Dear Colleagues,

As many of you may know, I submitted a review item to the Education Committee in November, E30.045, regarding an alternative construction method known as prefabrication. While I agree entirely with the Administration's assessment that Stamford must replace at least several schools as quickly as possible, I do have concerns about using a public-private partnership for constructing such schools. As such, I was hoping to start a conversation on alternative courses of action.

After continuing to research this matter, I believe that there is sufficient evidence that prefabrication is worth consideration as an alternative course of action. Therefore, I have prepared the enclosed summary of research for your reference.

This overview consists of three parts. In the first part, I've set out basic background on prefabrication construction techniques. In the second part, I've outlined the use of prefabrication construction for schools in particular. In the third part, I've included some high-level research on the costs of such projects, which appears to be competitive with other construction options. Each part is supported by my underlying research, which is set out in the exhibits attached hereto. The review proceeds sequentially.

1. Basic Background on Prefabricated Construction

Prefabrication is a different method of constructing buildings, though the end result is a building like any other. While traditional construction techniques simply call for assembling a structure on site, prefabrication divides a structure into its component sections, with each section being prepared in a factory and then simply assembled on site. [1] To be clear, this method of construction requires far more advanced planning, as each piece must fit together with great precision.[2] However, given the sophistication of modern construction technology and computer modeling, prefabrication is now feasible for even large structures.[3]

As outlined in Part 2, prefabrication has been used for many schools around the country. Suffice to say, there are several advantages to the prefabrication method of construction, including:

- **Lower cost**: Prefabrication reduces construction costs on two fronts.[4]
    - First, production in a factory and rapid assembly maximizes efficiency in construction, thereby reducing labor costs.[5]
    - Second, factories can take advantage of significant economies of scale in purchasing, thereby reducing the costs of materials.[6]
- **Higher quality**: Unlike traditional construction, which must account for exposure of materials to the weather and bespoke onsite assembly, prefabrication allows for

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[1] Such sections are also known as modules, hence the term "modular construction." Insofar as these terms are synonymous, I will refer to this construction technique as prefabricated construction throughout.

[2] See generally Exhibit A, page 8.

[3] Exhibit A, page 18; Exhibit B, page 8.

[4] Exhibit A, pages 12 – 14; Exhibit B, pages 18 – 19

[5] Exhibit A, page 14; Exhibit B, page 19.

[6] Exhibit A, page 14; Exhibit B, page 21.

construction in a weatherproof factory.[7] Further, quality control is significantly easier in a factory as each section can be inspected as it is completed.[8]

- **Faster assembly**: Prefabricated buildings can be assembled much faster than traditional construction for three reasons.
  - First, prefabrication allows for parallel pathing. While the factory produces the building sections, on site preparation and foundation work can begin, thereby compressing the construction timeline.[9]
  - Second, production in a factory allows for greater specialization of assembly tasks and, as noted above, more efficient use of time.[10] Whereas traditional construction is generally limited by the availability of daylight and weather conditions, a factory can reliably move a project along every day with limited delays.[11]
  - Third, assembly on site is much simpler than traditional construction, as each component simply needs to be combined in its proper place.[12]
  - It is possible to use prefabrication to completely build a given school in a single summer, thereby removing the need to relocate students.[13]

Given these advantages, it seems that prefabrication merits consideration for school infrastructure. To that end, I've set out the relevant research regarding school-specific application of modular construction in the next part.

2. Prefabrication for School Projects

Prefabrication has been successfully deployed for a wide variety of public projects, including hospitals, student housing, university buildings, and schools.[14] Prefabrication of schools has been done around the world and the United States, and in every context from responding to a particular large-scale building challenge to smaller building add-ons.[15]

For ease of reference, I have organized various examples of prefabricated school projects into exhibits. Respectively:

- **Exhibit C** contains a list of the winners of the Modular Building Institute's "Best Permanent Structure, Education, Over 10,000 Square Feet" from 2019 to 2015.[16]

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[7] Exhibit A, page 15; Exhibit B, page 18.

[8] Exhibit A, page 12 (notably, adding that traditional construction methods carry "the risk of defects not being identified onsite until many months or years later when it is far harder and more expensive to rectify." Because each section can be inspected in a factory in a factory prior to assembly, prefabrication can significantly reduce this particular construction risk. See also Exhibit B, page 23.

[9] Exhibit A, page 11; Exhibit B, page 18.

[10] Exhibit A, page 14.

[11] Exhibit A, page 11.

[12] Exhibit A, page 10.

[13] Exhibit C-6, which notes that the St. Joseph School was completed in the summer of 2016.

[14] Exhibit A, page 7; Exhibit B, page 8; https://www.hfmmagazine.com/articles/1275-speed-to-market).

[15] For an example of a large-scale project, see the following regarding a program to build 100 schools in Australia,https://www.childinthecity.org/2018/02/16/building-the-prefab-schools-of-the future/?gdpr=accept&gdpr=accept). For examples of smaller projects, see the Modular Building Institute's Award of Distinction in the "Permanent Modular, Education, Under 10,000 Square Feet" category.

[16] I note that the link for the 2016 winners appears to be broken and therefore I have omitted that year.

- **Exhibit D** contains five case studies from Whitley-Evergreen, a design firm that prepares prefabricated building plans.
- **Exhibit E** contains additional case studies from a joint report by the National Institution of Building Sciences, the Modular Building Institute, the Integrated Technology in Architecture Center, and the University of Utah.

The bottom-line is that prefabricated schools are substantively indistinguishable from schools built using traditional construction methods (though, as noted above, the final product has potential to be of superior quality). In the next part, I've set out some research regarding the costs of utilizing prefabrication for school projects.

3. Cost-Specific Research

It is difficult to compare school construction projects, as any given project may be subject to differing price considerations (e.g., cost of local labor, school requirements, and the unique customizations of a given project). Costs per square foot do provide a relatively uniform metric, but such data has been difficult to acquire, in that public information regarding projects do not always include such metrics. Nevertheless, preliminary research indicates that prefabrication can be quite competitive from a cost standpoint, with estimated costs ranging from approximately $188 - $300 per square foot.

Below, I have set out four projects from different parts of the country with costs per square foot results.

#	Project Name	Location	Grade Levels	Sq. Feet	Cost	Cost per Sq. Ft.
1.	Lexington High School Modular Addition	Lexington, MA	9-12	16,800	$4.9 million	$297/sf[17]
2.	High Tech High	San Diego, CA	9-12	61,445	$11.57 million	$188.30/sf[18]
3.	Stem High School	Lake Washington, WA	9-12	63,000	$15.6 million	$247.83/sf[19]
4.	San Benito High School Visual and Performing Arts	Hollister, CA	9-12	27,000	$7.9 million	$292.59/sf[20]

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[17] See https://www.wbdg.org/additional-resources/case-studies/Lexington-high-school-modular-addition

[18] Exhibit E, "High Tech High" case study.

[19] Exhibit E, "Stem High School" case study.

[20] See http://www.aedisarchitects.com/featured_projects/san-benito-visual-performing-arts/

Excepting High Tech High (built in 2009), all of these projects were constructed in the last ten years.

I would add that just as we anticipate that the scale of Stamford's needs may motivate competitive bidding for the privatization plan, it would be reasonable to assume that the prefabrication industry would respond favorably to the opportunity to work on a such a large-scale project.

Conclusion

Based on this research, I believe that prefabrication construction is potentially a significant opportunity for Stamford and should be thoroughly investigated as a possible solution to school infrastructure issues. I hope that you will share this view and I will be happy to discuss anytime.

Sincerely,

Ben

Benjamin Lee
Stamford Board of Representatives
District 15 Representative
Phone: 203-614-9366
Twitter: @BenLeeCT
Email: blee@stamfordct.gov

Exhibit A:

McKinsey & Company – Modular Construction: From Projects to Products

McKinsey & Company

Capital Projects & Infrastructure

Modular construction: From projects to products

by Nick Bertram, Steffen Fuchs, Jan Mischke, Robert Palter, Gernot Strube, and Jonathan Woetzel

June 2019

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Modularization can disrupt the construction and real-estate ecosystem. 23

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.

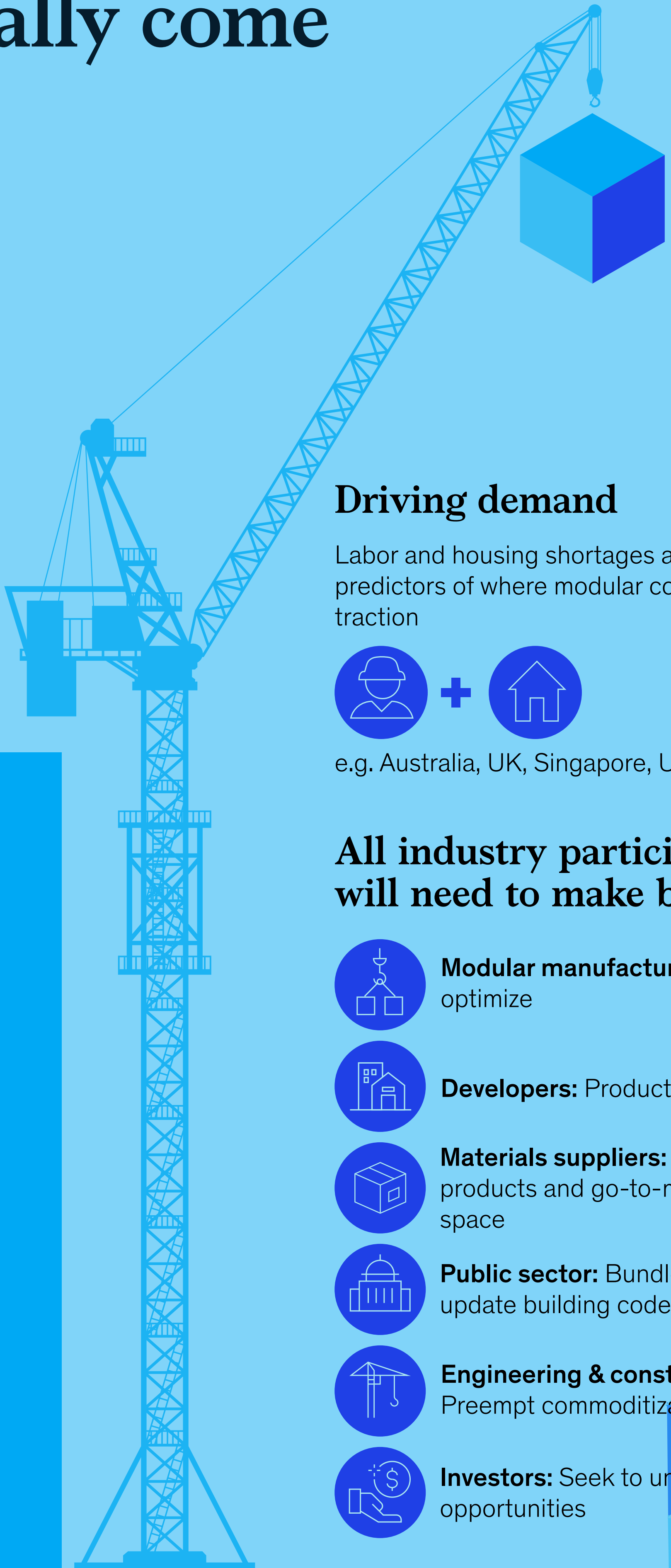
— Prefabricated housing has achieved a sustainable foothold in only a few places, including Scandinavia and Japan. It has been in and out of favor in markets such as the United States and the United Kingdom since the post-war era. Yet there is reason to believe the current revival could be different. 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, Gaulthier 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, Katerra, 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

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[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] $[8] 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			

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

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

[3] Informed 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.

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

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

[6] Small unit size allows standard transportation.

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

[8] Used 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).

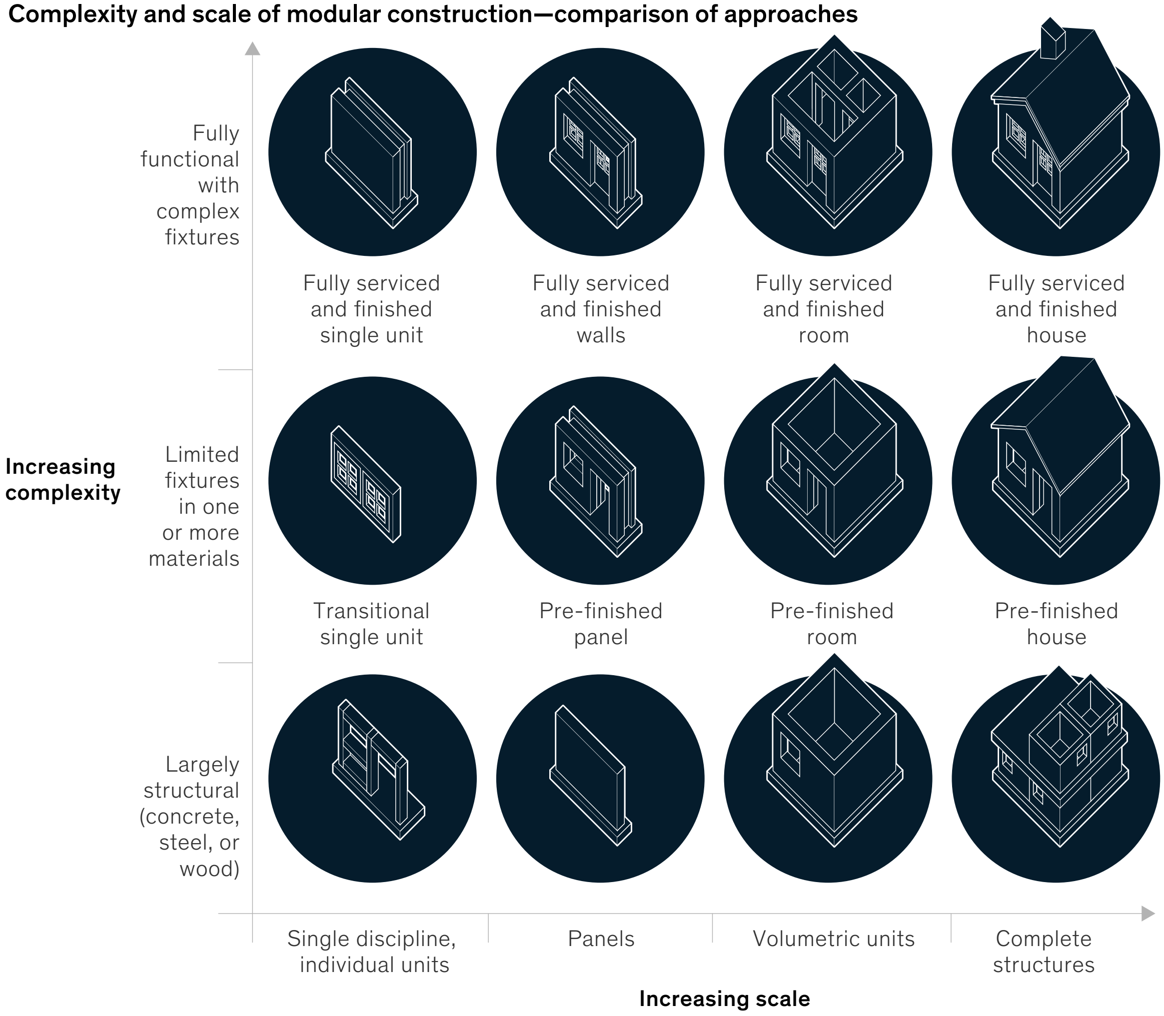
Modular construction encompasses a variety of methods

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



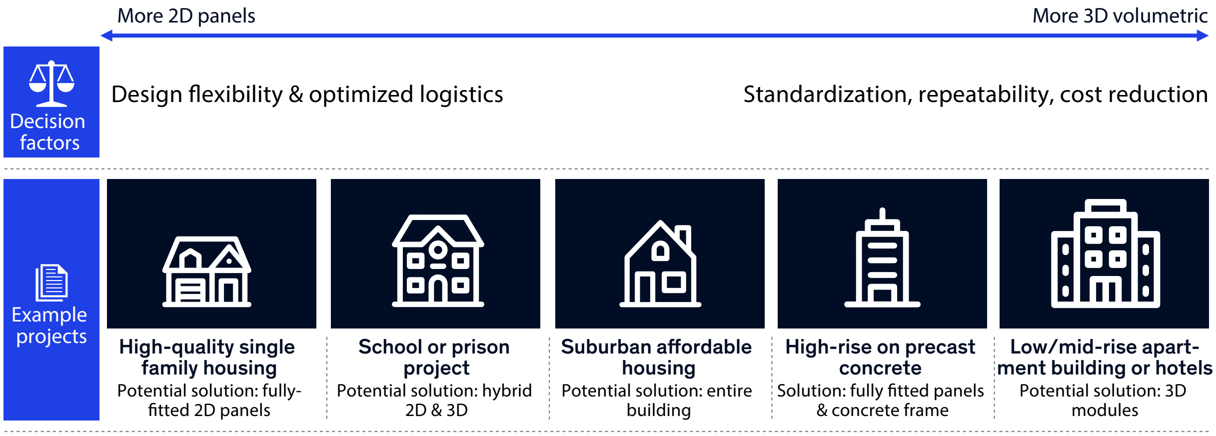
Source: Case studies; interviews; McKinsey Capital Projects & Infrastructure

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.



