common due to weight and logistics advantages. Onsite assembly involves lifting the modules into place and connecting services such as electrical and plumbing. Most of the work is done in a manufacturing facility offsite.

A 3D volumetric approach delivers the potential for maximum efficiencies and time savings—but the trade-offs include transportation costs and size limitations. The maximum width for road transport that does not require a police escort is typically around 3.5 meters. This either increases the cost of transporting larger units or limits the size of modules, making 3D volumetric most suitable for hotels, hostels, or affordable housing. It is also advantageous for rooms with more intricate finishing, particularly wet rooms such as bathrooms and kitchens. A 3D volumetric approach is most suitable for projects with a high level of repeatability and a high ratio of wet to dry rooms. It should be noted that repeatability does not mean all products need to look the same. Instead, a variety of standardized modules can be pieced together differently to produce a customized end result.

2D panelized: Optimizing logistics and flexibility

A 2D panelized solution resembles a flat-pack assembly approach used in home furniture. Where necessary, panels contain the necessary conduits for services such as heating, ventilation, and air conditioning (HVAC), and plumbing that can be linked together with standard connectors.

The assembly work onsite is much simpler than a traditional build, but it is more complex than putting together 3D modules and requires more internal finishing. On the upside, it is much easier to transport panels than bigger 3D modules. In an ideal case, the components required to build several rooms can fit in a single standard 25-foot container. Flat-pack panels therefore make it possible to transport materials for a significantly greater floor area at one time. It costs approximately \$8 per square meter floor space to ship 2D panels around 250 kilometers, but almost \$45 per square meter for the 3D equivalent.

2D panelized solutions offer greater flexibility than 3D modules: large open-plan offices, for example, are not very conducive to single 3D modular elements. 2D panels are also relevant for high-end residential projects, whether single-family homes or apartments, since differentiation matters and the ratio of wet areas to dry areas is lower.

2D & 3D hybrid: Combining the best of both worlds

It is also possible to use a mix of 3D modules and 2D panels on a project or to combine those approaches with traditional site work (for instance, for the basement and first floor of a larger project). Typically, wet areas are manufactured as bathroom pods, while the remainder of the building is made from 2D panels. This optimizes the process for the two different areas of the building, bringing high-productivity improvements to the bathroom areas and maximum flexibility to all other areas. However, the manufacturing process required to deliver both solutions becomes more complex, as does coordination of the supply chain.

When evaluating the difference between these three options for an affordable housing unit of four floors, for instance, we found that a 2D solution could be 17 percent cheaper than a traditional approach, while a 2D and 3D hybrid solution lowers costs by 20 percent, and a 3D solution by 24 percent. This would vary by project, but these estimates indicate the scale of potential savings.

Modular construction can cut schedule by 20–50 percent and construction costs by 20 percent

Modular construction requires a significant shift in mindset and methods—not to mention the need to establish manufacturing environments. But it can be used to build aesthetically pleasing, sound structures—and deliver considerable efficiencies along the way.

Modular construction is reliably accelerating projects

While early modular projects have a mixed track record of cost savings, they have consistently been completed 20–50 percent faster than traditional onsite builds (Exhibit 4).

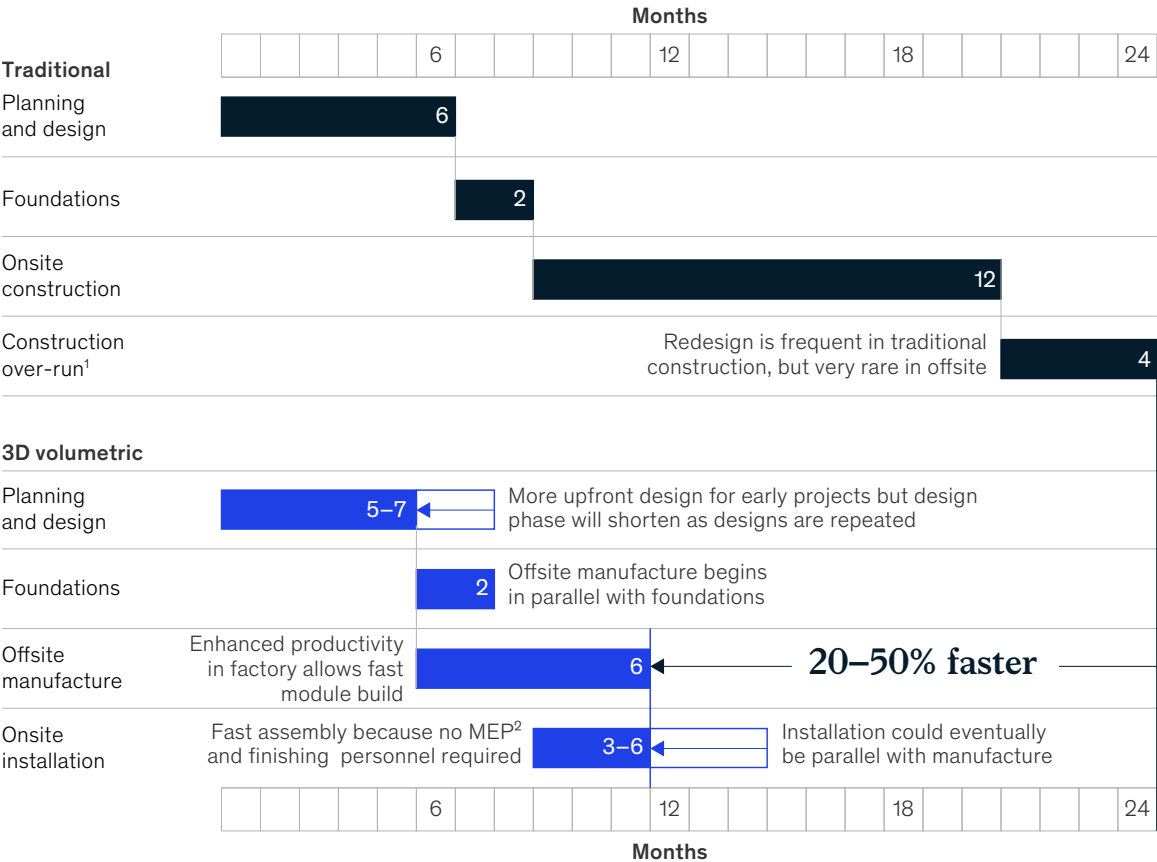
20–50%

build acceleration on
modular projects

- **Design.** Modular projects currently tend to take longer to design than traditional projects, as designers learn to align to the manufacturing process. Design decisions need to be made upfront and changes later in the process are both more costly and more difficult. The industry is not used to working in this way. Design firms are looking to develop libraries of modules for the manufacturing process, potentially accelerated and simplified through automated design, which will shorten the design period. One client identified savings of almost 15 percent in design time through using modular libraries.
- **Foundations.** On a typical project, the time it takes to build the substructure (that is, basements and foundations) is unaffected by the transition to modular. But since modules are designed to be

Exhibit 4
Using 3D volumetric modules can deliver 20–50 percent schedule compression.

Example apartment project construction duration, traditional vs offsite 3D volumetric, months



¹Over-runs of 25–50% of projected construction duration are common.
²Mechanical, electrical, plumbing.
Source: Case studies; interviews; McKinsey Capital Projects & Infrastructure

lightweight for transport, this can reduce the size and complexity of the foundations and yield some time savings.

- **Offsite manufacturing.** The lean offsite manufacturing process is far faster than the equivalent building process onsite. This is due to the enclosed and controlled factory environment, the ability to coordinate and repeat activities, and increasing levels of automation. Capacity and throughput times are also impacted by the number of shifts; typically, two eight-hour shifts are used, although if the appropriate labor is found, three shifts could in theory be possible. Manufacturing can take place in parallel with foundation work, unlike the linear timeline of a traditional project.

Modular projects likely to deliver the greatest cost savings are those that have the highest proportion of labor-intensive activities and the greatest levels of repeatability.

- **Onsite construction.** The onsite construction work involved in a modular approach is radically simplified from traditional builds. It essentially boils down to assembling 3D modules on site and connecting services to the main site connections. Typically, one team of five workers can assemble up to six 3D modules, or 270 square meters of finished floor area, per day. This is significantly faster, and therefore cheaper, than traditional construction.
- **Rework.** Quality control is much easier and better in a factory environment than on a construction site which has a big impact on rework. Reducing or eliminating rework significantly improves construction schedules, potentially by up to several months. There is often also the risk of defects not being identified onsite until many months or years later when it is far harder and more expensive to rectify.

Shorter project schedules are a huge advantage for developers that sell their units in blocks or rent them out. It allows them to begin collecting revenue sooner, paving the way to higher internal rates of return, improved cash flow, and reduced market cycle risks. Faster project turnover also allows developers to liquidate land-banks more effectively during opportunity windows. Although for-sale developers are limited by absorption rates and a fear of lowering prices by flooding the market with too many units, product diversification can alleviate these pressures. Self-builders save on rental costs for alternative accommodation while they are having a new home built for themselves. All stakeholders can benefit from greater certainty in project schedules.

Modular can and should deliver construction cost savings of up to 20 percent—if done right—and can deliver life cycle cost benefits

One of the fundamental benefits of a manufacturing approach in other industries is lower costs. But as yet there is no track record of consistent, game-changing cost savings among projects following this model. Indeed, there is often a premium associated with modular construction. This will likely change, however, as the construction industry changes mindset and gains capabilities. We have identified the factors that result in construction savings being zero in some cases, but reaching 20 percent in others. However, there are two further aspects relating to costs that are important to consider: the first pertains to the full life-cycle costs and the impact that modular construction can have on them; the second is the cost of the factory investment itself and how this impacts the overall cost savings that can be delivered.

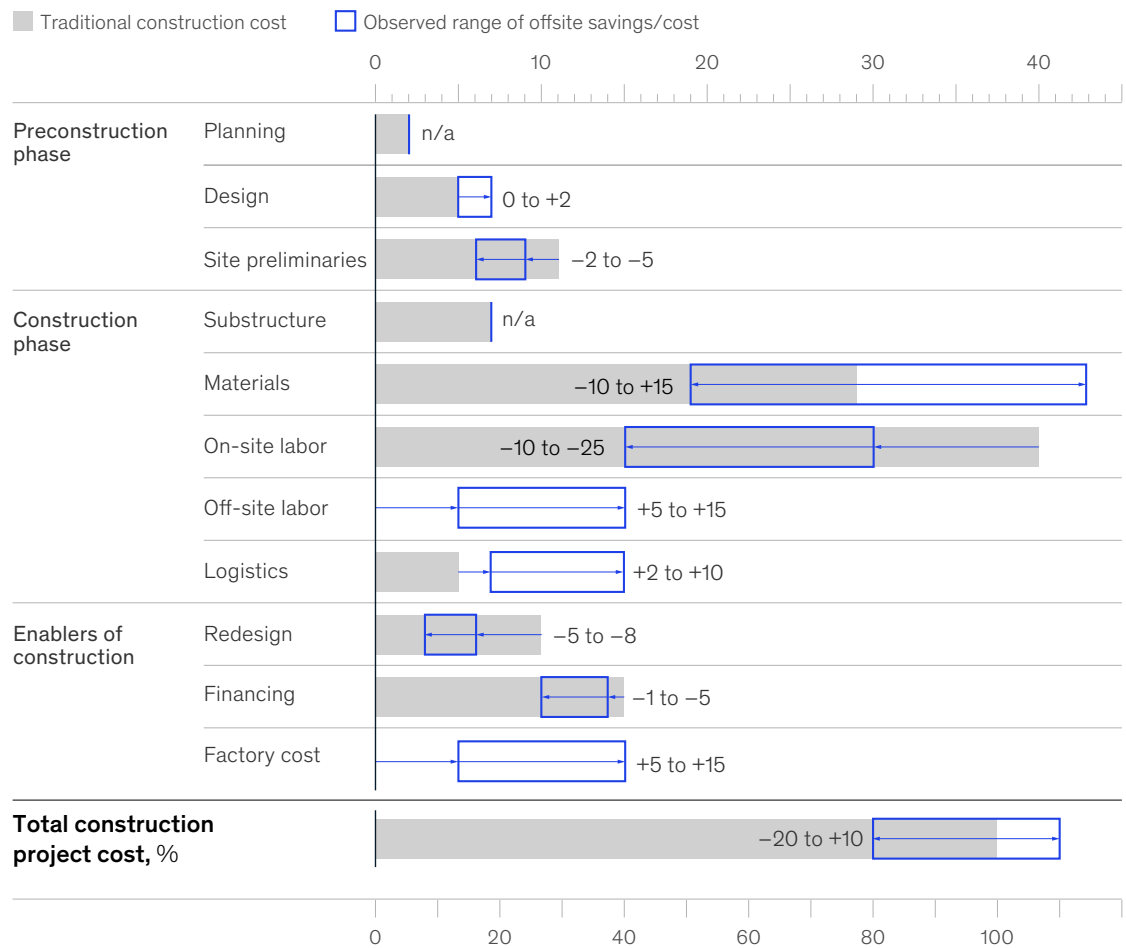
Construction costs

Savings in construction costs come from several different areas. Firstly, the integrated processes involved in modular construction remove the need for subcontractors and the margins that they include in their quotes. Next, the primary trade-offs are between the savings in onsite labor against potentially higher costs for materials and the increase in logistics costs. Modular projects also tend to have higher upfront design costs against lower costs for rework and redesign (Exhibit 5). Given these trade-offs, the projects which are most likely to deliver the greatest cost savings are those that have the highest proportion of labor-intensive activities and the greatest levels of repeatability. Therefore, student accommodation, hotels and affordable housing, for instance, offer high opportunity for savings, while high-end apartments and office buildings are examples of where significant savings are currently harder to achieve. Exhibit 5 considers the full cost of the construction project including the foundations. Where buildings incorporate more of an in-situ substructure this will have an impact on the overall savings that can be delivered by a modular approach.

Exhibit 5

There is an opportunity for 20 percent savings—but at a risk of up to 10 percent cost increases if labor savings are outweighed by logistics or materials costs.