More 2D panels ↔ More 3D volumetric

Decision factors

Design flexibility & optimized logistics — Standardization, repeatability, cost reduction

Example projects

High-quality single family housing	**School or prison project**	**Suburban affordable housing**	**High-rise on precast concrete**	**Low/mid-rise apartment building or hotels**
Potential solution: fully-fitted 2D panels	Potential solution: hybrid 2D & 3D	Potential solution: entire building	Solution: fully fitted panels & concrete frame	Potential solution: 3D modules

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

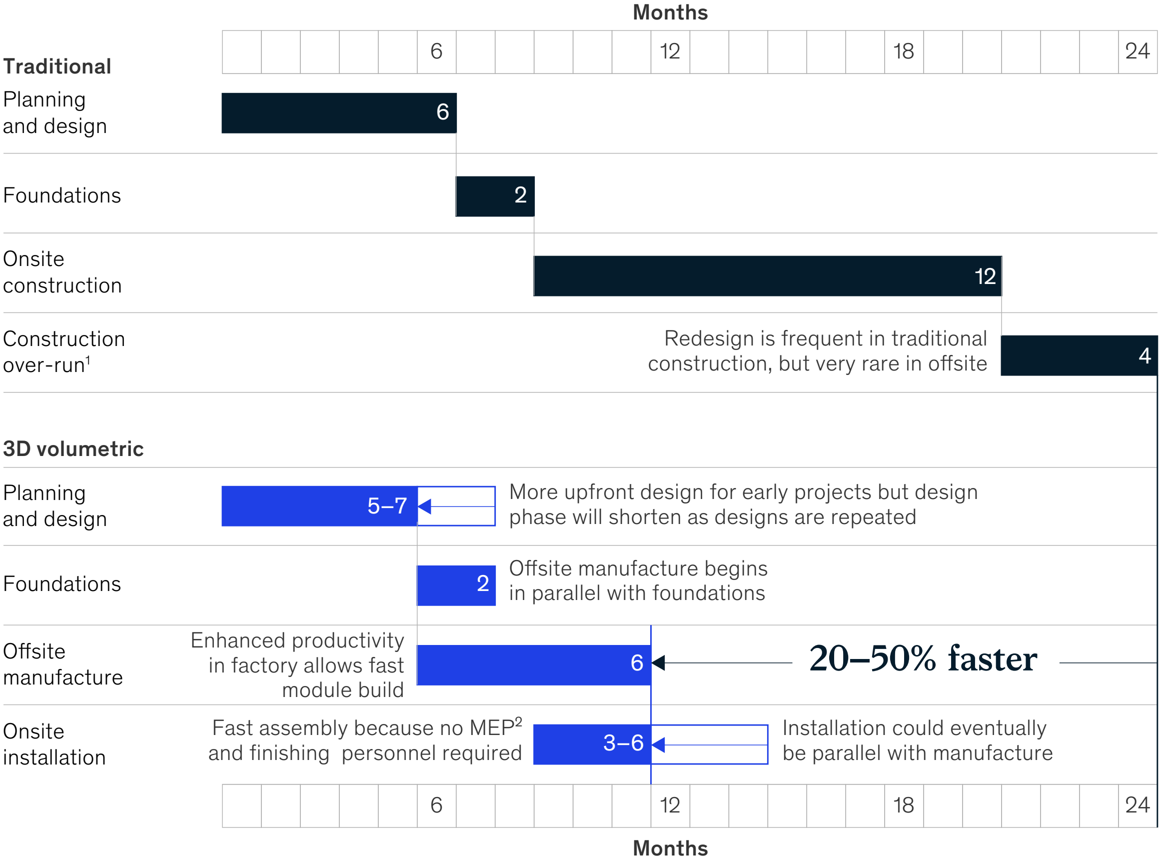
— ***Design.*** Modular projects currently tend to take longer to design than traditional projects, as designers learn to align to the manufacturing process. Design decisions need to be made upfront and changes later in the process are both more costly and more difficult. The industry is not used to 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



[1] Over-runs of 25–50% of projected construction duration are common.
[2] Mechanical, 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.

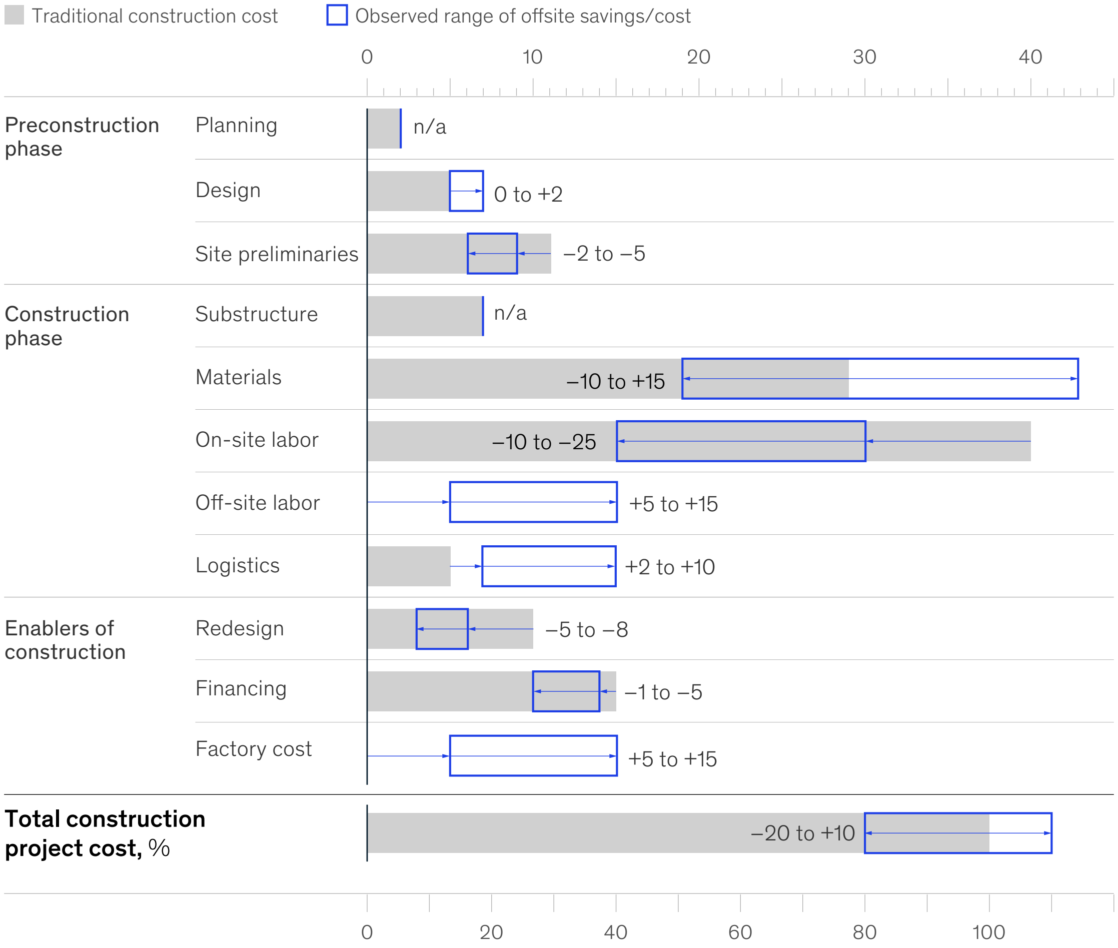
Construction costs

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



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[1] Indicative 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.

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[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 year[1] 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

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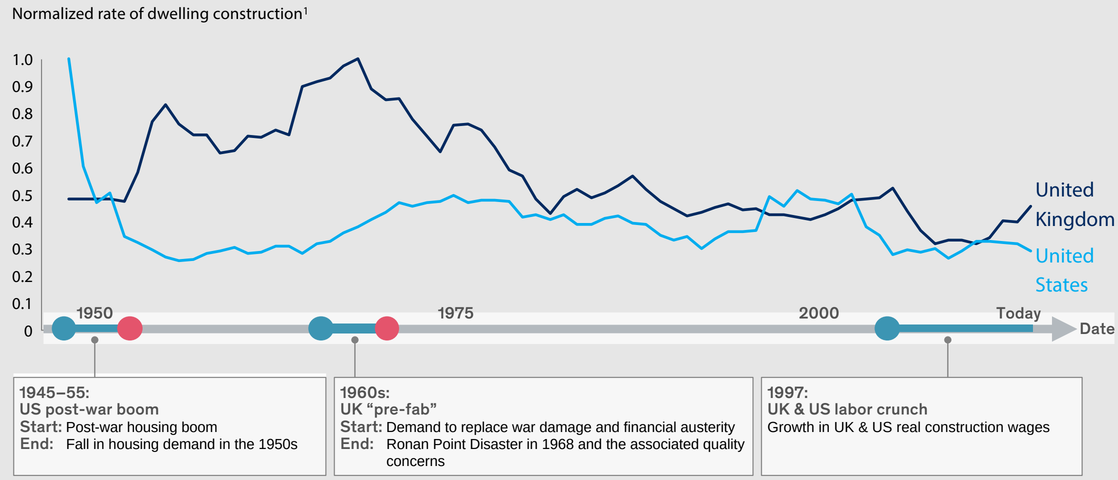
[1] Analysis based on Neil McDonald and Christine Whitehead, "New Estimates of Housing Requirements in England, 2012 to 2037," Town & Country Planning Tomorrow Series Paper 17.

[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.



1945–55:
US post-war boom
Start: Post-war housing boom
End: Fall in housing demand in the 1950s

1960s:
UK "pre-fab"
Start: Demand to replace war damage and financial austerity
End: Ronan Point Disaster in 1968 and the associated quality concerns

1997:
UK & US labor crunch
Growth in UK & US real construction wages

[1] Series 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]

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

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

changing the modular proposition. The further development of these tools, including automated design, will further enhance the modular proposition. For example, Katerra 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]

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[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.

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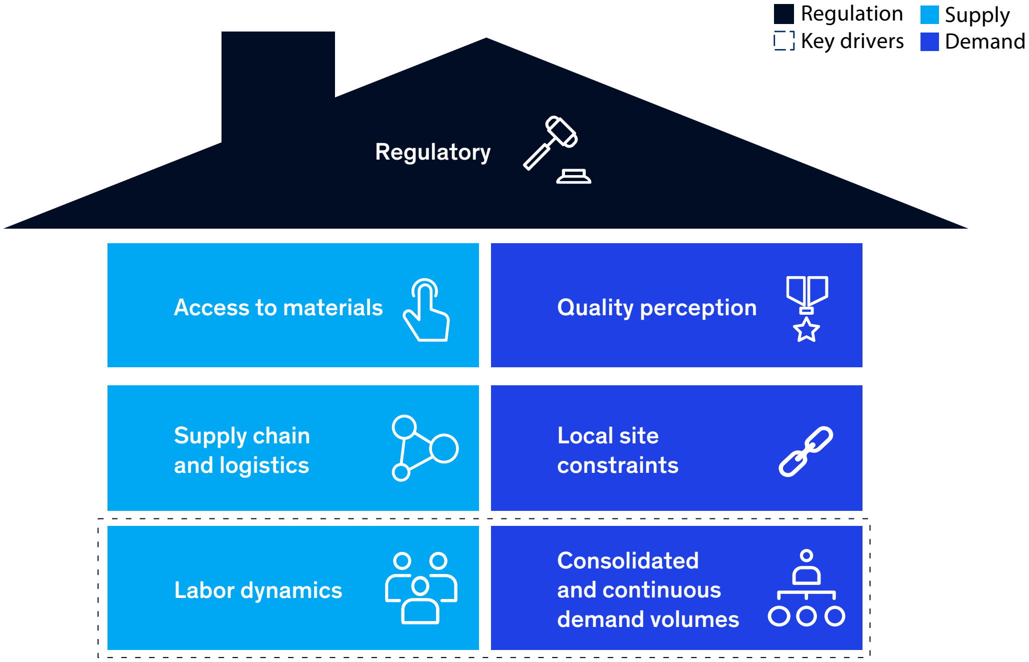
[4] *A tool kit to close California’s housing gap: 3.5 million homes by 2025,* McKinsey Global Institute, October 2016, McKinsey.com. For a discussion of this issue at a global level, see *A blueprint for addressing the global affordable housing challenge*, McKinsey Global Institute, October 2014, McKinsey.com.

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.

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

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.

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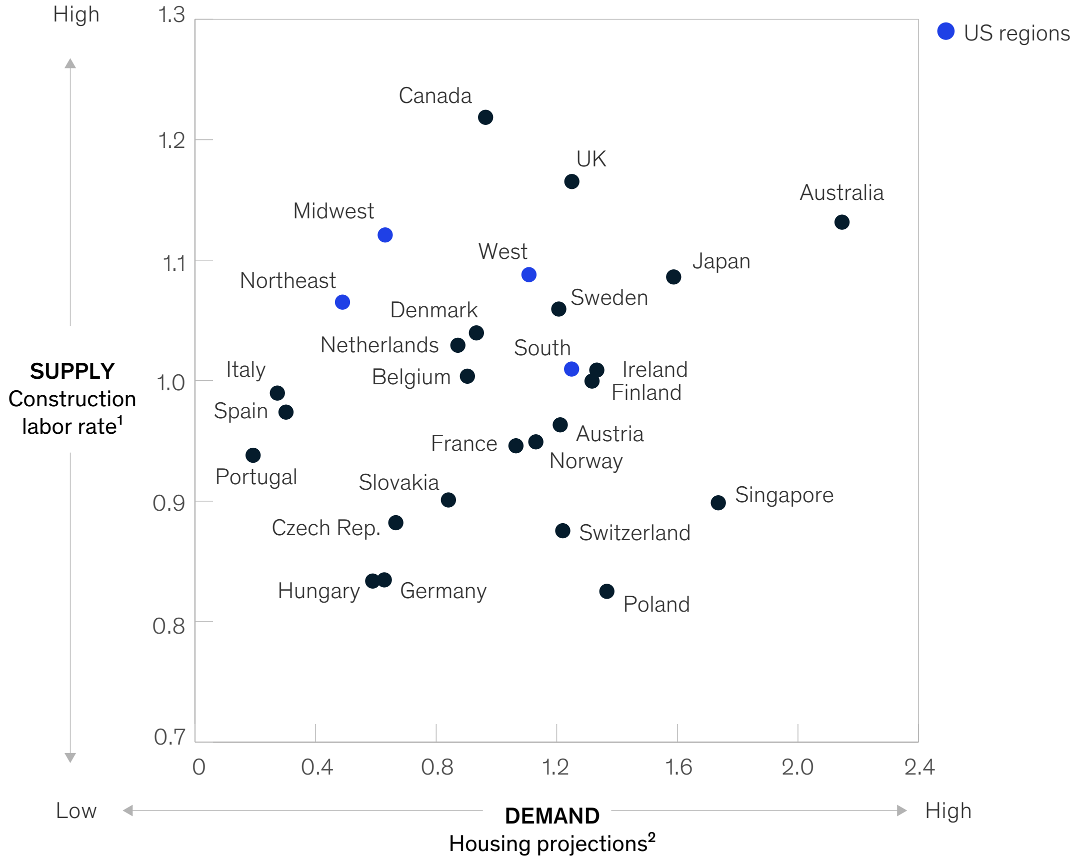
[5] Housing Industry Association, Australia.
[6] UK Ministry of Housing, Communities & Local Government.

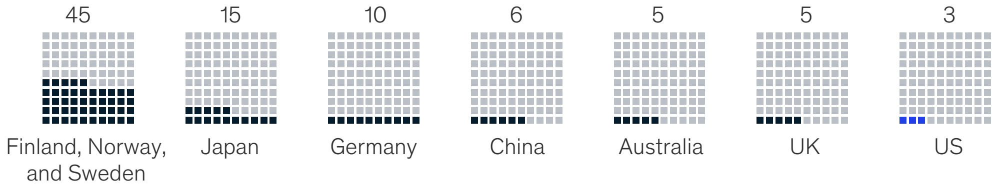
Exhibit 8

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, %



[1] Construction wage divided by national median wage.

[2] 2017–20 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

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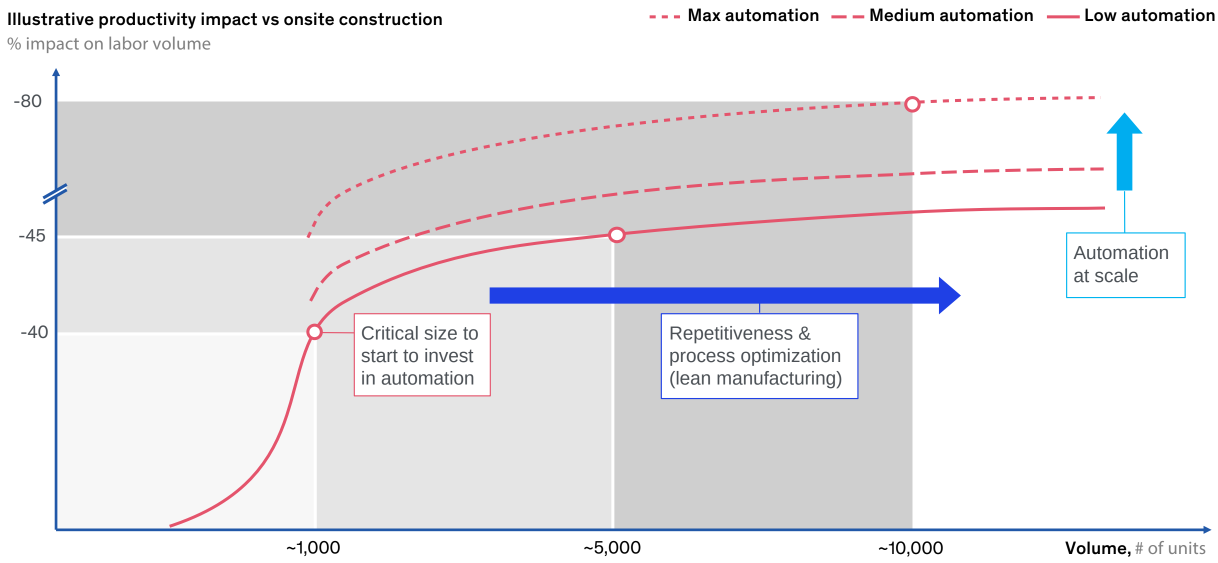
[7] German Federal Statistics Office.

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.

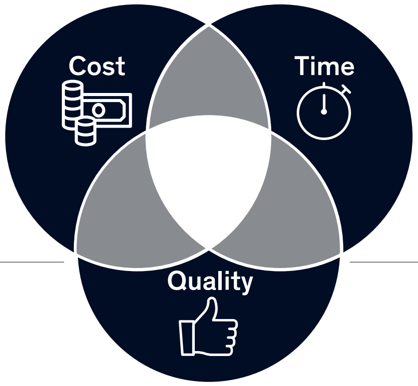
Developers: Scale up, move toward "product" offerings with a clear value proposition, and partner

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.



- Offered unit cost today
- Optimization potential with higher volumes, industry learning curve,or spec changes
- Penalties when agreed volume not reached
- Logistics cost incurred today—and after potential opening of new sites

- Time savings for construction, and end-to-end including foundations
- Ramp-up time until first supply
- Payment schedule/financing terms

- Material used vs local customer preferences
- Building dimensions and floor space vs optimized in-situ design
- Lifecycle: Durability, maintainability, energy and opex properties, and resale value

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 Katerra 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 transitionary period. Some may team up with

---

[8] Pitchbook deal analysis

Exhibit 11

All players need to prepare for shifts in value pools.

	Development	Design & engineering	General contractors	OEMs	Specialized trades	Operations & maintenance
Example profit margin, %	>10	5–10	2–4	3–15	3–5	2–3
Potential disruption	Buyers of more productized solutions OR Owner-integrators of bespoke projects	Design libraries and engineering automation Polarization of high-value vs repetitive work	Model could become obsolete if modules and better BIM models improve planning and lower risk More specialization	Opportunity for package solutions and service offerings BUT Risk of commoditization	Partial displacement via modular	More efficient lifecycle management and use of data

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.

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Exhibit B:

McGraw-Hill Construction – Prefabrication and Modularization

SmartMarket Report

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CONSTRUCTION
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Prefabrication and Modularization:

Increasing Productivity in the Construction Industry

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Design and Construction Intelligence

SmartMarket Report

McGraw-Hill Construction

President
Keith Fox

Vice President, Product Development
Kathryn E. Cassino

McGraw-Hill Construction Research & Analytics/ Industry Insights & Alliances

Vice President, Industry Insights & Alliances
Harvey M. Bernstein, F.ASCE, LEED AP

Senior Director, Research & Analytics
Burleigh Morton

Director, Partnerships & Alliances
John Gudgel

Director, Green Content & Research Communications
Michele A. Russo, LEED AP

Prefabrication and Modularization: Increasing Productivity in the Construction Industry SmartMarket Report

Executive Editor
Harvey M. Bernstein, F.ASCE, LEED AP

Editorial Directors
John Gudgel
Michele A. Russo, LEED AP

Managing Editor
Donna Laquidara-Carr, LEED AP

Director, Design & Production
William Taylor

Art Director/Production Manager
Alison Lorenz

Contributing Art Directors
Segal Savad Design
Harry Segal, Principal/Creative Director
Alex Flannery, Designer

Editor
Enver Fitch, LEED Green Associate

Contributor
Bruce Buckley

Research Project Manager
Dana Gilmore, MRA, PRC

Research Analyst
Mevhibe Barton

For further information on this SmartMarket Report or for any in the series, please contact:

McGraw-Hill Construction
Research & Analytics
Crosby Drive, Suite 201
Bedford, MA 01730

1-800-591-4462

MHC_Analytics@mcgraw-hill.com

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McGraw_Hill CONSTRUCTION

About McGraw-Hill Construction

McGraw-Hill Construction (MHC), part of The McGraw-Hill Companies, connects people, projects and products across the design and construction industry, serving owners, architects, engineers, general contractors, subcontractors, building product manufacturers, suppliers, dealers, distributors, and adjacent markets.

A reliable and trusted source for more than a century, MHC has remained North America's leading provider of construction project and product information, plans and specifications, industry news, market research, and industry trends and forecasts. In recent years, MHC has emerged as an industry leader in the critical areas of sustainability and interoperability as well.

In print, online, and through events, MHC offers a variety of tools, applications, and resources that embed in the workflow of our customers, providing them with the information and intelligence they need to be more productive, successful, and competitive.

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Introduction

Prefabrication and modularization are construction processes that the industry has used for centuries. So why in 2011 is McGraw-Hill Construction conducting forward-thinking market research on what many consider to be old, well-established methods used on construction projects?

Well, to paraphrase the song, everything old about prefab and modular is new again. This reemergence of prefab and modular as a "new" trend is tied to the rise of BIM and green building, critical new trends identified by McGraw-Hill Construction and other industry leaders.

The emergence of building information modeling (BIM) is influencing design and construction processes and how project teams collaborate. In the *Business Value of BIM SmartMarket Report* (2009), we found that a key benefit of BIM is enabling the increased use of prefabrication and modularization, which in turn improves worksite productivity and overall project ROI. Contractors were especially excited, with 77% believing that BIM would allow them to use prefabrication on larger, more complex projects in the future.

The phenomenal growth in green building has also had an undeniable impact on the construction industry. Just last year, in *Green Outlook 2011* we estimated that up to 35% of new nonresidential construction is green, representing a $54 billion market opportunity that will grow to $120 billion or more by 2015.

Last year, in the *Green BIM SmartMarket Report* (2010), we looked at the convergence of the BIM and green trends and found that construction professionals who use BIM on green projects are more likely to do model-driven prefabrication than non-green BIM practitioners. These green BIM practitioners saw model-driven prefab as a way to design and construct greener buildings and have a greener site.

Now, in this *SmartMarket Report*, we take a new look at prefabrication and modularization and their impact on a major initiative within our industry—improving productivity. Through an Internet survey of hundreds of AEC professionals, we gathered data on the impact of prefabrication and modularization on key industry productivity metrics including project schedules, costs, safety, quality, eliminating waste and creating green buildings. Some of the most significant productivity findings from prefabrication and modularization users include the following:

- **66% report that project schedules are decreased—35% by four weeks or more.**
- **65% report that project budgets are decreased—41% by 6% or more**
- **77% report that construction site waste is decreased—44% by 5% or more.**

We would like to thank our premier partners including NIST, the Modular Building Institute, Island Companies, and Syntheon; and our other corporate & association partners for supporting this study.

Harvey M. Bernstein
F.ASCE, LEED AP
Vice President
Industry Insights & Alliances
McGraw-Hill Construction

John E. Gudgel
Director,
Partnerships & Alliances
McGraw-Hill Construction

Donna Laquidara-Carr,
Ph.D., LEED AP
Manager, Green Research
and Communications
McGraw Hill Construction

Harvey M. Bernstein, F.ASCE, LEED AP, has been a leader in the engineering and construction industry for over 30 years. Currently, he has lead responsibility for MHC's market research group as well as MHC's thought leadership initiatives in areas such as green building, BIM, interoperability, innovation and global construction markets. Previously, Bernstein served as the President and CEO of the Civil Engineering Research Foundation. He currently serves as a member of the Princeton University Civil and Environmental Engineering Advisory Council and as a visiting Professor with the University of Reading's School of Construction Management and Engineering in England. Bernstein has an M.B.A. from Loyola College, an M.S. in engineering from Princeton University and a B.S. in civil engineering from the New Jersey Institute of Technology.

John E. Gudgel is responsible for managing MHC's relationships with both national and regional industry associations. He also produces and offers thought leadership on construction technology, managing MHC's *SmartMarket Reports* on BIM and Interoperability. He has over 17 years of experience in technology project management in the computer and telecommunications industries. John has an M.S. in eCommerce from George Mason University, an M.S. in Telecommunications from the University of Colorado and a B.S. in Geological Engineering from the Colorado School of Mines.

Donna Laquidara-Carr, Ph.D., LEED AP, has been Manager of Green Research and Communications at McGraw Hill Construction since December 2008. In that capacity, she provides editorial direction, analysis and content to the *SmartMarket Reports*, examining critical construction trends including BIM and green building. Previously, with MHC's Dodge division, she has nearly twenty years of experience in the construction news industry. Since 2005, as Editorial Training and Policy Manager, she educated a team of over 250 reporters on key trends in the industry, including public-private partnerships and the evolution of project delivery methods. Donna has a Ph.D. from Tulane University, an M.A. from Boston University and a B.A. from Middlebury College.

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Texas Health Harris Methodist Alliance Hospital, Fort Worth, Texas;
Fort Sam Houston Medical Education and Training Complex Barracks, San Antonio, Texas

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Executive Summary

Everything Old Has Become New Again!

Building information modeling (BIM), modern manufacturing methods, sustainability goals and recognized productivity gains rejuvenate centuries old-construction processes.

Prefabrication and modular construction are processes that have been used by generations of construction professionals. Over the past century, these processes have developed a stigma of "cheapness" and "poor quality." However, through modern technology, that image has changed. Now it's a key component of the drive to improve construction industry productivity.

Adoption and Usage

Prefabrication and modular building processes are not new activities—63% of those that are using these processes have been doing so for five years or more. Given that prefabrication/modular construction has been around for many years, it is not unexpected that 85% of industry players today are using these processes on some projects—including 90% of engineers, 84% of contractors and 76% of architects.

By 2013, nearly all players (98%) expect to be doing some prefabrication/modularization on some projects. Among users, usage today is fairly low. Only about a third of users (37%) have been using it at a high or very high level (more than 50% of projects). Over the next two years, usage on projects is expected to moderately grow, with high or very high usage reaching 45% by 2013. Among all players surveyed, the highest level of current and future usage is among fabricators, mechanical contractors and design-builders.

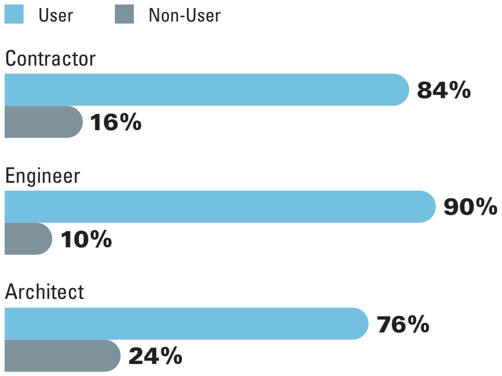
Among all players, the primary reason they are not using prefabrication and modularization on some or all of their projects is that the architect did not design it into their projects. Owner resistance was the primary reason given by architect users (39%) and non-users (54%) for not including prefabrication and modularization into their designs.

BUILDING SECTORS AND AREAS OF USAGE

Adopters are using prefabrication/modular building processes on a wide variety of commercial building projects. In particular, respondents today are using it on healthcare facilities (49%), college buildings and dormitories (42%) and manufacturing buildings (42%). These respondents see the most future opportunity in healthcare facilities (14%), hotels and motels (11%), commercial warehouses (11%) and other building types (10%) that included data centers, prisons, power plants and oil refineries. These opportunities do vary by player type.

Percentage of Prefabrication/Modularization Users Today (2011)

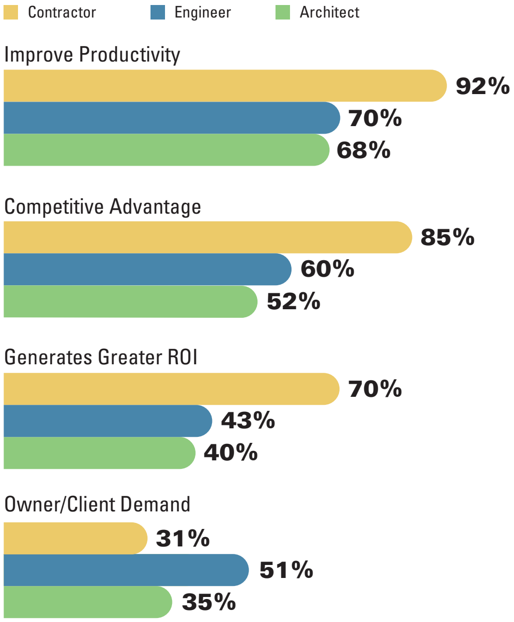
Source: McGraw-Hill Construction, 2011



Current Drivers to Use of Prefabrication/Modularization

(By Player)

Source: McGraw-Hill Construction, 2011



Within a building, prefabrication and modular construction are used in a variety of areas but most often in the building superstructure (27%), mechanical, electrical and plumbing (MEP) systems (21%) and exterior walls (20%).

When deciding whether or not to use prefabrication or modularization, the most important factor is the job site accessibility (58%) followed closely by the number of building stories (53%) and the type of building exterior (52%).

USAGE DRIVERS

The most important driver to current usage of prefabrication and modularization is its ability to improve productivity (82%). This is particularly important to contractors (92%). All players also see these processes as making them more competitive in the marketplace (75%).

Productivity Improvements—Primary Future Driver

Architects, engineers and contractors are also very closely aligned in the belief that the primary drivers to future usage will be the improvements that prefabrication and modularization can provide to elements of productivity including project schedule, cost, safety and quality.

IMPROVED PROJECT SCHEDULES

A key metric of productivity is the project schedule. 66% of user respondents indicated that prefabrication/modularization processes have a positive impact on project schedules, with 35% of those respondents indicating that it can reduce the project schedule by four weeks or more.

REDUCED COST AND BUDGETS

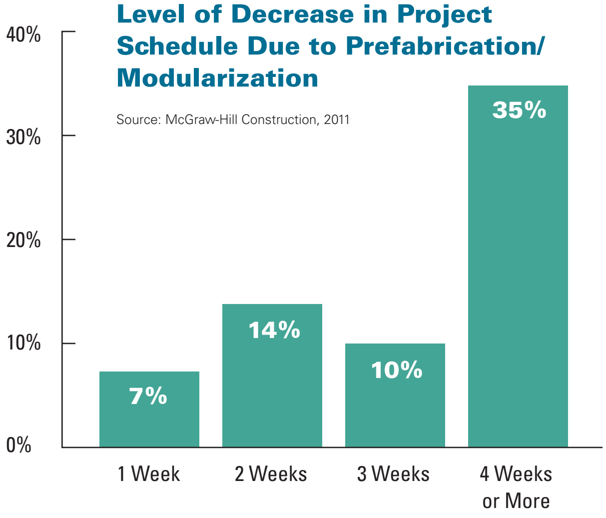
Another key productivity metric is project cost as measured by the project budget. 65% of user respondents indicated that the use of prefabrication/modularization had a positive impact on project budgets, with 41% indicating that it reduced project budgets by 6% or more.

SITE SAFETY

More respondents (34%) believe that prefabrication and modularization can improve site safety versus those who think the practices reduce safety (10%). Most users believe that these processes are safety neutral (56%).

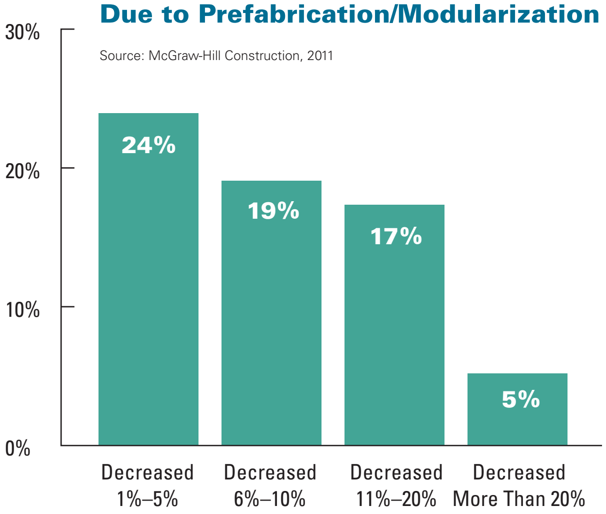
Level of Decrease in Project Schedule Due to Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011



Level of Decrease in Project Budget Due to Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011



GREEN BUILDING AND WASTE REDUCTION

Green was not a major driver to prefabrication and modularization adoption. However, when asked about elements of green, including site waste and amount of materials used, a different story emerges. 76% of respondents indicate that prefabrication/modular construction reduces site waste—with 44% indicating that it reduced site waste by 5% or more. In addition, 62% of respondents believe that these processes reduce the amount of materials used—with 27% indicating prefabrication/modularization reduced materials used by 5% or more.

Recommendations

The research findings have varying implications for different industry players.

Owners:

Consider using prefabrication and modularization processes on your projects. This is not your grandpa's prefab! With the precision bestowed by BIM and the quality provided by modern materials and manufacturing facilities, prefabrication and modular construction offer the opportunity to obtain significant productivity gains on your projects. Owner demand is the primary driver for architects to include prefabrication / modular construction into their project design.

Architects:

Understand and educate clients on the benefits of prefabrication and modularization. As the initial interface with the client, the architect has the greatest influence during the design phase in determining if prefabrication and modular construction will be used in a project.

Understand the key benefits that prefabrication/modularization offer, such as improved project productivity, producing more sustainable buildings and ultimately increasing ROI for the client and other members of the project team. Architects should educate clients that using prefabrication/modularization can measurably:

- Reduce project schedules—sometimes by a month or more.
- Decrease purchase and installation costs of materials—ultimately decreasing the project budget.
- Increase construction site safety—resulting in fewer accidents and lower insurance costs.
- Eliminate significant amounts of construction site waste, making the project greener.
- Allow the specification and installation of better quality and more sustainable building materials.

Specify prefabrication and modularization in your design. Once you get the client's buy-in, make sure you include prefabrication/modularization into your design. The early decision to bring it into the project allows for greater continuity of design maximizing potential productivity gains. The number one reason engineers and contractors give for not using prefabrication or modularization is that the architect did not include it in the project design.

Engineers:

As the professionals primarily responsible for the structural integrity and systems efficiency of buildings during their design and construction, **engineers should evaluate the quality and availability of prefabricated/modular products and be the catalyst for their use.**

Many engineering firms today are already using prefabricated /modular elements for the building superstructure, exterior walls, roof and floor, and they view their use as a way to differentiate themselves from their competition.

General Contractors and Construction Managers:

Build prefabrication/modular efficiencies into your pre-construction planning and bids. Prefabrication provides predictable results for your schedule and costs. The research shows that it can decrease the purchase and installation costs of materials and compress project schedules. These factors can ultimately decrease the project budget and allow GC and CM firms to be more competitive.

Include the green factor. It is clear that prefabrication and modular construction can help reduce waste and result in a greener construction site. Given that green has become a major factor in the construction marketplace, the fact that prefabrication/modularization can help achieve green objectives should be promoted and emphasized in bids.

Specialty Contractors:

Adopt for competitive reasons. For some construction specialty trades, such as mechanical and electrical contracting, prefabrication/modularization has become an integral part of their business. With the inherent efficiencies and productivity gains and current projections showing increased usage on projects, specialty contractors need to acquire experience with prefabricated/modular processes in order to remain competitive.

Manufacturers:

Promote the green benefits of your products. Although most architects, engineers and contractors do not view prefabricated and modular products as a primary way to achieve their green building objectives, all professionals agree that these processes reduce waste and the amount of materials used on projects. Manufacturers need to raise awareness of these green benefits.

Create BIM objects of prefabricated and modular products. BIM use continues to rise, and BIM is a driver to increased use of prefabrication/ modularization. ■

Data: Introduction

Construction Trends

Driving Prefabrication/Modularization

Prefabrication and modularization are certainly not new to the construction industry. However, current influential construction trends, such as the increasing interest in lean construction, the rising use of BIM technologies and the growing influence of green construction have caused many practitioners to reconsider their appeal. In fact, the National Research Council's 2009 report on improving productivity in the construction industry recommends prefabrication/modularization as an "opportunity for breakthrough achievement."[1] These factors, combined with recent advances in prefabrication/modularization, make this a critical trend in the construction industry.

Lean Construction

The strong increases in productivity offered by using prefabrication and modularization fit squarely into the lean building model. The difficult economic conditions in the construction industry have increased the appeal of lean methods and practices. For more information on the use of prefabrication and modularization to achieve a lean approach, see pages 24 and 25.

BIM

The increasing use of BIM also contributes to the potential for increased use of prefabrication and modularization. In a recent study about the use of BIM on green projects, McGraw-Hill Construction (MHC) found that the use of BIM model-driven prefabrication on more than one quarter of their projects is expected to increase from 37% to 73% among practitioners who use BIM for green work. Even those who are currently not using green BIM expect an increase from 22% to 57%.[1] BIM helps enable prefabrication of tightly integrated MEP systems, allowing designers to maximize space for other uses in high-tech buildings like hospitals.

Green Building

Green building has grown into a substantial part of the overall construction market. MHC's *Green Outlook 2011* estimates that nonresidential green building will comprise 28%–35% of the total market by the end of 2010. This dramatic increase in market share, from less than 5% in 2005, reflects the fact that green building sustained steady growth throughout the recession, even as the overall construction market shrunk by nearly one-third.[2]

MHC also predicts that the growth of the market share for green will not abate as the construction industry recovers from the recession. By 2015, MHC projects that 40%–48% of nonresidential construction will be green.

As the results of this study demonstrate, this has strong implications for rising interest in prefabrication and modularization, which helps eliminate waste onsite and conserve resources.

Bringing the Trends Together

What is most striking about prefabrication/modularization is its ability to enable all these trends, in addition to being more prominent because of them. It brings all of them together to improve productivity in construction.

Note About the Data

The data in this report are based on an online survey of 809 contractors, architects and engineers. The contractors comprise 65% of the total respondents, while architects total 12% and engineers 23%. The large number of respondent firms in all three player categories provides a statistically meaningful sample for the study conclusions.

For full methodology, see page 52.