Traditional construction cost,¹ % of total, and potential offsite savings/cost, percentage point shift



¹Indicative breakdown; varies by project.

Source: US Federal Highway Administration; McKinsey Capital Projects & Infrastructure

RAD Urban is an example of a modular supplier looking to generate 30 percent savings on high-rise buildings and 20–25 percent on mid-rise projects. The company aims to take 85–90 percent of onsite labor into the factory, where it estimates that labor is twice as productive as building in situ and with significant cost savings on hourly rates. Automation is lined up as a next step, and will aim to offer an exponential boost to productivity—moving manufacturing on from being twice as productive compared to traditional construction methods today, towards what they see as a future ten-fold advantage.

- **Design.** As with the schedule savings there is often a cost premium in the design due to a lack of experience in designing modular solutions, or due to the potential redesign required if the project has been initially designed for a traditional approach. But as the industry adjusts to creating repeatable designs that can be used and adapted multiple times, this cost will likely decrease. The development of digital tools such as automated design will help.
- **Site overheads.** Modular construction already has a proven track record of reducing project schedules, which in turn holds down the cost of site overheads (such as security and managing weather-related issues) and construction management.
- **Materials.** There are several factors which either add to or reduce the cost of materials for offsite manufacturing compared with onsite. Because of this it is difficult to be clear on whether material costs will be higher or lower overall; however, overall reductions in the order of 5 to 10 percent can be achievable.

Cost increases are driven first by the fact that as these new manufacturing facilities become more automated, there is a need for greater precision in the tolerances of the materials used.

Experienced carpenters working on traditional builds know how to compensate for wood that is slightly deformed in a way that precision robotics currently cannot handle. This increases the quality requirements for the material, which can drive up costs. Second, some duplication of materials is required to produce a transportable product. All properties need to be structurally sound in situ, but units built using offsite construction methods also need to be structurally sound whilst being raised and lowered throughout the transportation and assembly stages of the process. Key structural elements, such as beams, columns, and potentially walls and floors, must be repeated in three-dimensional modules for transportation purposes. This can significantly increase material costs depending on the material choice and level of design optimization.

Offsetting this is that builders can save on the cost of materials by centralizing procurement for a factory, rather than making multiple smaller purchases for individual projects. Three sources of savings can reduce cost by about 20 percent: first, if the factory uses direct procurement, it can often cut out intermediaries; second, this approach gives builders more control over optimizing deliveries to reduce logistics costs; and, third, economies of scale for the purchasing of all units going through a factory versus individual projects have a significant impact. Additionally, a factory production process will also have far lower wastage rates than a construction site, potentially reducing costs by up to 10 percent.

- **Labor force.** In a modular build, up to 80 percent of the traditional labor activity can be moved offsite to the manufacturing facility. Some of the most skill-intensive and expensive types of work (including mechanical, electrical, and plumbing) can be handled by lower-cost manufacturing workers, reducing the wage bill. More importantly, the more standardized, automated, and controlled operating environment of a factory can double productivity above what can be achieved with traditional builds, eliminating a great deal of onsite down time. This is even before considering the productivity benefits of establishing simplified, repetitive processes or advanced automation equipment. Onsite, assembly of modules also requires a lower-skilled and hence lower-cost labor force. And one manufacturer estimates that 25 percent of time onsite is spent creating value, while 75 percent of time spent offsite creates value. Overall, we would expect transitioning to offsite manufacturing to reduce the labor costs on a project by up to 25 percent. The savings are more

substantial when more of the high-value activities such as electrical, plumbing, and HVAC installation can be migrated offsite.

- **Logistics.** In the world of modular construction, coordination and delivery of modules to the site is critical—especially when large 3D units must be moved. The total cost of a project can increase by up to 10 percent in locations with restrictive transport regulations. When considering the use of 3D modules, builders have to ensure that the productivity gains outweigh this cost, carefully weighing wage differentials between the manufacturing facility and the product's end destination, as well as the distance involved in delivery.
- **Rework.** While prefabrication increases the onus on getting the design right first time, it offers an opportunity for cost savings; the vast majority of rework costs can typically be avoided, and they are easier to roll out in standardized units.
- **Financing.** Current supply chains are underdeveloped and fragmented, meaning a lack of standardization between the different operators. This lack of interoperability in a market with small operators and a limited track record makes the bankruptcy risk all the more potent. Today, lending rates for projects utilizing offsite construction tend to be higher since it is a relatively new concept and not always fully understood by the financing industry. But this will change over time as greater R&D is undertaken, track records are developed, and scale is achieved. More importantly, since time equals money, the ability to accelerate projects can lower costs. One caveat to note, however, is that upfront payments are typically higher in projects using this method. In a two-year traditional building project, the developer might pay half up front for the land and the other half spread across the two years of construction time. In a modular setup with cycle time compressed to a year, the entire payment could be due upfront, but financing would be required for only one rather than two years. Assuming 10 percent cost of capital, in this example, financing costs would decline by about 5 percent of the total project cost.
- **Factory costs.** The cost of building the factory needs to be considered against these cost savings. Repaying the capital investment and the ongoing operational expenses of running the factory need to be included. A typical range of the investment cost is hard to define since it is driven by the size of the facility and the level of automation being implemented. However, a value of between \$50 million and \$100 million is a reasonable range based on recent new facilities. By building a business case for the factory itself and assuming a reasonable rate of return on the facility as well as depreciation, operating expenditure, and machinery replacement we can estimate the cost impact on each project. Depending on the setup, allocated factory cost can make up between 5 percent and 15 percent of total costs on a construction project.

Lifecycle costs

When looking at the cost of any project it is important to focus on the full-life cost, not just the construction costs. The increased precision of construction which happens in a factory environment can have a significant impact on the performance of the building. One client has lowered energy bills in its buildings by 25 percent after the transition to modular construction.

Modular approaches can also improve quality. Every outdoor construction site poses its own set of environmental and logistical challenges, including being exposed to the elements. All construction sites seek to be weatherproofed as quickly as possible. Moving building activities into an enclosed, sheltered,

and carefully controlled environment where closer scrutiny is possible will directly improve the quality of the structures being produced. Robotics will further improve precision.

Substantial socio-economic benefits are feasible

Transitioning construction to an offsite manufacturing model can produce the kind of dramatic productivity improvements that have long eluded the industry—and improving the productivity performance of such a large lagging sector is important for economic growth. Globally we identified a \$1.6 trillion productivity gap between the construction industry and the rest of the economy.³ Closing this gap could bring value to project owners from cost savings, to construction firms and producers from margin uplifts, to workers from higher wages, as well as to society at large from delivery of more and better real estate, particularly at a time when many cities face serious shortages of affordable housing.

There could also be negative ramifications for jobs, although losses will be mitigated by increasing demand. Using a manufacturing approach would mean that each unit delivered would require significantly less labor; however, in most markets globally there is a significant infrastructure and housing gap where needs exceed the capacity of the industry to deliver. Therefore, an increase in productivity leading to a reduction in cost of each project could potentially increase the number of projects that can be delivered. Additionally, in many markets, the construction industry is facing a demographic cliff with an aging workforce. The sector's share of employees aged 45 years or older increased to 50 percent from 32 percent between 1985 and 2010. This means that bringing new people into the workforce is going to be critical, and a manufacturing approach offers a different pool of people to access. However, it should be acknowledged that these drivers will not be in place for all markets, and so there will be a risk of jobs being lost, particularly for unskilled onsite labor and for some skilled trades on the construction site.

On the upside, there can be a reduction in health and safety incidents. The secure environment of a factory reduces the risk of construction accidents. It allows for better coordination, with fewer trades competing for the same space. In addition, being based in a fixed factory location rather than having a transient lifestyle following projects and working outdoors in all kinds of weather conditions can improve the wellbeing of the labor force.

³ *Reinventing construction: A route to higher productivity*, McKinsey Global Institute and McKinsey's Capital Projects & Infrastructure Practice, February 2017, McKinsey.com.

Sidebar

Modular has had its moments before, but there is reason to believe its momentum is sustainable this time

Historically, modular construction seems to gain traction in markets with strong demand for housing and labor shortages in the building trade. The importance of the demand dynamics over time in the United Kingdom and the United States is shown in Exhibit 6.

Modular construction enjoyed post-war booms in the United States during the 1940s and 50s, and in the United Kingdom in the 1960s. This came after the world wars when there was a need for speedy reconstruction and social housing, when wartime factories lay empty, and when there were shortages of steel and labor. Its popularity waned as supply and demand began to even out in the United States, following the tragic 1968 collapse of the Ronan Point apartment tower in East London in the UK which sparked concerns about the safety of prefabricated buildings, and after social housing tower blocks developed negative societal reputations.

After a long dormant period, the United States and the United Kingdom are now seeing a renewed surge of modular projects, driven by the twin forces of extreme shortfalls in housing supply and a labor crunch that is making it hard to secure services, driving up their cost, drawing out build schedules, and threatening build quality. The United Kingdom alone needs to

add another 300,000 units per year¹ to keep up with demand for housing, but has not consistently built more than 200,000 new units per year since the 1970s.² Unlike the post-war era when local authorities contributed significantly to new-build completions, today's UK housing market is dominated by private developers, and they have only ever built more than 200,000 homes per year in the two years after World War II. Furthermore, the regular annual shortfalls have led to an estimated UK backlog of one to two million homes.

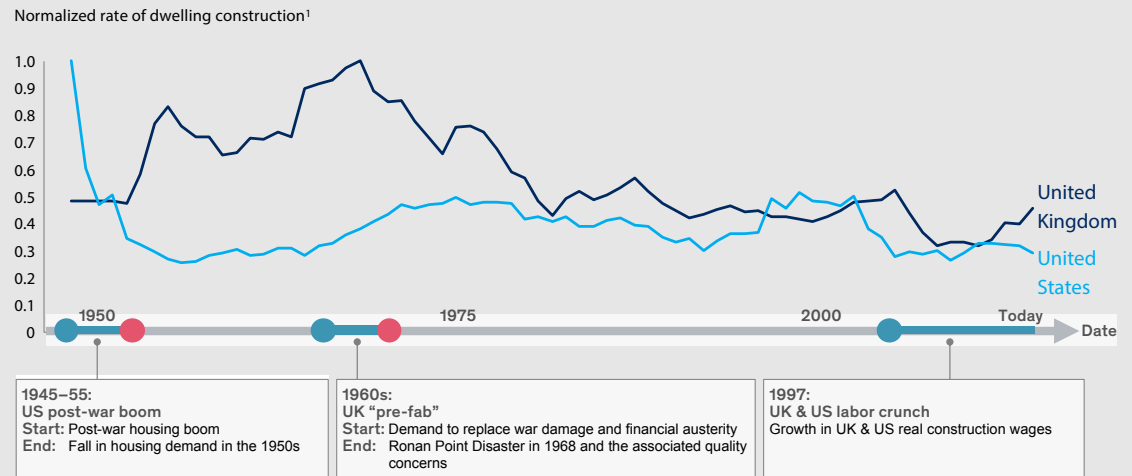
While the popularity of modular construction has fluctuated in the United Kingdom and the United States, it has become mainstream in other markets. Japan, for instance, has capitalized on synergies with other manufacturing industries. The high volume of modular units ensures economies of scale and lower costs of production. It has also become a premium product with modular homes often selling at a greater price due to the strong focus on quality, particularly with respect to earthquake resistance. One of Japan's key enablers has been inspections by industry-specific trained professionals rather than a general building code. In Sweden, short daylight hours and cold weather often constrain work on traditional

¹ Analysis based on Neil McDonald and Christine Whitehead, "New Estimates of Housing Requirements in England, 2012 to 2037," Town & Country Planning Tomorrow Series Paper 17.

² DCLG Housebuilding LiveTable 244.

Exhibit 6

UK and US housing demand combined with labor dynamics have made offsite construction a cost-efficient option at certain historical intervals—but its popularity in the market has proved short-lived.



¹Series is normalized to the maximum value in the period: e.g., US normalized to 1947 and the UK to 1968. Annual US construction figures are smoothed using a 5-year rolling average.

SOURCE: Farmer Report; McKinsey Capital Projects & Infrastructure analysis

construction sites, making modular approaches a logical alternative. A small number of large companies drive healthy economies of scale. Most manufacturers are located in rural areas near timber supplies, and currently around 85 percent of new homes are built using some form of industrial construction.³

³ Housing statistics from Bygghälsan [Building Facts]—Number of building permit applications, 2007–2014.

Why this time could be different

Several factors lead us to believe that the current renewed interest in modular construction may have staying power in additional markets worldwide, first and foremost due to digitization. The maturing of digital tools has radically changed the modular construction proposition. The design of the different modules, the coordination of the processes within the construction facility, and the optimization of the logistics of just-in-time delivery onsite are just some of the enhancements that are

changing the modular proposition. The further development of these tools, including automated design, will further enhance the modular proposition. For example, Katterra uses an integrated technology platform across the construction value chain—solutions include global enterprise resource planning (ERP) deployment, and other industrial Internet of Things tools. The company utilizes building information modeling to directly reach its global supply chain infrastructure for ease of ordering, tracking, and manufacturing. Quality assurance in-factory reduces resources and process time, while mining advanced analytics helps to optimize productivity onsite.

Additionally, some companies are successfully challenging the preconceptions of prefab housing as low-quality, prompting a change in consumer perceptions. These companies are offering high-end homes, often with a modernist look and an emphasis on sustainability. Some use residential designs by “starchitects”, and have even appeared on the pages of *Architectural Digest* and *Dwell*.⁴

⁴ Nick Mafi, “Yves Béhar debuts a line of beautifully designed prefab homes,” *Architectural Digest*, November 2, 2018.

Labor dynamics and demand are at the top of the list of factors driving adoption of modular construction

Seven factors determine whether modular construction is likely to penetrate a given market (Exhibit 7). Labor shortages and an inability to keep up with demand stand out as the most decisive.

A limited supply of skilled labor, which in turn drives up wages and costs, often sets the stage for modular construction solutions. As described earlier, shifting to offsite manufacturing work is cheaper—and it may even attract new people into the workforce who do not wish to move from one construction site to another following projects.