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1 National Research Council of the National Academies. *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry.* Washington DC: The National Academies Press, 2009. 2 *Green BIM SmartMarket Report: How Building Information Modelling is Contributing to Green Design and Construction.* McGraw-Hill Construction. July, 2010. 2 *Green Outlook: Green Trends Driving Growth,* 2011. McGraw-Hill Construction, October, 2010.

Data: Market Activity and Opportunity

Sectors with Opportunity for

Prefabrication/Modularization

Currently, prefabrication /modularization is being used on many types of building projects demonstrating its applicability across nonresidential construction.

The five sectors using prefabrication/modularization in over 40% of projects are:

- **Healthcare (49%)**
- **Higher Education (42%)**
- **Manufacturing (42%)**
- **Low-Rise Office (40%)**
- **Public (40%)**

These sectors also present strong opportunities in the construction market, which bodes well for a vigorous prefabrication/modularization future market.

Healthcare

Healthcare is a sector that is well-suited for prefabrication/modularization techniques. The interior layout of hospital rooms allows for efficient use of modularization, and it is a sector highly responsive to strategies that shorten schedule—a particular benefit prefabrication brings to a project (See page 18).

According to McGraw-Hill Construction's economic forecast, the market activity for healthcare construction is expected to increase in 2011 and 2012 to become more than a $28 billion market opportunity in 2012.

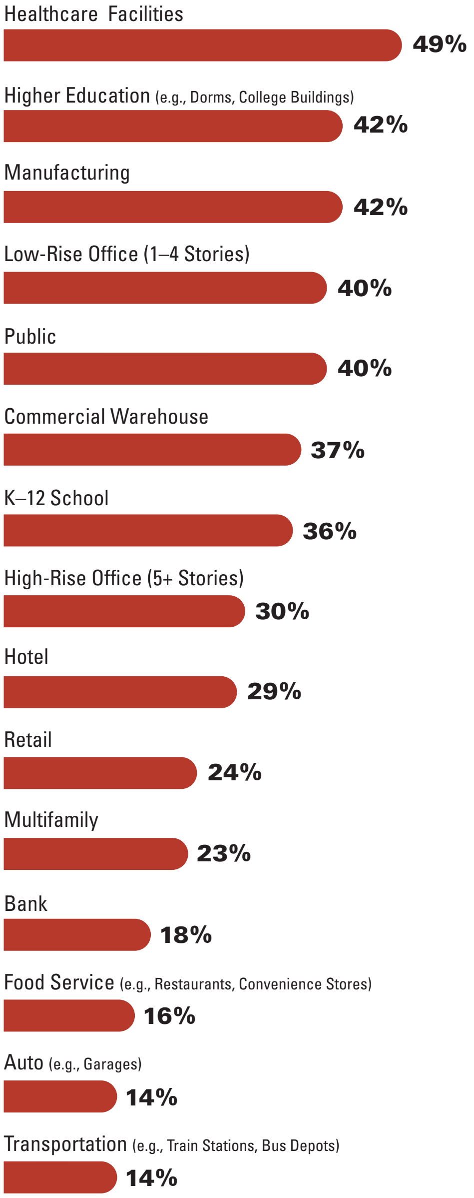
Dormitory and Education Projects

Like healthcare buildings, dormitories and school projects have features that are well-suited to prefabrication/modularization. Dorms and classrooms allow for use of modular room design, and these projects also benefit from faster construction schedules.

As the largest construction sector by value (over $43 billion in 2011), education presents a significant opportunity for prefabrication/modularization—both currently and in the future (see page 10).

Building Sectors Using Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011



Variation by Player

- **Contractors: Across the board, contractors report heavier current involvement in prefabrication/modularization, predominantly in healthcare (61%), dormitory/education (50%) and public buildings (46%).**
- **Engineers: Engineers are using prefabrication/modularization most often in manufacturing buildings (46%), followed by commercial warehouses (43%). Engagement in the other sectors is 30% or lower.**
- **Architects: Their heaviest use is in low-rise offices (43%) and healthcare facilities (36%), with less than a third reporting use in other sectors.**

Brief History of Prefabrication/Modularization

An early example of prefabrication/modularization use can be found in Britain's Great Exhibition of 1851, featuring a building called the Crystal Palace. Designed in less than two weeks, the building used light and cheap materials: iron, wood and glass. The construction period lasted only a few months and consisted of assembling the prefabricated components. After the exhibition, the palace was taken apart, piece by piece, and moved to another location.[1]

Modern Beginnings

For the U.S., modern prefabrication/modularization is said to have started in the early 1900s. Housing started being developed using prescheduled procedures based on modern mass production. Aladdin and Sears Roebuck Company sold prefabricated houses that were delivered to customers as mail-order homes.[2]

Prefabrication/modularization was increasingly used during World War II due to the need for mass accommodation for military personnel. The United States used Quonset huts as military buildings. These all-purpose, lightweight buildings could be shipped anywhere and assembled without skilled labor.[3]

Following World War II, both Japan and Europe had massive rebuilding needs and turned to prefabrication and off-site construction to fill the demand. It is because of this early adoption and acceptance that European and Japanese companies are still considered some of the most advanced in terms of modular construction techniques.

In the U.S., commercial applications of modular construction like hotels, offices, hospitals and schools began to emerge throughout the '70s, '80s, '90s, and into the 2000s as demand exceeded the supply of existing structures.

Recent Evolution

Recent innovations over the past few decades have allowed the prefabrication and modular construction industry to make significant advances in developing processes and materials to build and deliver more sophisticated and complex facility types.

An example of this is the Hilton Palacio del Rio Hotel in San Antonio. Built by Zachry Construction Corporation for the Texas World's Exposition of 1968, the 500-room deluxe hotel was designed, completed and occupied in an unprecedented period of 202 working days. All the rooms were placed by crane in 46 days. Still in use, the hotel is believed to be the tallest modularly constructed facility in the United States. The project is a testament to the durability of modular construction.[4]

A current example of just how well accepted modular units have become is their use in the construction of the new cruise liner Queen Mary 2, which is one of the largest and most expensive cruise liners in the world. The ship owners chose to use modular passenger cabins to ensure all cabins were built to the higher standards that are available in a factory environment; even their VIP suites utilized the modular building process.[5]

Prefabrication/modularization is also becoming more widely recognized as a resource-efficient and greener construction process. A clear example of this is the use of modularization at the Fort Sam Military Barracks being built in San Antonio, Texas. The buildings are on track to meet LEED Silver certification due to reduced material waste and pollution and increased use of recycled materials (see page 16 for more information on this project).

The Time Is Right Now

Prefabrication/modularization has not had a steady increase in use over time; instead, it has fluctuated based on the level of drastic need during war and economic booms. However, technological advancements over the past 20 years have increased what prefabrication/modularization can achieve in the construction industry. BIM, quality modern materials and sophisticated manufacturing facilities now offer significant productivity gains on projects not possible before.

Recently a committee of experts appointed by the National Research Council identified "greater use of prefabrication/modularization" as a key breakthrough opportunity that could significantly improve the efficiency and competitiveness of the U.S. construction industry going forward. [6]

With a construction market facing acute shortages in onsite skilled labor and also where players are trying to be leaner, many believe the time is right now, more than ever, for widespread adoption of off-site prefabrication/modularization solutions on a major scale in the construction industry. ■

1 Kelly, Burnham. *The Prefabrication of Houses*. The Technology Press of The Massachusetts Institute of Technology; John Wiley and Sons, Inc., New York; Chapman & Hall, Ltd., London. 1951.
2 The Encyclopedia of Chicago. *Housing*, Mail Order. Web. April 8, 2011. 3 The Steel Master Building Systems. Quonset FAQ's. Web. April 8, 2011.
4 Modular Building Institute."21-Story Modular Hotel Raised the Roof for Texas World Fair in 1968" Web. April 20, 2011. 5 Avalon Building Systems. "Interesting History of the Modular Construction Industry". Web. April 20, 2011.
6 National Research Council of the National Academies. "Advancing the Competitiveness and Efficiency of the U.S. Construction Industry". The National Academies Press. Washington DC. 2009.

Building Sectors with the Most Significant

Future Opportunity for Prefabrication/Modularization

Not only is the industry using prefabrication/modularization on a range of projects (see page 8), it also views future opportunity coming from a wide variety of building sectors.

In fact, there is no consensus as to which sector offers the most significant future opportunity. Only healthcare was slightly higher than the other sectors, but that is likely due to the heavy focus on this sector by contractors, who comprise the largest share of respondents (see pages 8 and 11).

This distribution suggests that any building type can benefit from prefabrication/modularization activities.

Comparison of Current versus Future Prefabrication/Modularization Activity

It is notable that some sectors with lower levels of current involvement (see page 8) are seen as offering the greatest opportunity in the future.

This suggests that the industry, which has been using prefabrication for years, is seeing a change in future use, reinforcing the notion that prefabrication/modularization is on the cusp on more significant adoption across the industry.

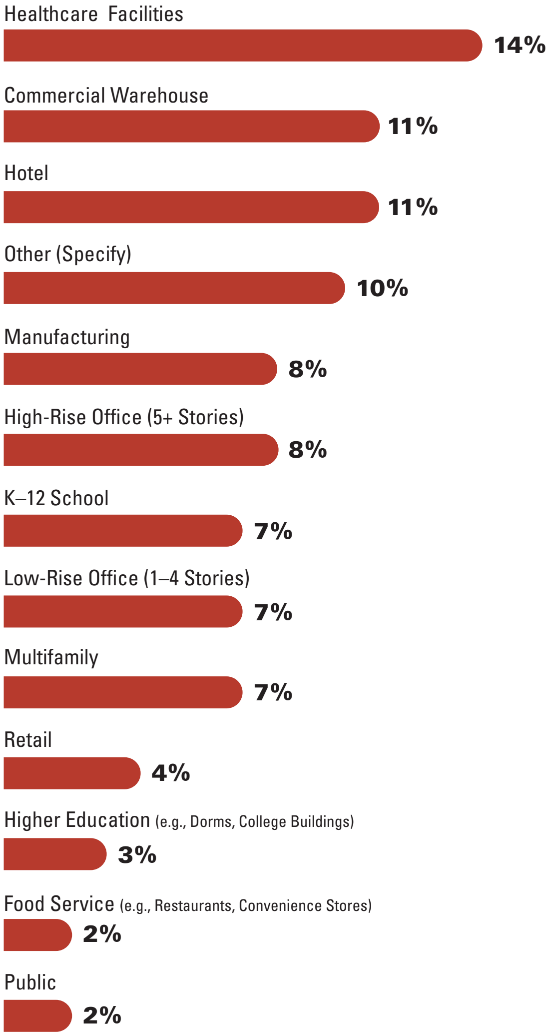
HEALTHCARE

Healthcare is the sector currently showing the highest use of prefabrication/modularization (see page 8), and it is noted as the most important sector for future growth—especially for contractors (see page 11).

McGraw-Hill Construction's (MHC) economic forecast reports that healthcare construction will steadily increase over the next five years. As the third largest nonresidential construction sector (behind education and office), healthcare projects pose an important area for prefabrication/modularization if owners can recognize its benefits.

Ranked Building Sectors for Prefabrication/Modularization Opportunity

Source: McGraw-Hill Construction, 2011



COMMERCIAL WAREHOUSES AND HOTELS

Though these sectors are not commonly using prefabrication/modularization now, they are considered strong opportunities for the future, cited as the next highest sectors for opportunity behind healthcare, despite being ranked #6 and #9 in current use. In fact, fewer than one third of prefabrication/modularization users are currently using these techniques on hotels.

Though these sectors represent lower levels of construction activity, MHC economists forecast significant growth over the next five years, making them an untapped opportunity for prefabrication/modularization.

EDUCATION

Though ranked lower than other sectors, it is important for the industry to continue to seek opportunities in the education sector because it has the highest share of nonresidential construction activity. Furthermore, after several years of decline, MHC's economic forecast

Market Activity and Opportunity

Building Sectors with the Most Significant Future Opportunity for Prefabrication/Modularization

CONTINUED

reports that school construction will begin to pick up in 2012, with dramatic increases in the longer term—projected to be a market worth over $70 billion in five years.

Variation by Player

There is notable variation in how different players view the sectors with the most significant future opportunities for prefabrication/modularization.

Overall, the players agree that hotels are a major untapped market for prefabrication/modularization activity, but more architects and contractors emphasize its importance.

CONTRACTORS

Nearly a fifth (19%) of contractors believe healthcare offers the most significant future opportunity for prefabrication/modularization, notably higher than the next most important sectors—hotels (13%) and high-rise offices (10%).

This marks a shift from current use, where dorms and public buildings take the second and third spots, respectively.

ENGINEERS

Engineers view the most significant sectors for prefabrication/modularization opportunity to be warehouse and manufacturing projects.

In terms of construction activity, both the warehouse and manufacturing sectors are on the rise, but they are smaller by value as compared to other building types. In five years, they are forecasted to offer a combined $30 billion opportunity. Perhaps they offer a niche market for engineers that is currently untapped.

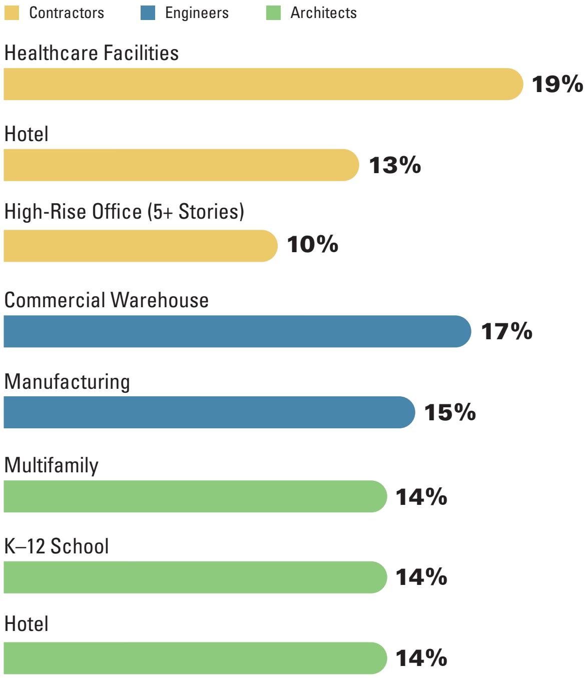
ARCHITECTS

There is an even split among the sectors that architects cite as having the largest levels of future activity: multifamily residential, K–12 schools and hotels. Multifamily residential is an especially important opportunity for prefabrication/modularization given that the combined value of starts is forecasted by MHC to be $60 billion over the next two years.

As the largest nonresidential building type, education projects pose very significant opportunities for prefabrication/modularization, with a strong long-term forecast (see page 10).

Top Building Sectors for Prefabrication/ Modularization Opportunity (by Player)

Source: McGraw-Hill Construction, 2011



Users of Prefabrication/Modularization

Overall Users of Prefabrication/ Modularization

Today, there is broad use of prefabrication/modularization on building projects—85% of respondents are using these strategies to design and construct projects at some level.

While this level of use is encouragingly high, the activities that are included under the broad definition of prefabrication/modularization can range widely from entire modular rooms to floor planks to racks of mechanical ductwork. The impact on reducing site materials, labor demands, project budget and schedule and waste can vary significantly depending on how prefabrication/modularization is used on a project. (For more information on the definitions of prefabrication and modularization, please see page 51.)

VARIATION BY PLAYER

There is heavier involvement in prefabrication from engineers and architects, as compared to architects— 90% of engineers and 84% of contractors report using prefabrication at some level, while 76% of architects report usage.

Length of Prefabrication/ Modularization Use

Prefabrication and modular building processes are not new activities.

- **Almost two-thirds (63%) of respondents are long-time users of prefabrication/modularization strategies, using them for more than five years.**
- **Only 8% are new users—using prefabrication/modularization for less than a year.**

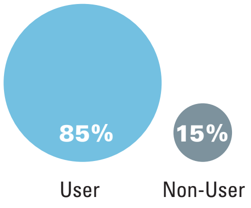
VARIATION BY PLAYER

Engineers have been using prefabrication/modularization for the longest, with over three-quarters (77%) reporting use for more than five years, significantly higher than architects (64%) and contractors (57%).

Contractors lag the other two players in length of use even though they are heavier users than architects (see above). However, the lag could be due to more limited architect involvement, given that contractors are driven to use prefabrication/modularization if it is designed into the project (see page 32).

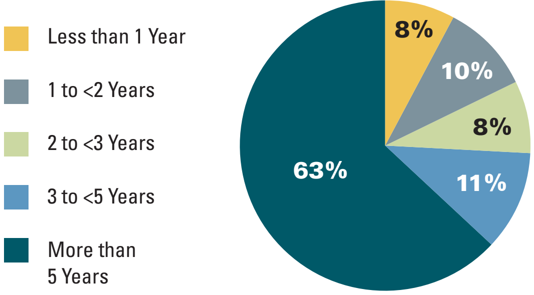
Percentage of Prefabrication/ Modularization Users Today (2011)

Source: McGraw-Hill Construction, 2011



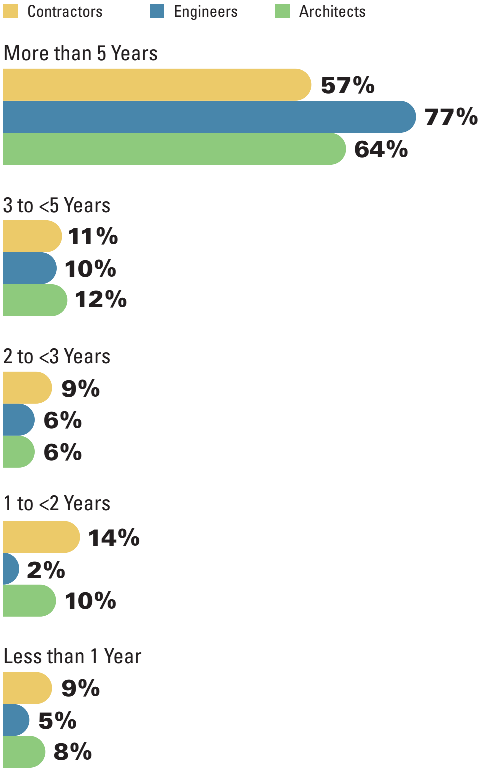
Length of Time Using Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011



(by Player)

Source: McGraw-Hill Construction, 2011



Levels of Use of Prefabrication/Modularization:

Today and in the Future for Current Users

While reported levels of prefabrication are already quite high (see page 12), a notable increase is still expected over the next two years—both in the percentage using prefabrication and in the intensity of use.

Future Use of Prefabrication/ Modularization

By 2013, 98% of industry players (current users and non-users) will be users of prefabrication/modularization.

- **Current Users: Virtually all current users will still be using prefabrication/modularization in 2013.**
- **Current Non-Users: 87% of current non-users will become users over the next two years, resulting in a decrease in the overall number of non-users from 15% of the industry in 2009 to an insignificant 2% in 2013.**

Various factors are impacting this increased use, including growing concerns about construction productivity, advancements in prefabrication and the quality of prefabricated materials, and the wider adoption of BIM, which helps enable more intensive, productive use of prefabrication.

VARIATION BY PLAYER

Contractors, engineers and architects all report that their level of use of prefabrication/modularization will increase by 2013.