The shift from onsite to offsite construction requires significant investment in manufacturing facilities—and companies will only undertake that investment when they feel certain there is a robust pipeline of projects to keep the facility humming over the long term. Traditionally, projects are procured one at a time, making it hard for facility owners to have that confidence, especially given the cyclical nature of development and the impact this will have on factory utilization rates. But today, many markets are facing deep, structural supply shortages that will take years to address. Previous MGI research, for example, found that California needs to build 3.5 million units by 2025 to close its housing gap.⁴ Demand is clearly more than sufficient in many markets to maintain manufacturing facilities, especially given that many existing facilities are already running at capacity with long waiting lists.

⁴ *A tool kit to close California's housing gap: 3.5 million homes by 2025*, McKinsey Global Institute, October 2016, McKinsey.com. For a discussion of this issue at a global level, see *A blueprint for addressing the global affordable housing challenge*, McKinsey Global Institute, October 2014, McKinsey.com.

Exhibit 7

Seven factors determine the attractiveness of a market for modular.

Source: McKinsey analysis

Several additional drivers can have an important impact on the attractiveness of modular construction, including supply chain and logistics. Transport regulations constrain the size of modules that can be moved by road in some markets (including some US states), and access may also be limited in some dense urban locations. The second and related point involves other types of local constraints. In Scandinavia, for example, limited daylight in winter makes it particularly attractive to reduce onsite construction. In other cases, compact sites may make it desirable to deliver and rapidly install modules without requiring significant storage of materials. Third, geographies with ample access to low-cost materials (such as timber) are natural markets.

One major factor is quality perception. In some markets, the industry will need to overcome lingering perceptions from the post-war era that prefab housing is only a poor-quality, cookie-cutter solution for the masses. One route is to emphasize sustainability and future savings on energy and repair bills. Another route would be to focus on the appeal of modular construction in parts of the housing market where consumers already expect standardized offerings at scale, such as hostels, public-housing projects, retirement communities, and hotels. Our clients have also indicated that their customers, particularly in the younger generation, appreciate the quality implications of transitioning to an industrialized manufacturing approach. Also, from a developer's point of view, in many segments in the

build-to-let market and also parts of build-to-sale, customers are not even aware of the difference between a modular and traditional build approach, so won't have strong opinions on the difference as long as design and functional quality needs are met.

The final determinant is regulation. Quality certification standards and warranties are big drivers that can inform customers and give them confidence. These certifications and warranties also facilitate the provision of financing as development financiers and mortgage providers need them to agree loans. Financing will also become easier as scale is achieved and insolvency risk is alleviated. Governments can additionally help to drive adoption by including offsite manufacturing targets in public projects. In Singapore, for example, all government housing projects must use prefinished volumetric modules. Sustainability requirements and incentives will also help to drive the industry toward the most carbon-neutral products and practices. Another option is to support mortgages for the purpose of offsite manufactured homes. Similarly, building standards will have an important role in driving the uptake of modular construction. The more that they can move towards harmonization across different geographies and sectors, the more that suppliers will be able to drive scale into their pipeline.

Many markets worldwide have the conditions in place for modular construction to take root

Since unmet housing demand and the relative scarcity and cost of construction labor are the biggest predictors of where modular construction can gain traction, it is helpful to identify where those two conditions intersect. Exhibit 8 illustrates why this shift has taken hold in Japan and Scandinavia—and it highlights growth potential in markets such as Australia, the United Kingdom, Singapore, and the US West Coast.

Although modular construction is currently used for only about 5 percent of new homes in Australia, the right conditions appear to be in place, since the country has both high construction wages and great unmet demand for housing.⁵ Most of the offsite manufacturing that takes place today uses relatively basic manual production lines, but there is increasing interest and investment from leading players.

Singapore's Housing Development Board is building 20,000 to 30,000 units a year using offsite manufacturing, driven by a desire to speed construction.

In the United Kingdom, offsite manufacturing has been used in about 15,000 new homes in 2018. Production costs are still high, but rising labor costs are making modular products more competitive.⁶

In the western United States, the ecosystem is generally fragmented and small scale, with around 200 low-capacity manufacturers. However, high and rising construction wages in skilled trades such as electricians have driven a recent shift toward offsite manufacturing. This is related to the sustained construction boom that is outstripping capacity, which is driving comparatively higher and rising wages. This is making it economical to start using modular construction. Major investors (including SoftBank, Google's parent company Alphabet, and even Amazon) have invested in prefab home developments and builders such as Katerra, RAD Urban, and Factory OS.

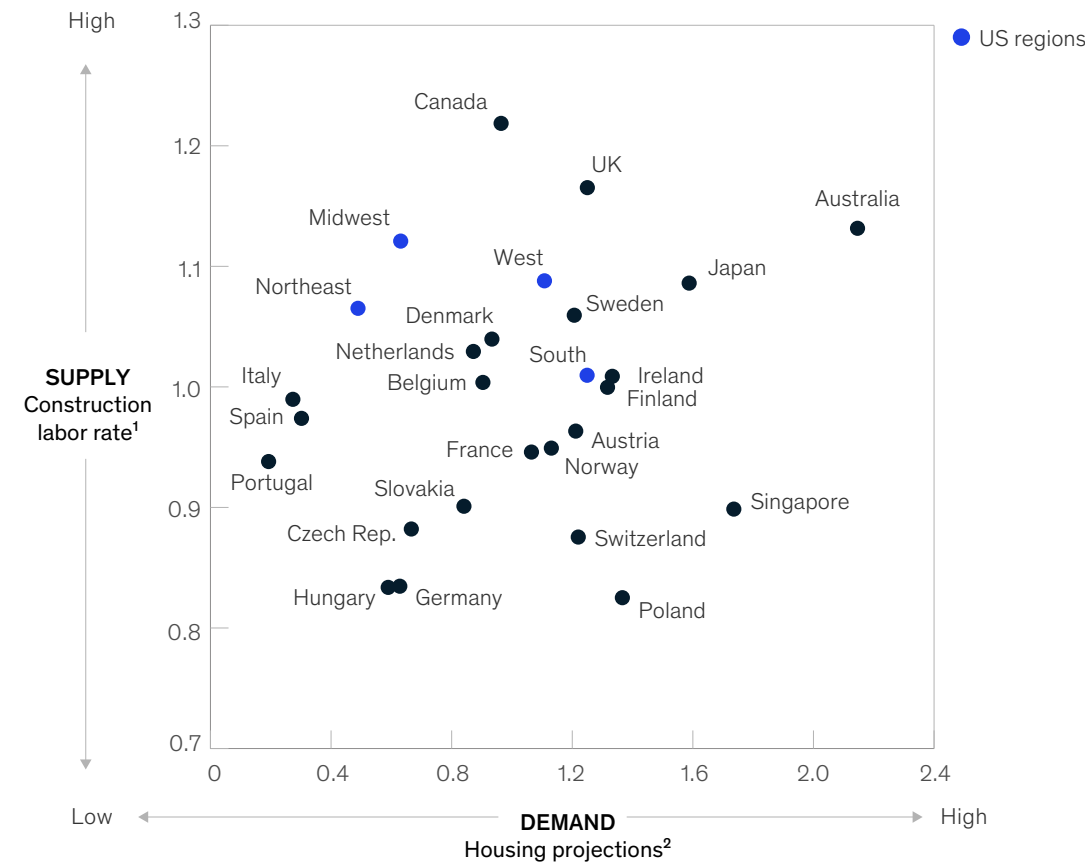
Unmet housing demand and relatively scarce construction labor are the biggest predictors of where modular construction can gain traction.

⁵ Housing Industry Association, Australia.

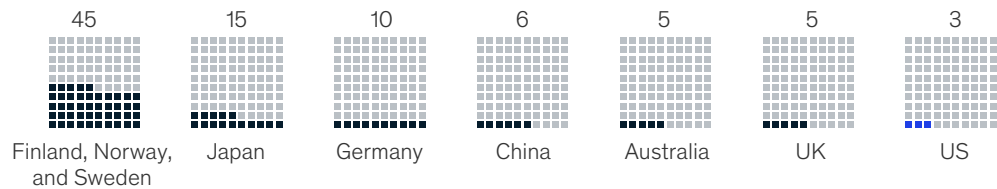
⁶ UK Ministry of Housing, Communities & Local Government.

Exhibit 8
Many countries exhibit conditions appropriate for growth in offsite construction, and some markets are already established.

Near-term demand for new housing vs construction labor supply



Current offsite share of housing, %



¹Construction wage divided by national median wage.
²2017–20 average housing projection as a % of national housing stock
Source: 5 in 5 Modular Growth Initiative (Ryan Smith); ABS.Stat; CMCH; curbed.com; Euroconstruct; HIA Australia; ILOSTAT; interviews; Ministry of International Trade and Industry (Japan); Mitsui Fudosan; Natural Resources Canada; OECD; Prefab Housing (Matthew Aitchison); Roland Berger; UK Ministry of Housing; Urban Redevelopment Authority; US Census Bureau; McKinsey Capital Projects & Infrastructure

One surprising aspect of the chart is the relatively low apparent position of Germany in terms of the two drivers versus the relatively high penetration of offsite construction in the market. One reason for this may be that 75–80 percent of residential buildings and 85–90 percent of offsite-produced residential buildings in Germany are built by private households, meaning that the market is driven by different dynamics, where owners place a premium on convenience, cost and schedule certainty, and energy savings.⁷

Modularization can disrupt the construction and real-estate ecosystem

Shifting from traditional, familiar building techniques to more efficient modular prefabrication will require major changes—not only from modular manufacturers but also for developers, construction firms, investors, and the public sector.

Modular manufacturers: Scale and optimize

Modular manufacturers need business models and plants that maximize efficiencies and quality. Today, many are operating at capacity and facing the need to scale up quickly to respond to demand. The next set of challenges will therefore include attracting the right forms of financing, expanding facilities, and moving to higher operational standards.

Six priorities can help achieve further improvement in productivity and maximize the cost savings over traditional onsite construction:

1. **Achieving economies of scale.** One of the key drivers of cost savings comes from economies of scale. This requires large-enough factories as well as sufficient output to ensure repeatability, learning, and volume savings on procurement. Our interviews indicate that companies achieve a rapid and substantial step-up in productivity when they begin turning out approximately 1,000 units per year. Another step-up, typically associated with another 5 percent boost in productivity, seems to be reached at about 5,000 units per annum (Exhibit 9). The fundamental dilemma facing many modular suppliers at this stage of their evolution is whether they can tap into a reliable pipeline of work within geographic reach to justify these larger-scale and more productive plants.

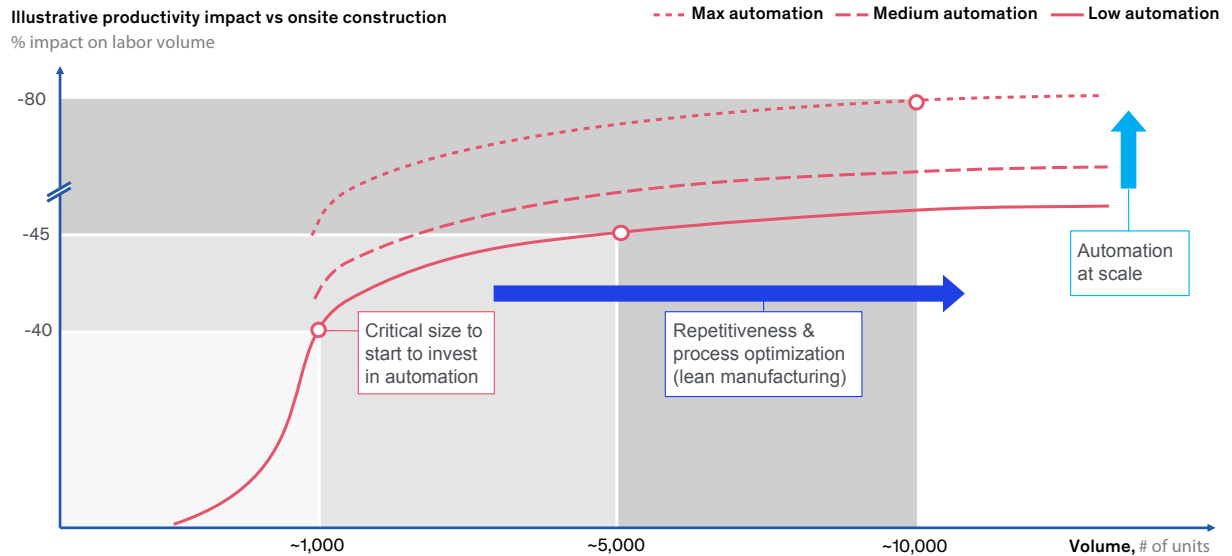
One strategy to achieve utilization of a factory is that used by BoKlok. The concept is owned 50-50 by Skanska and Ikea, while all of the production and construction is carried out by Skanska. BoKlok produces apartment blocks, terraced houses, and flexible flats. A key consideration in its approach is factory capacity utilization. The company leverages several factories: one owned factory in Sweden and several sub-contracted factories (in Poland and the Baltic states) which handle production overflow. This multi-site solution allows for optimization of capacity utilization, ensuring the “home” factory is always at 100 percent utilization, where Skanska can also look to further lower costs through driving continuous improvement.

2. **Integrating along the value chain.** Modular players can ensure sufficiently large portfolios of projects to maintain the utilization of their factory if they integrate or partner with owners and developers to guarantee a pipeline. This will help sustain the productivity benefits provided by the

⁷ German Federal Statistics Office.

Exhibit 9

The first critical productivity step is achieved at approximately 1,000 units a year, beyond which productivity gains slow down.



Source: Expert interviews

manufacturing approach. In addition, developing design capabilities or partnering with designers can ensure the development of standardized products tailored for the manufacturing process. Integrating materials supply at the back-end of the value chain can help capture the gains from standardization and internalize distributor and OEM mark-ups. This highlights potential for modular construction to initiate deeper structural changes in the industry. The likes of Katerra and BoKlok are examples of players taking a more integrated approach.