Architects report the highest increase in prefabrication/modularization use—from 76% in 2009 to 98% by 2013. However, because their levels were originally lower, this more dramatic increase is to be expected.

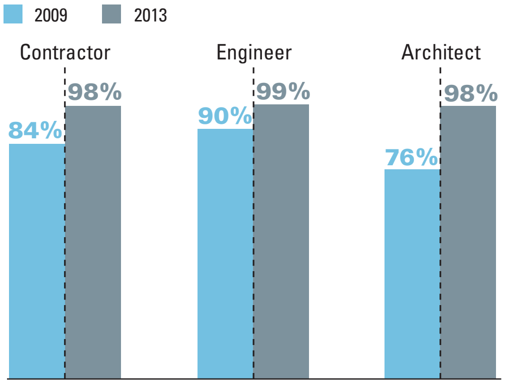
Level of Use

The level of use of prefabrication/modularization is also expected to increase. The number of players using prefabrication/modularization on over 50% of projects is expected to increase from 37% in 2009 to 45% in 2013.

Despite the level of activity increasing, these results do not indicate the complexity of the prefabricated or modular components used on these projects. And it is important to note that adoption needs to involve more than installation of simple prefabricated elements for the full benefits of prefabrication/modularization to be realized. For example, significant benefits are gained when prefabrication/modularization is used on major building components, resulting in a reduced need for scaffolding, coordination of multiple trades onsite and equipment use.

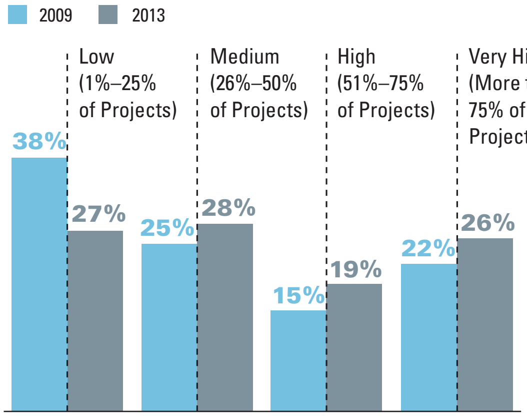
Percentage of Respondents Using Prefabrication/Modularization on Projects 2009 to 2013 (by Player)

Source: McGraw-Hill Construction, 2011



Percentage of Prefabrication Use for Current Users (2009 versus 2013)

Source: McGraw-Hill Construction, 2011



Future Activity by Current Non-Users

of Prefabrication/Modularization

While most firms not using prefabrication or modularization expect to do so in the future, most expect to use these approaches on a low percentage of projects.

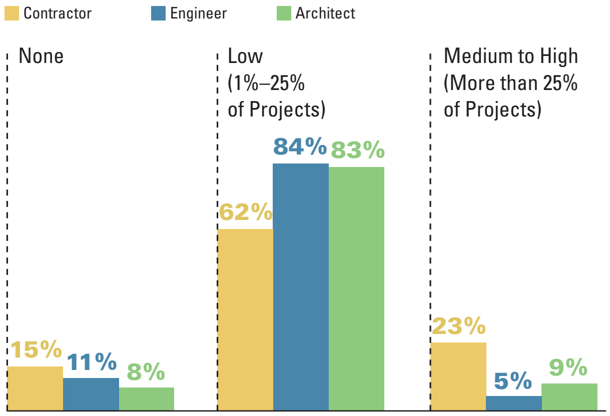
- **An average of 70% of current non-users report they will engage in prefabrication/modularization on 1%–25% of future projects.**
- **Contractor non-users expect to engage in prefabrication/modularization at much higher levels than their industry counterparts—23% report they will use it on over 25% of projects by 2013, compared to much lower percentages of engineer (5%) and architect (9%) non-users.**

This suggests that there is still significant market penetration that can be created with more education and awareness on the productivity, financial and green benefits associated with prefabrication/modularization.

Percentage of Future Prefabrication Use for Current Non-Users

(by Industry Player)

Source: McGraw-Hill Construction, 2011



Firm Size of Prefabrication/Modularization Users

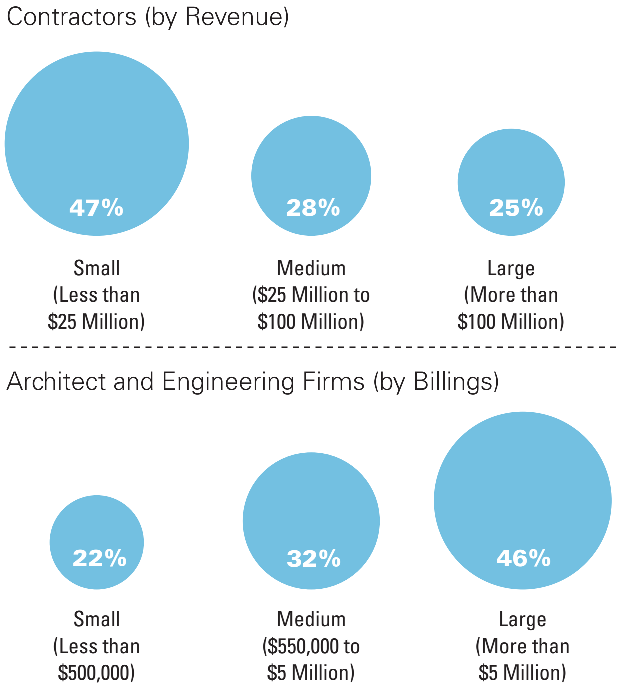
The size of firms using prefabrication/modularization vary dramatically by industry player, with architect and engineer users coming predominantly from larger firms (billings over $5 million) and the reverse true of contractors where significantly more users are from smaller firms (revenues less than $25 million).

This is consistent with the roles and functions of each player. Many contractors engaging in prefabrication/modularization are specialty contractors, such as mechanical contractors, electrical contractors and fabricators, that tend to be smaller in size.

Architectural firms engaging in prefabrication/modularization are likely those engaged in more expensive, complex projects where designing for prefabrication/modularization can yield greater savings.

Share of Prefabrication/Modularization Users by Firm Size

Source: McGraw-Hill Construction, 2011



Interview: Thought Leader

Improving productivity to enhance our quality of life and our ability to compete globally.

J. Doug Pruitt, Chairman and CEO
Sundt Construction

Doug Pruitt emphasized the need to improve productivity in the construction industry as a central theme of his term as president of the Associated General Contractors of America in 2009. Today, Pruitt continues to pursue industrywide initiatives to address productivity issues through task forces and research groups.

Why did you create a call to action around productivity?
The construction industry plays an important role in our economy and our society. Do we really want to be an industry that—because of our inability to improve productivity—is doing damage? In the private sector, if we aren't productive that drives [private-sector clients'] capital costs higher. By not improving, we're not helping private-sector companies compete in a global economy. In the public sector, a lack of productivity means we pay more and more for fewer and fewer assets. We're not helping taxpayers get more for their tax dollars. This is about our quality of life and our ability to compete in a global economy. We want to be the industry that helps drive that, not hinder it.

How bad is the problem?
If you look at construction industry statistics over a 40-year span, we've had no productivity improvement as an industry. If you look at other industries, they've had significant productivity improvements. Every industry should strive as a collective body to improve itself. Are we being responsible as an industry if we can't improve productivity?

Is the industry making significant improvements?
A small percentage of our industry is making a dent. But what percentage of our industry uses integrated project delivery? What percentage uses design-build? What percentage uses lean practices? What percentage leverages BIM to improve productivity? I would suggest it's a small percentage. The ones that do are making gains, but it needs to spread to the masses.

What are some key issues that hinder productivity today?
When you look at improvements being made today, innovation is being driven primarily through technology companies, not through construction companies. Look at contracts and contract language; that's a productivity issue. If you look at the lack of collaboration between designers, engineers and contractors, that's a productivity issue. Delivery methods are a productivity issue. Regulatory issues that create tremendous costs and do very little in terms of value added also drive productivity down. You spend extra dollars and the endgame doesn't change productivity. There are a whole host of things that need to be addressed by construction companies. One reason is that we're too fragmented. We need a forum where we can discuss these issues and create solutions.

If companies are unwilling to change themselves, can owners drive change that will improve productivity?
Just like they did with safety, owners can insist on change. There are things owners can do now to influence change. Owners can select the delivery method. They can make contracts fair or onerous. They can define how we work together as a team. There can also be incentives versus penalties. A lot of owners approach productivity with penalties. They want a job done fast, and if you don't get it done on schedule, you pay damages. So as a contractor, you spend all of your time trying to protect yourself, and there's a cost associated with that. That's going at the problem the wrong way. We want to do [projects] better and faster, so there should be incentives to do so.

Can prefabrication and modularization play important roles in improving productivity?
Ultimately, their use can be widespread. There's a lot of prefabrication that can be done and is being done already. [Sundt Construction] has done some modular work for the Navy. There's a lot of potential out there to use it, especially with standardization [of military projects]. The technology to design and build it is there and getting better. You just have to avail yourself of it. ■

Speeding Delivery to Meet a Military Mission

Fort Sam Houston Medical Education and Training Complex Barracks

SAN ANTONIO, TEXAS

In an attempt to meet the massive workload of such programs as the Base Realignment and Closure Act of 2005, the Army Corps of Engineers and others have adopted transformative approaches to improve the delivery of buildings, including modularization. At the Fort Sam Houston Medical Education and Training Complex Barracks project, crews are installing more than 1 million square feet of permanent modular construction.

Decision to Use Modular

The basic project scope called for facilities to house a total of 6,000 soldiers, as well as a mix of administrative offices and classrooms. In order to meet the tight schedule of 42 months and budget constraints, general contractor Hensel Phelps of Greely, Colorado, and subcontractor the Warrior Group of DeSoto, Texas, devised a plan that heavily leverages permanent modular construction.

The team worked with designer Carter Burgess (now part of Pasadena, California-based Jacobs) to assist in reimagining the design. The new plan calls for five four-story buildings, roughly 320,000 square feet each, to be built using a hybrid of site-built construction and permanent modular components. All of the barracks use modular construction, representing nearly 220,000 square feet of space per building.

Mix of Modular and Site-Built Construction

Each building has a void form foundation sitting on piers that are driven between 65 feet and 70 feet deep. At the center of each facility's footprint, site-built steel structures are used for a mix of classrooms, storage rooms, offices, elevators and mechanical rooms. Once that portion is completed, the modules are added, extending out as wings in the building. These wings turn in a series of 90-degree angles to form two courtyards. At each of the corners created by those 90-degree angles, site-built construction is again used to create classrooms, utility rooms and stairwells.

Standard barrack modules include two living quarters per module, separated by a central corridor. Each weighs 35,000 pounds and is 60 feet long by 13.6 feet wide. Some modules are installed with one living quarter.

The modules are "more than 85% complete when they arrive onsite," says Ed Zdon, senior project manager with the Warrior Group. The rooms in each module include the shell, sheet rock, doors, light fixtures, Corian vanities, ceramic bathroom tiles, all utilities, and even the poles and shelves in the closets.

Shipping and Installation of Modules

The modules are constructed at a facility in Belton, Texas, an approximately 2.5-hour drive north of Fort Sam. The manufacturer is able to construct and store hundreds of modules at no extra cost before they need to be shipped to the job site, according to Zdon.

Although shipping of the modules can be costly, Zdon notes that they can be built at the factory rain or shine, unlike site-built construction, which is subject to weather delays.

Each module is trucked to the site and lifted from the carrier bed by a 250-ton crawler crane. First-floor

At the center of each facility's footprint, site-built construction. Once the site-built portion is completed, the modular components are added, extending out as residential wings in the building. At each of the corners, site-built construction is used to create mechanical rooms and stairwells.

Photo courtesy of The Warrior Group

CONTINUED

case study CONTINUED

Fort Sam Houston Medical Education and Training Complex Barracks

SAN ANTONIO, TEXAS

Modules are picked from a carrier bed by a crawler crane and stacked on top of each other with no additional structure. Crews install eight to 12 per day.

Photo courtesy of The Warrior Group

modules can be set directly to the foundation. Modules are stacked directly on top and next to each other with no additional structure added. The factory-installed utilities are routed to the corridor in each module, so onsite crews are easily able to access them and tie them into the appropriate lines. After work inside each module is complete, finishes like carpet and paint are added. In each corridor, drop-ceiling grids and lighting fixtures are added.

Zdon says the build team has seen minimal errors within the factory-built modules. In Building 1, every corridor wall lined up within designed tolerances. In Building 2, two corridor walls had to be adjusted.

The team is able to install between eight and 12 modules per day, Zdon says. Installation for an entire building—each housing 341 modules—takes about eight weeks.

Meeting Green and Resiliency Goals

Buildings must meet a minimum LEED Silver certification and exceed ASHRAE standards by at least 30%. EPDM roofing makes each module more airtight, which helps the building achieve its high-performance goals. Other contributing factors include the insulation used, the recycled-material content of products used and the U-factor of windows.

The buildings are also designed in accordance with the military's uniform facilities code to meet requirements for progressive collapse and blast resistance.

When completed in December 2011, crews will have installed 1,705 modules. Zdon says that the modular plan made the project possible. "[Modular] was the perfect fit with the schedule, the needs of the Corps and the budget," he adds. ■

stats

Project Facts and Figures

Owner
U.S. Army Corps of Engineers

Architect
Jacobs (Carter Burgess)

General Contractor
Hensel Phelps

Subcontractor (Modular)
The Warrior Group

Size
1.6 million square feet (total)

Number of Buildings
5 (roughly 320,000 square feet each)

Height
4 stories

Number of Modules
1,705 (total; 341 per building)

Data: Productivity

Impact on Project Schedule

A shorter project schedule is the most commonly reported productivity benefit of prefabrication/ modularization, as well as the one with the largest reported payback.

Two-thirds of firms who currently use prefabrication/ modularization experience reduced project schedule, with 35% experiencing decreases of four weeks or more.

Prefabrication can yield time savings through the ability to conduct work simultaneously onsite and off-site, as well as helping with better coordination among different trades. In addition, less onsite staging, such as scaffolding, is frequently involved. Regionally, the ability to avoid weather impacts can reduce construction time. Site conditions factor significantly in the ability of prefabrication to impact schedule.

Additional time may be spent in the design phase on complex projects to coordinate the use of prefabrication and modularization. However, the time saved onsite typically reduces the overall project schedule.

Benefits of Project Schedule Reduction

Since construction onsite is both labor-intensive and expensive, this time savings can yield significant cost savings as well. Prefabrication can also provide critical assistance with scheduling in sectors like higher education where project deadlines are frequently inflexible. Also, for buildings on active sites, like a new building in a hospital complex, a reduced schedule minimizes the impact on the rest of the business.

Variation by Player

A slightly larger percentage of contractors experience benefits compared to other players. The difference is not large in any one category, but it is consistent through each:

- **Decrease by two weeks: Contractors—15%;** Architects—10%; Engineers—12%
- **Decrease by three weeks: Contractors—12%;** Architects—9%; Engineers—8%
- **Decrease by four weeks or more: Contractors—37%;** Architects—31%; Engineers—31%

Because extensive use of prefabrication/modularization can involve a more intensive, coordinated design period, contractors may be more likely to see the schedule gains because their involvement typically occurs later in the project lifecycle.

Variation by Firm Size

More medium to large firms (47%) report achieving a schedule decrease of four weeks or more compared to large firms (44%).

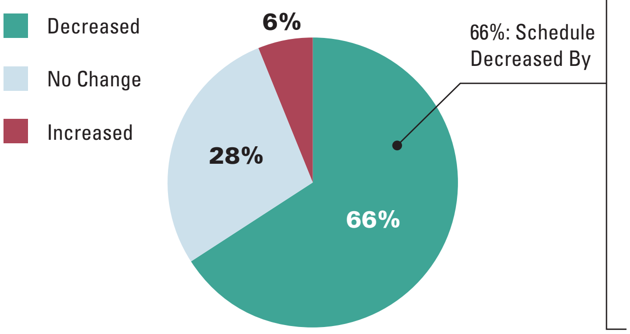
Firms Using BIM

50% of the respondent firms that use BIM on more than 50% of their projects experienced a schedule decrease of four weeks or more due to their use of prefabrication.

Use of BIM can support a smoother process and better communication between members of the project team.

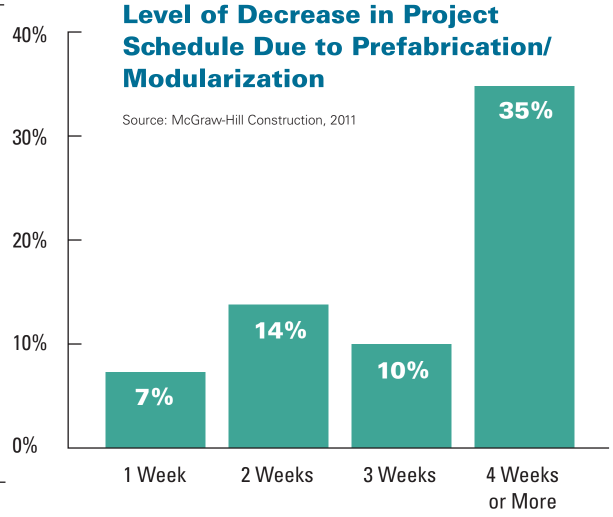
Total Impact of Prefabrication/Modularization on Project Schedule

Source: McGraw-Hill Construction, 2011



Level of Decrease in Project Schedule Due to Prefabrication/ Modularization

Source: McGraw-Hill Construction, 2011



Impact on Project Budget

65% of firms who currently use prefabrication/modularization report that it reduces their project budget. 42% of the total respondents find that these techniques reduce their budget by 6% or more.

Construction work often has very tight profit margins, so even relatively small reductions in cost can make a strong impact on the firms involved.

Source and Value of Reductions

While prefabricated materials can cost less, in general the cost savings are due to secondary issues, such as reduced reliance on expensive onsite labor, the ability to avoid overtime pay and other unexpected labor costs, and the ability to reduce onsite resources required. With labor off-site, even basic site support facilities like portable toilets can be reduced.

Several owners interviewed for this report also discussed the value of having a guaranteed, fixed cost. Project budgets on traditional construction projects are infamous for their increases due to change orders during the construction process. Even when prefabrication appears to be slightly more expensive at the outset, the avoidance of unexpected costs during the process is valuable, especially for owners with inflexible budgets like those in the public sectors. This reliability increases in value when combined with the guaranteed, high-quality workmanship also offered by prefabrication/modularization.

Variation by Player

More contractors experience budget savings due to prefabrication/modularization than architects or engineers. (See chart on page 20.) This may be influenced in part by role that the schedule improvement plays in the overall reduction of project budget offered by prefabrication, since contractors also experience slightly larger schedule reductions.

Budget savings are reported by:

- **74% of Contractors**
- **42% of Architects**
- **52% of Engineers**

The biggest difference between the savings experienced by contractors compared to the other players occurs in lowest level of savings (1%–5%), with approximately twice the percentage of contractors (30%) in that range than architects (16%) or engineers (15%).