3. **Optimizing design.** Modular construction requires different design thinking to account for production efficiencies, opportunities to develop standardization to offer mass customization, and ease of transport and assembly. All of this has to work within the same mandate that always governs construction projects: creating pleasing and functional spaces for the eventual occupants. The right design can improve productivity by 3–12 percent. One useful analogy is the automotive industry. Car makers use the same chassis in multiple car models but swap out various features to make different models look and feel distinct. Even within these models, customers are often given options to personalize a vehicle, all of which can be achieved in the manufacturing process. The design needs to lend itself to maintaining a processing line, without the need constantly to change the line itself to deliver some custom features.

4. **Digitizing and harnessing data.** As the construction sector digitizes more broadly, modular players should have a head start they can continue to capitalize upon. Providing a platform, perhaps utilizing virtual and augmented reality, for customers to tailor designs will be easier for modular players, which will also naturally evolve with digital models and processes throughout the manufacturing process and supply chain. Digitally enabled just-in-time delivery to sites will be critical, since it will not be efficient to stack and store modules on site for later use.

RIB SAA Software Engineering, for instance, provides planning and robot software for modular construction manufacturers. It is developing full-system solutions for the industry, including production planning and logistics, as well as control systems for prefabrication machinery.

5. **Automation.** There are two stages involved in the transition to offsite manufacturing. The first is simply moving construction offsite and into a facility, even though tasks are still carried out by hand. This will result in significant productivity benefits. However, companies can achieve another step change in productivity by introducing robotics and other automation technologies into the manufacturing process. This will take the construction industry into a similar realm to automotive manufacturing. Two challenges need to be overcome. First, determining the optimal setup and then setting up a highly automated facility requires significant upfront investment, reinforcing the need for a steady demand pipeline. Second, construction materials are currently supplied to the specification necessary for highly manual onsite construction. While humans with judgment can make adjustments to work around imperfections in materials, machine processing requires greater precision. This puts the onus on the supply chain to deliver high-specification products at a comparable cost. The productivity benefits from automation are not just limited to the manufacturing process. They also have a role on construction sites. For example, automated cranes will be able to lift and move the modules into the required position, made easier by the repeatable nature of the modules.

Lindbacks, a modular construction firm in Sweden, uses Randek's industrial construction machinery to automate a variety of construction tasks including nailing, milling of openings, sheet cutting, gluing, inkjet marking, and sheet addition and handling. Another is controlled by CAD-generated data as a solution for the production of insulated walls that can be configured for different wall lengths, widths, and heights, as well as the number of wall layers.

6. **Improving capabilities.** Most modular suppliers will need to invest in building skills and expertise. Companies will need new capabilities in design, manufacturing operations, and digital technologies. Their go-to-market strategies may include deeper partnerships with developers, construction firms, and financiers. They will need to compete with other industries for scarce digital talent. Finally, they will need to introduce and maintain the classic kind of "continuous improvement" mentality that leading manufacturers have developed over the years. This contrasts with the struggles the construction industry has faced in training talent, which is a result of the low-margin nature of the business.

Our high-level modeling suggests that companies pushing forward successfully on all six fronts could lower costs on a total project by more than 30 percent, topping the 20 percent potential discussed earlier.

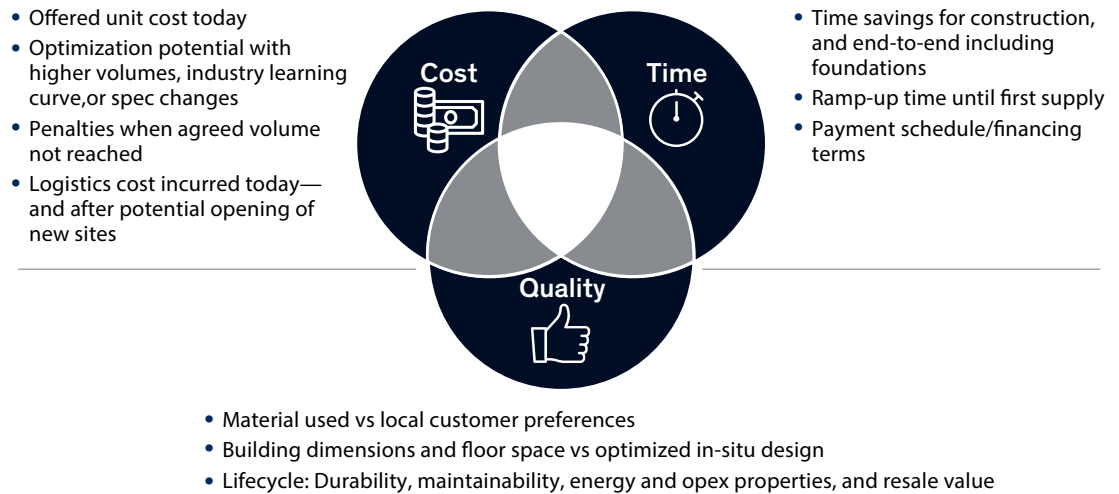
Developers: Scale up, move toward “product” offerings with a clear value proposition, and partner

An increasing number of developers are intrigued by modular construction’s potential, but are not sure how to make the leap in a way that guarantees reliable advantages.

A good starting point for developers is identifying the segments of a portfolio where volume, repeatability, and retained ownership come into play. These can be designed as a “product core” that remains consistent across developments. These products may then need to be tailored for a modular approach (for instance, reducing the use of basements and bespoke ground floor designs, changing room widths to maximum road transport limits, or minimizing variability). Using prefabrication, while offering a degree of customization—such as enabling customers to choose some interior finishes and altering the façade and layout, will be crucial to satisfying both end customers and local authorities. Developers should look to understand and optimize the strategic trade-offs in the products they commission and develop between quality, cost savings, and time savings (Exhibit 10).

Exhibit 10

For developers, value creation requires trade-offs between various factors.



Investors: Disruption will create winners and losers—and hence attractive opportunities

Disruption in construction has been talked about for decades. There is growing evidence that it is coming. This disruption will result in winners and losers and the construction landscape will look very different, which makes it a particularly interesting sector for smart investors seeking alpha at this time. Investors should seek to understand the markets that will most likely be disrupted and the detailed trends, strategies, and capabilities that will set the winners and losers apart.

Activity in this area is heating up, too. Beyond the recent funding rounds for Kattera led by Softbank, we see that, for instance, Polcom—the modular supplier to hotels—was purchased by the Griffin and PIMCO funds for over \$250 million, indicating the attention that investors are starting to pay to the industry. Overall investment in the construction industry has increased on average by 9 percent a year since 2009, concentrated in North America and Western Europe but also growing significantly in Asia.⁸

Materials suppliers: Prepare for a shift in products and go-to-market—or enter the space

First and foremost, building materials suppliers face a shift in their choice of building materials. For instance, if cross-laminated timber and steel-frame based modules gain market share, this will affect cement companies—not only providing new material choices for the structure, but also reducing the need for foundation materials due to a structure’s lighter weight.