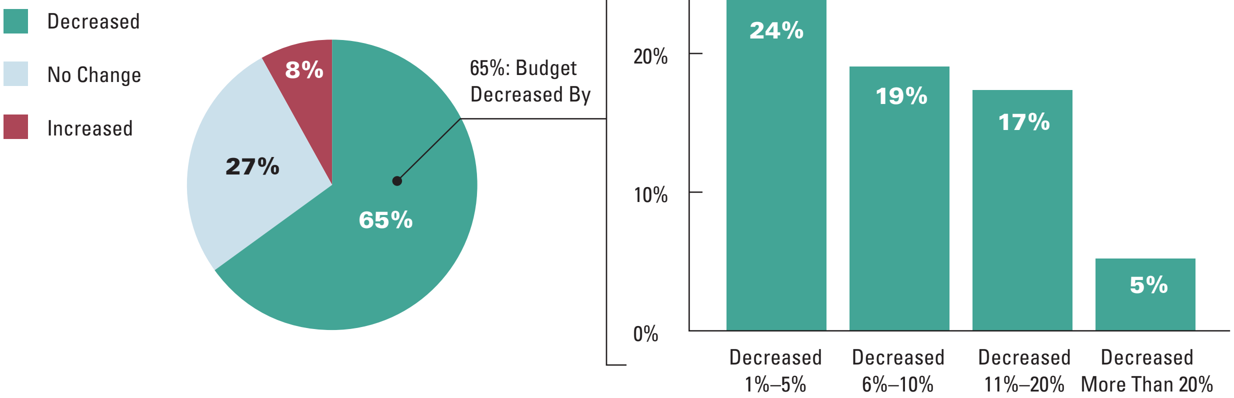
CONTRACTORS

- **Design-Build Firms**

Design-builders experience a very different pattern of budget savings compared to other kinds of contractors. **18% experience budget decreases of more than 20%, compared to a 4% average across all contractor types.**

Total Impact of Prefabrication/Modularization on Project Budget

Source: McGraw-Hill Construction, 2011



Level of Decrease in Project Budget Due to Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011

CONTINUED

Productivity

Impact on Project Budget CONTINUED

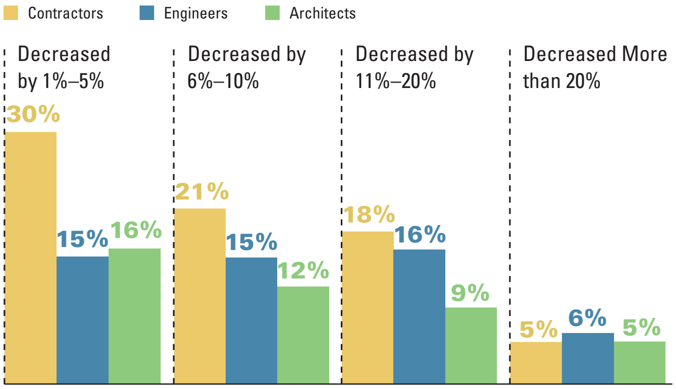
Design-Build firms also report more budget increases than other firms. Only 8% of total respondents report budget increases (see chart on page 19). However 22% of Design-Build firms have experienced an increase.

Design-Build firms carry the most risk and are positioned to achieve the strongest rewards on a construction project compared to contractors with other delivery methods. Therefore, it is not surprising that they are able to reap the greatest rewards and also occasionally suffer the greates losses when employing prefabrication and modularization.

Level of Decrease in Project Budget Due To Prefabrication/Modularization

(by Player)

Source: McGraw-Hill Construction, 2011



Impact on Site Safety

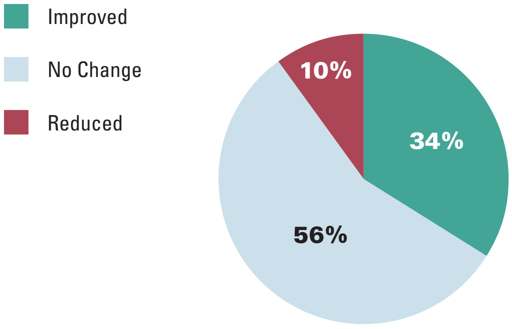
Even with the slowdown in overall construction, the fatality rate in the construction industry has remained constant.[1] Improving safety continues to be a challenge industrywide, which the benefits offered by prefabrication/modularization can help address.

Over one third of the survey respondents (34%) who are currently using prefabrication/modularization find that they have seen site safety improve as a result. Reasons for this result may vary from site to site, but factors that contribute to increased site safety include reduced need for workers on scaffolding or ladders, as well as avoiding close work in tight spaces.

However, 10% found that safety actually decreased onsite. Prefabricated pieces are frequently large, and the approach to their installation needs to be carefully considered to avoid a negative impact on overall site safety.

Impact of Prefabrication/ Modularization on Site Saftey

Source: McGraw-Hill Construction, 2011



Variation by Player

Not surprisingly, the percentage of contractors reporting site safety increases (37%) and site safety decreases (12%) were significantly higher than design firms. Contractors are more likely to bear the financial and legal responsibility for site safety than design firms and therefore would be more aware of and concerned about this issue.

CONTRACTORS

In general, a larger percentage of subcontractors are experiencing site safety improvements than general contractors, construction managers or design/builders. More mechanical contractors and fabricators in particular find their work to be less hazardous when conducted in a fabricating facility off-site.

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[1] Buckley, B. & Ichniowski, T. (2010, August 30) Fatalities Down But Rate Stays Flat. *ENR*, 265 (6), 13.

Impact on Purchase and Installation Costs

for Materials

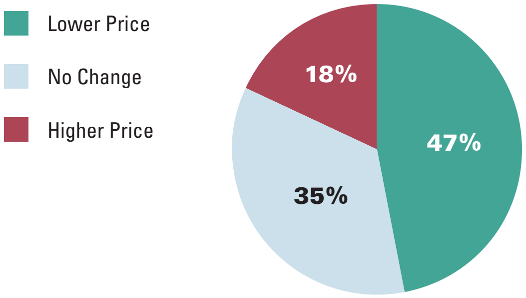
Almost half (47%) of the respondents who are current users of prefabrication/modularization find that the combined purchase price and installation cost for prefabricated components is lower than the regular purchase and installation of materials onsite.

This result demonstrates that the savings to the project budget attributed to prefabrication are not solely due to schedule improvements. Not only is the project schedule reduced, but the actual cost of procuring and installing materials is found by a significant percentage to be less than the cost of traditional construction.

This is particularly important given the perception that prefabricated materials are more expensive. While the cost of the materials alone may be greater, a large percentage of respondents recognize that the total costs of materials and installation is reduced.

Impact of Prefabrication/Modularization on Purchase and Installation Prices for Materials

Source: McGraw-Hill Construction, 2011



Degree of Change in Materials Purchase and Installation Costs

Most respondents find their costs to be significantly reduced.

- **Reduction in Materials Purchase and Installation Costs:**
  - Less by greater than 10%: 12%
  - Less by 6%–10%: 18%
  - Less by 1%–5%: 16%
- **Increase in Material Purchase and Installation Costs:**
  - More by 1%–5%: 8%
  - More by 6%–10%: 7%
  - More by greater than 10%: 3%

Interviews with owners (see page 43) suggest that many owners find that prefabrication also yields measurable quality improvements compared to materials installed onsite, so that even when a significant cost savings is not achieved, there are still compelling reasons to employ prefabrication.

Variation by Player

There is little variation in the percentage of architects (45%), engineers (45%) and contractors (47%) who experience reduced materials purchase and installation costs.

However, fewer architects (10%) report cost increases than engineers (20%) and contractors (18%). In addition, no architects reported an increase greater than 10%.

CONTRACTORS

- **Only 7% of mechanical contractors report increased costs, far lower than any other category of contractors.**
- **Fabricators are less likely to see a cost decrease than other types of contractors:**
  - 37% of fabricators report seeing costs decrease, compared to 45%–53% of all other contractor types.
- **28% of electrical contractors and design/build contractors report cost increases.**
  - Most of the design/build contractors (23%), however, report increases of 1%–5%.
  - 18% of electrical contractors report increases of 6% or more.

Expected Impact on Project Schedule According to Prefabrication/Modularization Non-Users

Expectations of firms not currently using prefabrication/modularization reveal the industry's current predisposition towards these strategies.

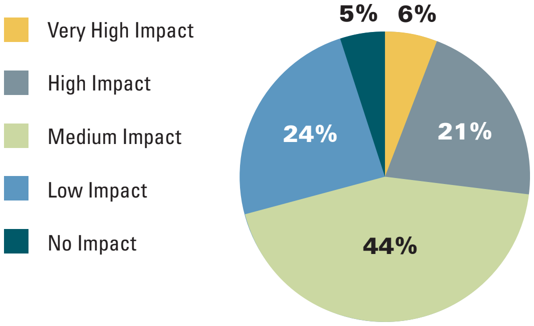
71% of firms not currently using prefabrication/modularization recognize that these methods have at least a moderate impact on the project schedule. This result demonstrates that key benefits of prefabrication/modularization are recognized by the industry as a whole.

However, those not using these techniques also underestimate their impact. Only 27% expect a high/very high impact on schedule, but 45% of those using prefabrication/modularization report a reduction of three weeks or more in project schedule as a result.

This result demonstrates that the industry would benefit from increased information about the true schedule benefits offered by prefabrication. In particular, sectors like education, where schedule is highly impactful, need to consider whether their projects are good candidates for using prefabrication/modularization.

Impact of Prefabrication/ Modularization on Project Schedule (According to Non-Users)

Source: McGraw-Hill Construction, 2011



Impact on Project Budget According to Non-Users

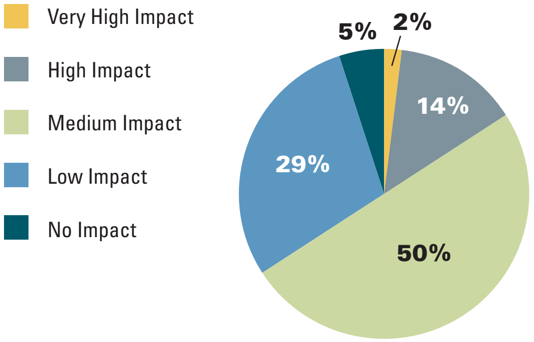
Firms not currently using prefabrication or modularization are still aware of their potential impact on the project budget. **Two-thirds (66%) expect the use of these approaches to have a medium to very high impact on the budget.**

Only 5% expect prefabrication/modularization to have no impact at all. This is in contrast to those currently using prefabrication/modularization, where 27% actually experience no notable change in their project budget.

This suggests that the industry as a whole may have overly optimistic expectations about the direct savings associated with prefabrication/modularization beyond the savings due to a shortened schedule and decreased materials and installation costs. **Therefore, the prefabrication/modularization market may benefit by educating the industry about other advantages beyond budget impact, including quality, safety and sustainability improvements.**

Impact of Prefabrication/Modularization on Project Budget (According to Non-Users)

Source: McGraw-Hill Construction, 2011



Impact on Reducing Onsite Resources

According to Non-Users

83% of firms not currently using prefabrication or modularization expect their use to have a medium to very high impact on reducing onsite resources such as manpower and equipment.

In fact, the case studies and owner interviews show extensive reductions in site resources needed, such as scaffolding, staging areas and material storage (due to just-in-time delivery) and portable toilets.

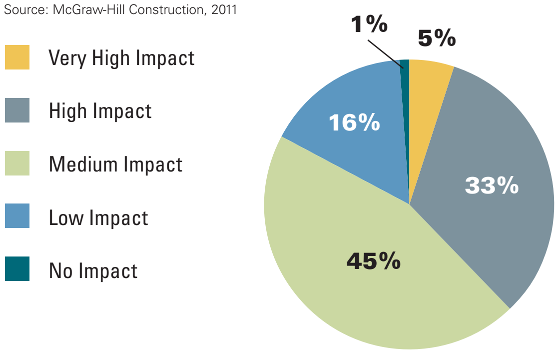
This result demonstrates that the industry believes that prefabrication/modularization has a positive productivityimpact, so this point can be effective in making the case for these strategies.

Variation by Player

Architects are the most optimistic about the impact of prefabrication/modular construction on reducing onsite resources. Strikingly, 54% expect a high to very high impact.

Impact of Prefabrication/Modular Construction on Reducing Onsite Resources
(According to Non-Users)

Source: McGraw-Hill Construction, 2011



Impact on Improving Project Quality

According to Non-Users

65% of firms who are not currently using prefabrication or modularization expect them to have at least a medium impact on project quality. Quality of the materials is one of the major benefits of prefabrication. In owner surveys, even those who find no compelling cost benefit to prefabrication/modularization often choose to use it because of the dependable quality. As with budget, owner interviews also indicate that the reliability of the quality is an important factor in their decision.

Reasons for Quality Improvement

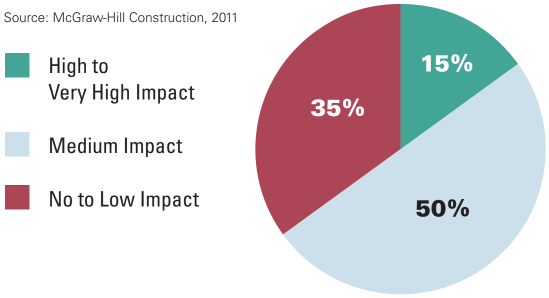
Factory conditions offer the ability to do extensive quality control checks on each piece produced. Prefabricated concrete, for example, can avoid the imperfections frequently found in concrete poured onsite. The lack of exposure to the elements also increases the quality, as does the ability to fabricate in factory conditions rather than on ladders or from scaffolding.

Variation by Player

Architects expect the greatest impact on quality, with one quarter (25%) expecting high to very high impacts, versus 16% of engineers and 12% of contractors.

Impact of Prefabrication/Modular Construction on Improving Project Quality
(According to Non-Users)

Source: McGraw-Hill Construction, 2011



One factor that may influence higher architect recognition of this benefit is that prefabrication may also allow the architect greater input into the final materials selected for the prefabricated component. While an architect can specify particular types of materials, contractors seeking a cost-effective project may select materials they think are comparable that cost less money. If prefabrication is included as part of an integrated project design process, the architect will have greater influence over the selection of the final products.

Interview: Thought Leader

Rethinking management systems to create leaner projects

Gregory Howell, Cofounder and Managing Director,
Lean Construction Institute

Greg Howell cofounded the Lean Construction Institute with Glenn Ballard in 1997 to reform the management of production in design, engineering and construction. Among LCI's primary initiatives is the creation of a new operating system to replace the traditional critical path method used for project management. LCI developed its Lean Project Delivery System, which includes its Last Planner system, for production control.

Why do you believe the critical path method is flawed?
The current operating system is activity centered. The critical path method is the heart of that traditional operating system. That's the tool used to manage projects as a series of contracts. It's a logical system of one activity after another after another. In that operating system, you optimize the project by optimizing each of the pieces. It sounds good, but the problem is that it doesn't produce predictable workflow from one crew to the next. A lean operating system focuses on workflow as opposed to each activity. We put our attention on making the workflow predictable.

How can you make workflow more predictable?
We know that it's an uncertain world out there. There's a significant amount of complexity, and it's difficult to map everything out. We don't propose that we can get it right at every moment, but rather that we can learn consistently through the life of a project. In current practice, the scheduler is supposed to get it right from the start. The schedule is what's supposed to happen. In our system, we want to get as good a schedule as we can, but we recognize that we'll need to learn and adjust throughout the life of a project. The current system pretends that we can know everything in advance, and if you don't, you're making an error. We believe you can make an estimate and continuously improve it as you go through the project.

Your approach is very collaborative. How can different team members work together to keep the schedule dynamic?
One example: We invented a planning system that is designed to create predictable workflow and rapid learning, but what took us into "lean" was the realization that it didn't work unless the foreman could say no and decline to make a bad assignment. Traditionally, the foreman is told by the superintendent what work they are supposed to do this week. And the foreman says he'll try, but in the end the work doesn't get done because the materials he needed weren't there. So if you want your planning reliability to be higher, you need to stop making bad assignments. It's a really radical act for a foreman to say no.

LCI has been around for 14 years, but the lean movement only gained steam in recent years. What has made the difference?
People didn't pay attention to what we were doing until the integrated form of agreement came out and changed the commercial terms of projects. That was a big step. On those first projects that used an integrated form of agreement, we saw trades agree to share one fuel truck coming out to the site every day rather than several. They agreed to share certain pieces of equipment and coordinate the usage instead of everyone having their own. Then you saw things like trades coordinating so they could prefab pipe racks. It took people out of their silos.

What is your view of prefabrication and modular components in lean construction?
It's a new structure of work, which means you have to rethink how you are managing tolerances. We don't pay a lot of attention to tolerances in construction. When you're doing stick built, everyone can adjust things in the field. When you do prefab and modular, the game is different because pieces that are out of tolerance can stack up. They build on each other and create a situation where things are out of tolerance at a bigger level. You have to be careful if you work ahead because you don't want to get stuck with a large inventory of [prefab and modular] components that are flawed. That's waste. ■

Lean Construction

Tools and techniques for reducing waste lay the groundwork for expansion of prefabrication and modularization.

Lean construction is a big buzzword among contractors these days, and some are leveraging those principles to gain impressive results. With a focus on eliminating waste, lean contractors report significant savings in both schedules and budgets.

Collaboration and Integration

At New York City-based Turner Construction, lean is an increasingly common practice, particularly on complicated jobs. James Barrett, national director for integrated building solutions at Turner, says the company uses a variety of techniques in achieving lean projects, but keeps a few primary tools in its kit. Collaboration and integration in particular are paramount to any lean job.

"We use the big room concept," he says. "We get everyone in a room to work together rather than launching things back and forth over the fence. We go through weekly schedule meetings and drill down to excruciating detail to see who is doing what and when."

The Turner approach to scheduling isn't top-down, but rather sets milestones in the field, then looks upstream at the dependencies between parties and finds common solutions. To help achieve that goal, Turner uses BIM extensively as an integration tool.

With improved integration among subcontractors, Turner sees added opportunities to use prefabrication for waste reduction. On traditional healthcare projects with onsite fabrication, metals waste average 15% to 25% of total recycled materials. On healthcare projects employing lean principles with BIM-enabled prefabrication, metals waste average only 5% to 10% of total recycled materials.

At the $340-million, 1.3-million-square-foot University of Kentucky Patient Care Facility in Lexington, crews used BIM and lean construction to facilitate the installation of 1.2 million pounds of prefabricated sheet metal in six months. Nineteen miles of 3-inch to 6-inch conduit was also installed in six months, and all pieces were bent off-site by the subcontractor, Gaylor Electric. Electrical deliveries were made using a small trailer pulled behind a pickup.

Overcoming Multitrade Obstacles

Skanska USA's Nashville, Tenn. office pushed the traditional limits of prefabrication on the $152-million 484,000-square-foot Miami Valley Hospital addition in Dayton, Ohio. Multitrade prefabrication was used to create 178 patient rooms and 120 overhead corridor utility racks. Marty Corrado, project executive at Skanska, estimates that prefab cut two months from the schedule and trimmed up to 2% off the budget.

Corrado says original estimates called for a peak workforce of 700 workers, but by using off-site fabrication, peak workforce was less than half of that estimate. "The quality is better, your workers are happier, and you have less workers onsite so your safety numbers are better," he says.

Although trying to bring together multiple trades for a prefabrication project could be problematic in traditional construction, Corrado says that through BIM-enabled coordination and team integration, it's not only possible, it's necessary. "The industry needs to change," he adds. "This is a real movement. You can't go anywhere in the healthcare industry and not hear people talk about prefabrication. Multitrade is the next step."

Making the Move to Modular

Specialty contractor Limbach Facility Services of Warrington, Penn. not only creates multitrade prefabricated components, it is also teaming on multitrade modular projects. The firm worked with Lebanon, NJ-based Kullman Offsite Construction on the Cheyney University New Student Housing Project in Cheyney, Penn., a 133,000-square-foot four-story facility that will be built primarily with modular units.

Although prefabrication is a technique that is often driven by specialty contractors, Kevin Labrecque, senior vice president of operational excellence at Limbach, says that multitrade prefab and modular need a top-down approach.

"If it's a full-blown modular building, the owner has to be engaged in selecting that route," he says. "If it's multitrade prefab, the general contractor and owner need to define an approach and work closely with trade partners on collaborative coordination and installation. It has to be an integrated approach." ■

Pushing the Envelope in Prefabrication

Texas Health Harris Methodist Alliance Hospital

FORT WORTH, TEXAS

From the start, Texas Health Resources (THR) approached the Texas Health Harris Methodist Alliance Hospital project with the goal of improving the process for constructing hospitals moving forward, for THR and for the industry as a whole. The two main opportunities the project team has found were in using integrated project delivery and in maximizing use of prefabrication, including seeking prefabrication best practices in Europe.

The Texas Health Harris Methodist Alliance Hospital in Fort Worth Texas

Image Courtesy of Perkins & Will Architects

Creating a Learning Opportunity

According to Denton Wilson, the director for facilities development at THR, the development team was charged with using this project as a test case for future work: "One of the tasks that THR put to this team was to get outside the box. Go out and find other things in other industries that would benefit our process."

In a previous project, Wilson had begun to experiment with the use of BIM tools and an integrated design process. He took the opportunity to fully embrace these approaches in the Alliance project because of the benefits he had observed: "If you align the people together that actually build things as units and cohesive parts and pieces, it just opened up the world to do that. All the metrics [demonstrated] more value, quicker [work], fewer change orders." Thus the Alliance project began with a full commitment to an integrated design process and use of BIM.

The team at the Beck Group, the construction manager, shared THR's goals. Dominick Calabrese, the director of heathcare services at the Beck Group, affirms that the opportunity to improve the construction process was the main benefit sought rather than immediate cost or schedule savings: "I don't think we'll see a huge savings [on this project], but what Beck is interested in, what our subcontractors and THR mainly are interested in, is what can we learn? How can we learn to do prefabrication on this project so that we'll improve the industry and how we deliver [future projects]?" He clarifies that the cost and schedule gains of using prefabrication on a small 188,000-square-foot hospital like this one can be minor, but the experience that they gain on it will pay off on larger projects.

Integrated Project Delivery, BIM and Prefabrication

For Wilson, using prefabrication in an integrated design process has an impact on the process itself; he argues that it encourages "the design philosophy of how to do the right thing from the beginning." The need for accurate, buildable specifications early in the process reinforces the collaborative nature of the process between the designers, the fabricators and the builders.

Wilson affirms that an open, collaborative design approach, especially one using BIM technology, can also increase the use of prefabrication. "When you have a technology-based, strong project team who are BIM modeling, you are going to test prefabrication."

Calabrese also finds this connection. He states, "Because IPD allows [the project team] to come together early in the design process, we are able to use the collaboration, our BIM technologies and other 3D modeling technologies to work with the architect, the owner and the major trades

CONTINUED

Texas Health Harris Methodist Alliance Hospital

FORT WORTH, TEXAS

to identify what can be prefabbed." He cautions that "if you go through the traditional process and design everything first without considering prefab, you are just creating a whole lot of rework [if you ultimately want to implement prefabrication]."

Jeff Ratcliff, project manager with the Beck Group, points out the particular value added by working in BIM. "If it wasn't for BIM, we would not get the level of prefabrication we are doing. We are coordinating so much in such detail, [and BIM allows us] to really maximize the prefabrication and go into the detail that we need to."

BUILDING TEAMS

The greatest challenge associated with IPD is building the team's sense of trust and cooperation, but that is also its greatest opportunity. Calabrese argues that one challenge for any new team is to get everyone, especially the subcontractors, to adopt what he dubs "the IPD mindset," a recognition that it is the productivity savings for the project as a whole rather than for their own individual piece that matters.

"When Jeff and I were interviewing subcontractors for this project," reports Calabrese, "we would talk about prefabrication. Invariably, everyone we talked to [said], 'No, I don't want to do prefab. I can do it faster in field,' or 'Yes I do prefab, so I don't need to do anything differently.'" However, each contractor was only regarding their own individual trades, "looking at what is best for them as far as manpower and productivity, but not what is best for the project." He explains that working in a factory setting may not save any of the individual contractors anything, but "that is better and more productive for the overall project than it may be for one singular entity." He reports that once the subcontractors adopted this mind-set, "that is when they really got excited about the project."

The adoption of the IPD mindset was particularly critical for the success of their most unusual use of prefabrication: the creation of multitrade racks for the hospital corridors.

CROSSING THE LINE

According to Wilson, team members were regularly surveyed to find out how well the process was working. One question asks whether the team is working with true trust and respect, while another asks, "Are the parties on the team actually crossing the line?" For Wilson, that ability to participate beyond the traditional boundary of their specialty is a good measure of the success of this project. However, the process of collaborating and seeking better approaches takes longer than simply doing what has worked in the past.

Wilson believes that the process change led to a different product: 50% implementation drawings are weaker than a normal set of construction documents because in this kind of IPD project, "you are not building the drawings, you are building shops." The entire process is fundamentally changed because it is geared toward implementation as a whole rather than just completing a set of documents, focusing on the end result rather than on the individual steps to achieve that result.

stats

Project Facts and Figures

Owner
Texas Health Resources

Architect
Perkins + Will

Constrution Manager
The Beck Group

MEP Engineer
CCRD Partners

Structural Engineer
LA Fuess Partners Inc.

MEP Subcontractor
DynaTen Corporation

Drywall Subcontractor
Lasco Acoustics & Drywall

Construction Cost
$60,439,735

Size
188,124 square feet

Height
4 stories

Started
December 2010

Scheduled Completion
August 2012

Green Certification Sought
LEED Silver

Multitrade Prefabrication

The most promising and challenging application of prefabrication on this project is the multitrade prefabrication of the racks in the hospital corridors. Since that approach is not common in the United States, the team went to the United Kingdom to learn how it could best be applied.

Scott Brady, the president of DynaTen, the mechanical/plumbing subcontractor, describes a typical process in the U.K. for creating these racks: —"mechanical contractors hire [independent prefabrication firms] to case study

Texas Health Harris Methodist Alliance Hospital

FORT WORTH, TEXAS

do the BIM model for these horizontal systems, and [the prefabrication firms] have developed software that converts the BIM model into a bill of materials on a prefab rack by prefab rack basis." These racks combine the work of multiple trades, including duct work, medical gas mains, hot water supply and return for comfort heating, domestic water piping, electrical conduits, communication system pathways and low-voltage systems. Typically, in the U.K. these racks are assembled in factory and shipped to the site.

Since there are no equivalent prefabrication firms in the United States, Brady explains,"DynaTen developed a strategic relationship with a company in the UK ... They are doing the BIM model work for the areas where we will be installing the rack, and then they are using the software they've developed to send us a kit of parts for each rack." The racks will be assembled in a fabrication shop adjacent to the project site, with all the trades coordinating their assembly together.

Brady sees three clear advantages to following this approach: reduction in the manpower peak, safety and quality.

MANPOWER

He states, "If you look at the normal manpower curve on a project, there is a distinct peak, and we think we'll be able to reduce that peak by as much as 20% and move it forward so we are doing that work earlier."

The hospital will feature multi-trade prefabricated racks in the corridors, an approach that is still new in the U.S.

Image Courtesy of Perkins & Will Architects

SAFETY

According to Brady, the workers will be able to do at least 90% of their work with the racks at waist level rather than working from ladders in a multi-story building.

QUALITY

Working in a controlled environment also typically yields better, more consistent results than those produced by workers on ladders.

Of course there are challenges associated with this process as well, especially when it comes to installing the fully loaded racks. "These racks weigh in excess of 2,000 pounds and they are 20 feet long, seven feet wide," states Brady, "but we've developed methods for lifting them, and we have made special lifts to get them in place."

Other Prefabrication Opportunities

The multitrade racks were the most innovative use of prefabrication, but not the only example of this approach. The patient rooms will also have prefabricated bathroom modules and headwalls. Wilson states that "those two components are a win on every facility we will ever do" because of the efficiency and quality of the construction.

He mentions the ability to conduct sound attenuation studies of the headwalls at the factory as a factor that contributes directly to patient satisfaction. "Who wants to hear the patient next door? Now we get to do all those studies in a warehouse ... and we get to do multiple scenarios to [measure the benefits]."

Finally, there will likely be few deviations from the schedule. Wilson notes that dependability—knowing exactly when the project will be completed—is a major benefit of prefabrication. ■

Data: Influence Factors

Drivers for Use of Prefabrication and Modularization

Factors Driving Current Use

Productivity is the top driver of prefabrication/modularization use among all firms.

As the findings on pages 18 and 19 reveal, reductions in project schedule and project budget are key productivity benefits reported by all firms. Time savings and even small cost reductions make a big difference for players in the construction industry, where profit margins are slim due to the labor-intensive and expensive nature of onsite construction.

VARIATION BY PLAYER

- **92% of contractors see productivity as a stronger driver to use prefabrication/modularization, compared to engineers (70%) and architects (68%).**
- **Competitive advantage (85%) and generating greater ROI (70%) are stronger drivers for contractors than they are for architects and engineers.**

This difference may be influenced in part because contractors experience reductions in project budget due to schedule improvements more than architects and engineers do; also in part because the very competitive market in which contractors operate make them highly responsive to potential cost savings and gains in market share.

Anecdotal feedback from owners also indicates that improving productivity is the biggest driver for using prefabrication/modularization. Owners report project schedule reductions of 10% to 30% resulting from off-site work.

Factors Driving Future Use

Lower project costs (85%) and project schedule improvements (84%) are the top drivers behind current users' decisions to use prefabrication/modularization in the future. Other top factors driving future use:

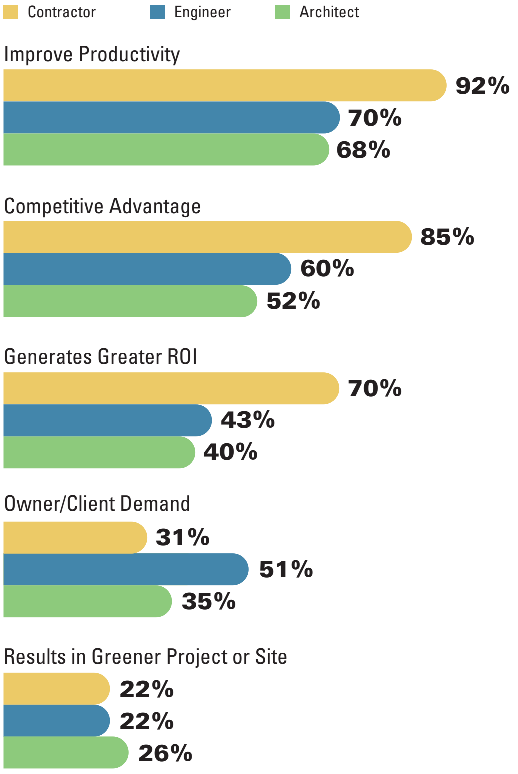
- **Project quality improvements (70%)**
- **Cheaper labor costs (69%)**
- **Project safety improvement (58%)**

These drivers are also consistent with anecdotal information from owners—most report that they plan to use prefabrication/modularization in the future because they see cost, schedule and quality benefits.

Current Drivers to Use of Prefabrication/Modularization

(By Player)

Source: McGraw-Hill Construction, 2011



CONTRACTORS

Improving productivity is reported as the top driver for using prefabrication/modularization by construction managers, general contractors and design-builders.

- Design-builders report competitive advantage (82%) as a stronger driver, compared to general contractors (73%) and construction managers (78%).
- Design-builders also see generating greater ROI (64%) as a stronger driver, compared to general contractors (54%) and construction managers (55%).

SUBCONTRACTORS

Improving productivity is also reported as the top driver by mechanical contractors, electrical contractors and fabricators.

- **Mechanical contractors (94%) and electrical contractors (96%) report competitive advantage as a bigger driver than fabricators (63%).**

Factors Driving Future Use

of Prefabrication/Modularization For Non-Users

Saving money is the top driver, identified by 77% of current non-users as a factor influencing their decision to use prefabrication/modularization in the future.

Firms report these other top drivers:

- **Saving time (66%)**
- **Owner demand (66%)**
- **Competitive market advantage (65%)**

These findings indicate that in this down economy, firms that decide to use prefabrication/modularization in the future are mainly concerned about what will help their bottom line and allow them to be more competitive. In the construction industry, where profit margins can be slim, any reduction in project time and cost can be critical.

The fact that owner demand (66%) is a significant influence factor suggests that with more owner education on the benefits of using prefabrication/ modularization, more adoption is likely in the future.

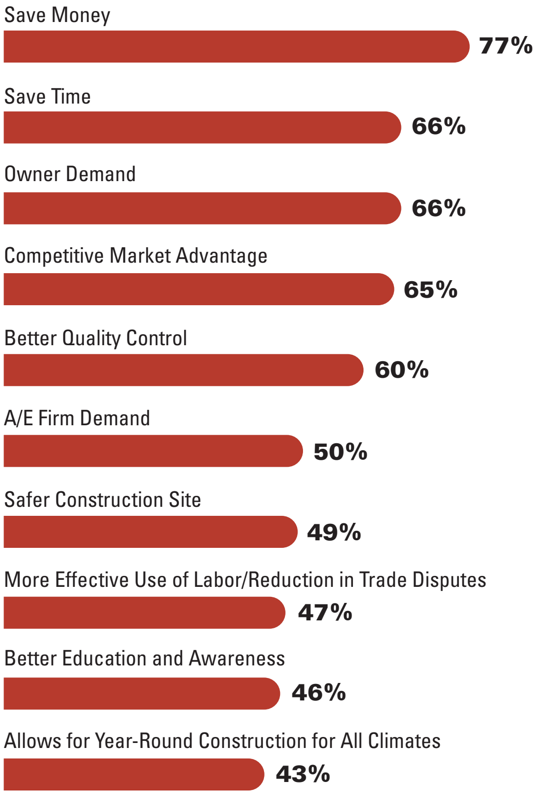
The majority of firms (60%) also report better quality control as a significant driver, demonstrating that in a competitive market, being able to distinguish your product is highly important.

Although it is not a top factor, 46% of firms see better education and awareness as a driver for future adoption of prefabrication/modularization. This is currently needed, as it will help the industry as a whole understand the key benefits of prefabrication/modularization and ways it improves project productivity.

Factors Driving Future Use of Prefabrication/Modularization

(For Current Non-Users)

Source: McGraw-Hill Construction, 2011



Non-Users' Current Reasons

For Not Using Prefabrication/Modularization on Projects

46% of non-users report not using prefabrication/modularization because the architect did not design it into the project.

- **Not being familiar with the process ranks second highest, tied with project type not being applicable, according to 34% of non-users.**
- **Higher cost is the least reported reason (10%) for not using prefabrication/modularization.**

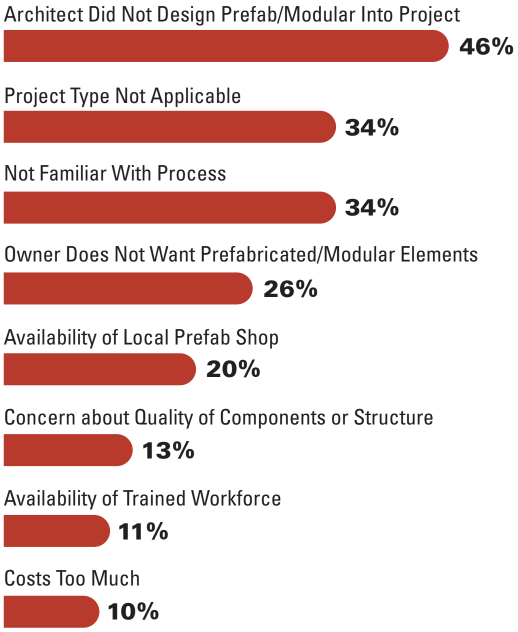
These results are similar to those of current users that are not using prefabrication/modularization on some of their projects. One exception is that being unfamiliar with the process ranks considerably higher with non-users.

The findings suggest that the cost benefits of prefabrication/modularization are better known while there is still a need for understanding the processes and the wider applicability of prefabrication/modularization.

Anecdotal evidence from owners demonstrates that various challenges exist, such as the need to commit to design work at an early stage and to figure out the logistics of shipping components to the site. However, once those obstacles are overcome, owners report that multiple benefits can be achieved in addition to schedule and cost improvements, such as increased safety, waste reduction and overcoming skilled workforce shortages.

Non-Users Current Reasons for Not Using Prefabrication/Modularization on Projects

Source: McGraw-Hill Construction, 2011



Users' Current Reasons

For Not Using Prefabrication/Modularization on Some Projects

The top reason for current users to not use prefabrication/modularization is because the architect did not design it into the project.

Other top reasons for current users deciding not to use prefabrication/ modularization on some projects:

- **Project type is not applicable (29%).**
- **Owner does not want prefabricated modular elements (32%).**

These findings show that the use of prefabrication/modularization in some cases is particularly dependent on the decisions of the owner and the architect. Reported by owners anecdotally, some of the challenges to using prefabrication/modularization include having to commit to a well-defined scope early in the planning stage, increased transportation and logistics requirements, and the limited number of providers of off-site fabrication.