Materials suppliers may also face an entirely different go-to-market landscape. Their customers may no longer be fragmented installers or traditional distributors, but larger manufacturers that are optimizing for different objectives.

Materials suppliers, however, may be well placed to enter the prefabrication space. They have knowledge of both the industry as well as of efficient manufacturing and supply chain environments and, as such, may have a head-start over smaller engineering and construction firms.

Public sector: Bundle the project pipeline and update building codes

Public-sector entities, like private-sector developers, have an opportunity to achieve cost savings and productivity benefits by taking a modular approach with any large-scale publicly funded projects that have repeatable elements, including schools. They can have a bigger impact by bundling these projects across cities, regions, or states. If government clients establish standards, they can turn to different manufacturers and help to drive change throughout the industry.

The public sector can also facilitate modular adoption by modernizing building codes—which dovetails with the goal of removing barriers to more affordable housing. To the extent that can be achieved and is appropriate, the streamlining of building codes can drive manufacturing efficiency across different geographies. Approval processes can be faster and more efficient if product designs and production processes can be approved in factories rather than on each individual project site, reducing the inspection burden on site to assembly verification only.

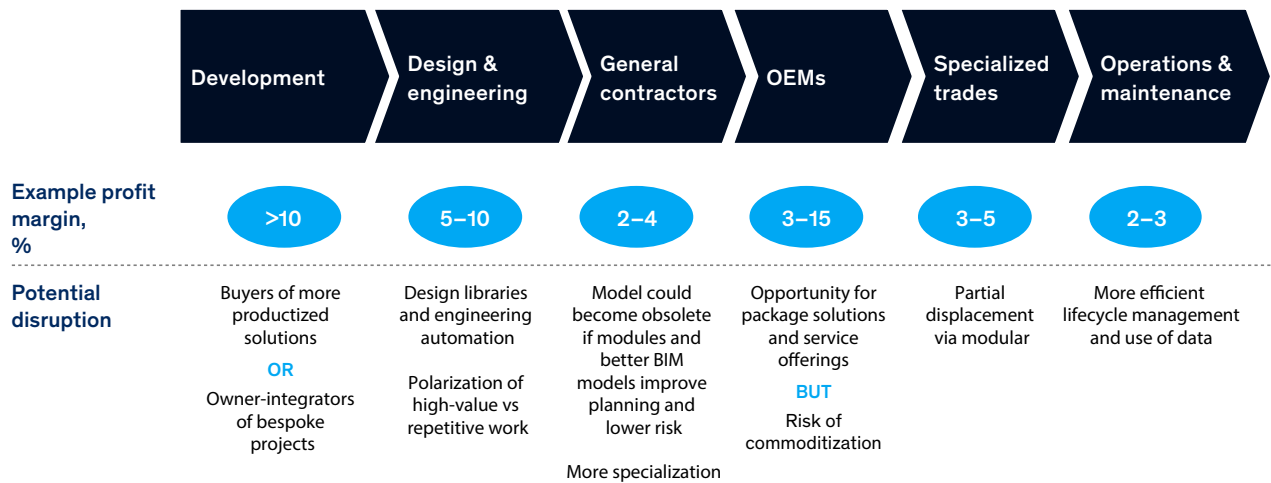
Engineering and construction firms: Preempt commoditization in a shifting value chain

Delivering projects in a new way begins to challenge the traditional role of engineering and construction firms. While modules will still need to be assembled, onsite construction may become a smaller and more commoditized part of the value chain. Today general contractors manage complex projects with many subcontracted trades involved and shoulder executional risks, but they are at risk of being cut out of a value chain focused on simple module assembly with high cost and schedule certainty (Exhibit 11).

Traditional engineering and construction firms can counter this risk by moving into development, consulting, and planning. They can also aggressively make use of modules to gain margin advantages over competitors for what looks to be an extended transitional period. Some may team up with

⁸ Pitchbook deal analysis

Exhibit 11
All players need to prepare for shifts in value pools.



Source: Client studies; expert interviews; McKinsey analysis

module manufacturers. Finally, they can focus on highly complex projects that demand more onsite work, since custom projects will not disappear even in a more modular world. Even for firms that choose to maintain a traditional focus, accelerating digitization, being open to new collaborations, and keeping operations lean will be critical to competing in the future.

These players could also look to compete in the modular construction space. For example, Skender in the United States has pursued a strategy of vertical integration to try to bring in-house as much of the modular value chain as is feasible, including architectural design, engineering fabrication, and construction. The contractor sees this approach as giving it a point of difference in Chicago's housing market.

After decades of relatively slow change, an at-scale shift to modularization—alongside digitization—looks likely to disrupt the construction industry and broader ecosystem. All players should evaluate the trend and impact, and assess their strategic choices, to ensure they can benefit rather than risking being left behind.

Bibliography

Barbosa, Filipe, et al., *Reinventing construction: a route to higher productivity*, MGI, February 2017.

Berg, Nate, "Germany's prefab mansions are sleek, sturdy, and expensive-housing-design," *Curbed*, 2017.

Burgess, Gemma, Michael Jones, and Kathryn Muir, *What is the role of off-site housing manufacture in a digital built Britain?* Cambridge University, 2018.

Chevin, Denise, "Is offsite really the answer to our housing problems?" *BIM+*, June 2018.

Farmer, Mark, *The Farmer Review of UK Labour Construction Model*, Construction Leadership Council, October 2016.

Hall, Robert W., "Tokyo Sekisui routinely builds 80% of a house in 3 days," *AME*, 2008.

Hoover, Sabine and Jay Snyder, Ethan Cowles, *New day, new mindset: Rethinking offsite construction*, FMI owner survey, FMI, 2018.

Peltokorpi, Antti, et al, "Categorizing modularization strategies to achieve various objectives of building investments," *Construction Management and Economics*, 2018.

Quale, John, *Offsite architecture: Constructing the Future*, Ch10: "High-performance affordable homes, 2017."

Smith, Ryan E. and Ivan Rupnik, *5 in 5 modular growth initiative*, Modular Building Institute, 2018.

Smith, Ryan and Talbot Rice, *Offsite architecture: Constructing the Future*: Ch7: "Permanent modular construction," 2017.

Smith, Ryan and Talbot Rice, *Permanent modular construction: Process, practice, performance*, Modular Building Institute, 2015.

Stern, Dale, "Steel-framed modular construction for high-rise hotels: What you need to know," *Hotel Online*, December 2017.

Velamati, Sri, *Conference Report: State of the Art Modular construction in 2017, 2012*.

Xie, Jenny, "Preparing for our prefab future," *Curbed*, 2015.

Feasibility, benefits and challenges of modular construction in high rise development in the United States: A developer's perspective, Modular Building Institute, 2017.

Innovation in buildings workstream: Demand creation, investment and volume surety, Construction Leadership Council, November 2017.

Lloyds Bank, *Housebuilding Report 2018*.

MBI 2017 Q3 Report, Modular Building Institute, August 2017.

Modern methods of construction: Views from the industry, NHBC Foundation, June 2016.

Permanent Modular Construction, Modular Building Institute, 2017.

Prefabrication and Modularization: Increasing Productivity in the Construction Industry, McGraw-Hill, 2011.



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June 2019

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