VARIATION BY PLAYER

- **Almost half of contractors (48%) and engineers (44%) report not using prefabrication/modularization because the architect did not design it into the project.**
- **More architects (39%) report that the owner does not want prefabricated modular elements than do contractors (21%) and engineers (35%).**
- **More architects (29%) also indicate concern about quality of the prefabricated/modular component or structure than do contractors (10%) or engineers (19%).**

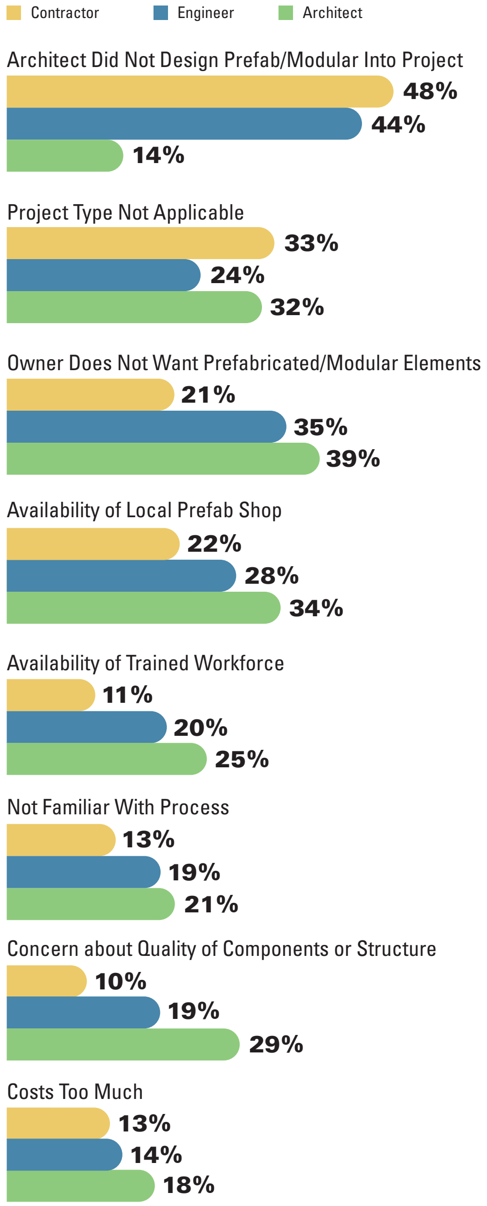
The fact that architects show concern over quality suggest that they need more information on the benefits of prefabrication/modularization other than cost, since one of its major advantages is being able to produce better quality work under controlled conditions.

These results, in general, demonstrate that the industry as a whole could benefit from more education on the processes, the use of materials and labor, and the wider applicability of prefabrication/modularization.

Armed with the right knowledge architects can use prefabrication/modularization in more creative and innovative ways in their designs as well as educate and influence owners to use prefabrication/modularization in the future.

Users Current Reasons for Not Using Prefabrication/Modularization on Some Projects
(By Player)

Source: McGraw-Hill Construction, 2011



Influence of Job Site Conditions

Job site conditions are an important factor in the decision to use prefabrication/modularization, with over half of respondents influenced by job site accessibility (58%), number of stories (53%) and type of building exterior (52%).

JOB SITE ACCESSIBILITY

This factor influences around 50% of architects and engineers, and it is selected by 62% of contractors, the largest percentage for any of the job site conditions. For sites with severe restrictions, prefabrication can prevent job site congestion.

NUMBER OF STORIES

The number of stories can influence the decision to use prefabrication for structural elements or exterior walls. However, with the rise of BIM and with taller buildings with complex mechanical and electrical systems, prefabrication in taller buildings is becoming more common. In fact, although low-rise offices currently see more activity according to respondents, high-rise offices are selected by a slightly greater percentage as a strong future opportunity (see pages 8 and 10).

LAYOUT OF BUILDING INTERIOR

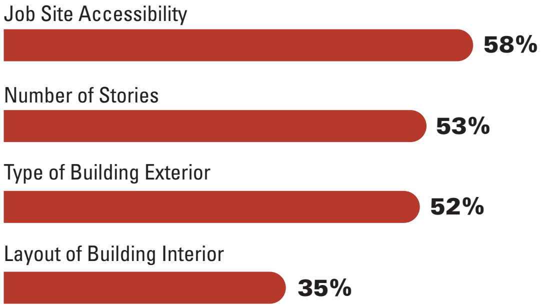
At 52%, this factor is deemed influential by the highest percentage of architects. A relatively repetitive layout for a large number of rooms makes the modularization of whole rooms a cost-effective approach in building types such as hospital or dormitories. Not surprisingly, this element influences contractors the least (27%) since the decision on room layout comes earlier in design.

TYPE OF BUILDING EXTERIOR

A larger percentage of engineers (61%) are influenced by this than architects (40%) or general contractors (50%).

Percentage of Respondents Influenced by Job Conditions

Source: McGraw-Hill Construction, 2011



Most Commonly Used Prefabricated and Modular Building Elements

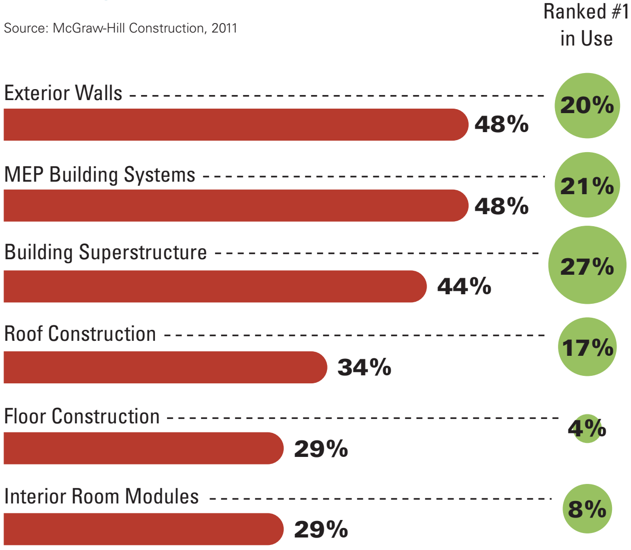
Nearly half of all respondents (48%) use prefabrication and modularization for mechanical, electrical and plumbing (MEP) systems and the exterior walls. Prefabrication and modularization are used for the building superstructure by 44%.

Those same three building elements are also used the most by individual respondents, with the building superstructure the most highly ranked, at 27%.

The benefits to be gained help account for their widespread use:

- **MEP Systems: Prefabrication of complicated MEP systems can help reduce the space required for the ductwork. In addition, assembly off-site can positively impact the overall project schedule and keep ductwork cleaner for sensitive projects like high-tech or biomedical facilities.**
- **Exterior Walls: Prefabrication of exterior walls can significantly reduce the time required to assemble a building onsite. Also, some owner interviews revealed that reducing exposure to the elements during construction by assembling the walls in a controlled environment has benefitted the overall quality.**
- **Building Superstructure: Constructing all of the building above the foundation with prefabricated or modular units is most likely to yield the strongest cost and schedule benefits, which is probably why those who use this strategy also report that they use it most extensively.**

Percentage of Respondents Using Prefabrication/Modularization for Building Elements



Source: McGraw-Hill Construction, 2011

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Prefabricated and Modular Building Elements

Most Commonly Used Prefabricated and Modular Building Elements CONTINUED

Variation by Player

The specific building elements constructed with prefabrication/modularization used by the highest percentage of architects and engineers differ dramatically from those used by the highest percentage of contractors. Only exterior walls are reported by a relatively large percentage of all three groups.

In addition, a smaller percentage of contractors in general are involved in projects with specific elements prefabricated or modularized, with MEP systems as the only category reported by more than 50% of the contractors.

ARCHITECTS AND ENGINEERS

The largest percentage of architects and engineers report using prefabrication and modularization for:

- **Building Superstructure**
  - Architects—68%
  - Engineers—71%
- **Exterior Walls**
  - Architects—68%
  - Engineers—60%
- **Roof Construction**
  - Architects—62%
  - Engineers—56%

CONTRACTORS

The highest percentage of general contractors use prefabrication/modularization for the following building elements:

- **MEP Building Systems (62%)**

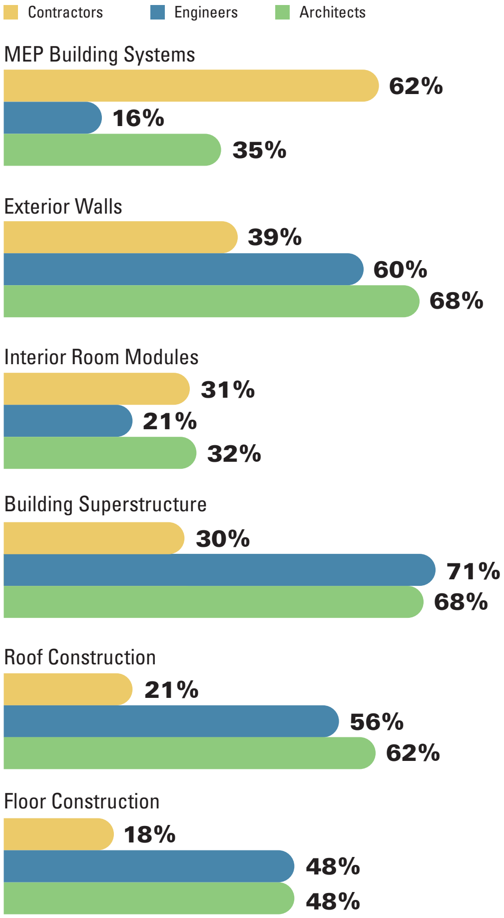
While this number is strongly impacted by the MEP subcontractors surveyed, it is still notable that 40% of construction managers rank these systems as the area where they most commonly use prefabrication/modularization, the largest for that group. Over a fifth (22%) of general contractors also rank MEP systems first, the second highest category for them.

- **Exterior Walls (39%)**

30% of construction managers and 35% of fabricators rank exterior walls as the building element for which they most commonly use prefabrication/modularization.

- **Interior Room Modules (31%)**

Electrical contractors and design-builders report the highest use for interior modules, with 31% and 19%, respectively, ranking these as the highest categories.



Percentage of Respondents Using Prefabrication/Modualization for Building Elements (by Player)

Source: McGraw-Hill Construction, 2011

Firms with more than 75% Green Projects

10% to 15% more firms who primarily do green projects report using prefabrication in every category except MEP systems.

- **Building Superstructure—68%**
- **Exterior Walls—65%**
- **Roof Construction—56%**
- **Floor construction—47%**
- **Interior room modules—47%**

Innovation in Prefabrication to Achieve a Tight Schedule and Green Results

The Summit at Queens College Student Residence Hall

QUEENS, NEW YORK

The wall panels used to create the Summit project include a wide range of exterior materials, including brick and metal panels.

Photo Courtesy of Liam Frederick

The Summit student housing project at Queens College in New York City employed extensive use of prefabrication, including innovative load-bearing exterior panels, to complete a high-quality building on time and on budget that achieved significant green goals.

Decision to Prefabricate

While the budget was always a consideration on this project, it was the tight 16-month construction schedule that led the project team to consider prefabrication. In part, the type of building contributed to the tight schedule; as Dr. Sue Henderson, the vice president for institutional advancement at Queens College, explains, "When you build a residence hall ... you only get one time of year to open it up. If you have it finished in September, that doesn't quite work."

In addition to the inflexible completion date, Bruce McKee, vice president at Capstone Development, describes additional schedule challenges: "We had a relatively challenging site. We had to move some things off the site. We had to put a garage underneath the structure, and with that part of the schedule, we knew it was going to take a substantial amount of time, more than we typically see." And in fact, the site work and garage took even longer than they originally anticipated.

Therefore, the integrated design and construction team immediately considered prefabrication as a possible solution, and ultimately it proved effective. According to McKee, "The only way we were really able to get the project completed on time was by [making up time lost during the site work phase] through prefabrication of panels in the erection process."

Innovative Use of Prefabrication

The project mainly employed prefabrication in two ways. The first was the use of prefabricated concrete floor planks, a relatively common practice.

However, they also decided to create lightweight, load-bearing prefabricated exterior walls, a new approach that the team developed just for this project. The system consists of wall sections that typically measure 30 feet. Each involves a metal stud structure with nearly all of the wall components factory installed, including glazing, exterior skin, insulation, vapor barriers—every component except the electrical wiring and interior sheetrock.

For the system to work effectively for a multistory building, it had to be lightweight, as Eric Goshow, a partner at Goshow Architects, explains. "We wanted to make it lightweight

CONTINUED

The Summit at Queens College Student Residence Hall

QUEENS, NEW YORK

so that it could be easily transported, and would reduce the weight in the bottom of the building and the size of the footing." That goal led to the use of high-strength, lightweight metal studs in the panels. In addition, the brick used as the primary exterior finish for the building was one inch split tile as opposed to typical four inch face brick, which also significantly reduced the weight of the panels.

For Antoine AbiDargham, vice president at WSP Cantor Seinuk, the structural engineer, the main design challenge to this structure was "handling the stresses and distributing loads" around the openings and inserts in the facade. This challenge was increased by the fact that half of the building was going to be sitting on the parking garage. AbiDargham explains that they had to "make sure that [they] can place the loads through all these walls from top to bottom and minimize the deflection of the effect of the loads as you stack the walls on top of each other."

Early Research Was Critical

All of the team members, from the architects to the developer to the construction manager, credit the research they did early on to not only help them create a system that worked effectively but also to help them gain the buy-in of both the owner and the developer, a critical success factor for this approach.

To begin, the team considered many different structural options. AbiDargham describes how they "looked at various structural schemes to expedite construction," including steel frame and plank system, steel frame and cast-in-place concrete, and metal stud load-bearing walls. None of these strategies were able to fully address concerns about schedule and cost.

Once they decided to consider a prefabricated, panelized load-bearing wall system, the project team's main concern was the capacity of the fabricator/manufacturer. As Goshow states, "The key with prefabrication is whether the prefabricator can develop enough panels on time?"

Before they committed to this strategy, the design team visited several prefabrication facilities. The entire team was impressed with Island International Fabricators, and they began to work with Island to develop the walls. Goshow points out that getting the manufacturer involved, even before they had been formally contracted, was important. "If you want to do something that is out of the ordinary, you want to bring in the people who are vendors and have some experience. These people are always willing to collaborate."

By the time the decision was made, the team involved included the architect, developer, owner, construction manager, structural engineer, civil engineer and panel fabricator. Because of the research they had conducted, there was broad support across this wide group for the strategy. "You have to have early buy-in from all the players that 'this is the way we are going to go, and we all have to work together to make this work'," affirms AbiDargham.

Construction in progress on the load-bearing wall sections that even include the glazing.

Photos Courtesy of Liam Frederick

case study

The Summit at Queens College Student Residence Hall

QUEENS, NEW YORK

Benefits of Using Prefabrication

TIME SAVINGS

Doug Renna, project manager at T.G. Nickel & Associates, the construction manager, describes the result of their innovative system: "We erected a 175,000-square-foot building from January to April. We worked through the winter months with no holdup, and we put up a six-story building in less than four months."

Eric Goshow estimates that this shaved at least six months off the construction schedule. Two interrelated elements contributed to these time savings. First, enclosing the building as quickly as possible "allowed the interior workmen doing the sheet rock and all the interior finishes to work much more efficiently," according to Goshow. Manhar Bhatt, project manager at Goshow, also credits the phasing enabled by prefabrication of different sections of the building with contributing significant time savings.

FEWER ONSITE RESOURCES

No scaffolding was required because the brick was attached to a prefabricated wall in a factory, rather than laid on site. Several players involved in the project credit this with improvements in time, budget and safety.

In addition, only one crane was required for the entire project, another positive contributor to budget and safety concerns.

ACHIEVING GREEN GOALS

Amanda Langweil, the director of sustainability at Goshow Architects, finds that prefabrication assists with the following green goals:

- **Waste:** Prefabrication in a controlled environment creates much less waste. "Any stud material that is left over, any gypsum sheathing that is left over can be reused by that facility for another project."
- **Materials:** The use of split tile brick, which is lighter than face brick, means less raw material use. It also has better tolerances to match the dimensions needed. Langweil estimates that the use of split tile brick resulted in savings of 70%–80% in raw material use compared to face brick.
- **Tighter Envelope:** Large prefabricated panels have fewer joints that need to be sealed on site.
- **Site Impact:** The lack of scaffolding reduced the site impact.

QUALITY

AbiDargham reports that the "perfect bearing of the metal studs" in the prefabricated panels minimizes deflection and thus helps the structural system.

McKee finds that "there is consistency across the building that we wouldn't otherwise see [because] testing and certification can go on in a plant that are harder to replicate in the field."

Henderson admired the sturdiness of the construction due to the metal braces, and also reports that both the wall panels and floor slabs do not contain the imperfections that are typical of onsite construction. In addition, two years into operation, she reports that students love the building and that they have experienced no problems at all due to the construction.

Goshow sums up the main response to concerns about quality: "People look at it, and they have no idea it has been prefabricated ... From an aesthetic point of view, just because it is prefabricated doesn't mean it cannot look almost any way you want." ■

stats

Project Facts and Figures

Owner
CUNY Queens College

Developer
Capstone Corp.

Architect
Goshow Architects LLP

Construction Manager
T.G. Nickel & Associates

MEP Engineer
Goldman Copeland and Assocs.

Structural Engineer
WSP Cantor Seinuk

Exterior Load-Bearing Wall Contractor
Island International Fabricators

Interior Load-Bearing Wall Contractor
Godsell Contracting

Precast Plank Contractor
NY Precast

Project Cost (Construction Cost)
$58 Million

Size
175,000 square feet

Height
6 stories

Started
June 2008

Completed
August 2009

Green Certification
LEED NC v2.2 Registered (Seeking Gold Level Certification)

Data: Green Building

Using Prefabrication/ Modularization

on Green Building Projects

According to McGraw-Hill Construction's *Green Outlook 2011*, green projects comprised nearly a third of all new nonresidential construction activity in 2010, with that share expected to grow significantly over the next five years. Given this increase, it is important that the industry recognizes the contribution prefabrication/modularization can offer in meeting green goals.

Though the level of use of prefabrication/modularization in green projects is limited today, most of the industry (88%) is using it on at least one green project, with 19% using it on more than half of their green projects. This suggests that some industry players understand the value these off-site practices can contribute to green goals (see case study on page 36 for an example).

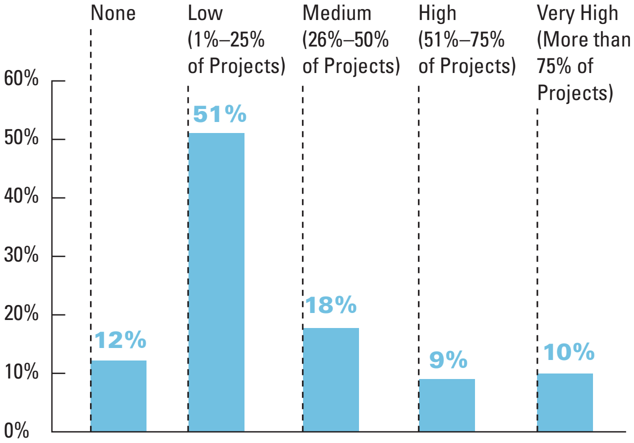
Use of Prefabrication/Modularization on LEED Projects

Currently, 31% of the industry believes that use of prefabrication/modularization can help projects achieve LEED credits under the U.S. Green Building Council's LEED green building certification program. However, there is still a majority that do not recognize that intersection.

There are several ways prefabrication can contribute to a greener project—and potentially to LEED credits. Aside from the waste reduction benefits (see below), off-site work could reduce habitat and site disturbance; protect some materials from rain and inclement weather—translating to less exposure to moisture and better indoor air quality; and offer flexibility—contributing to development of a more adaptive building.

Percentage of Green Projects Using Prefabrication/Modularization

Source: McGraw-Hill Construction, 2011



Construction Waste

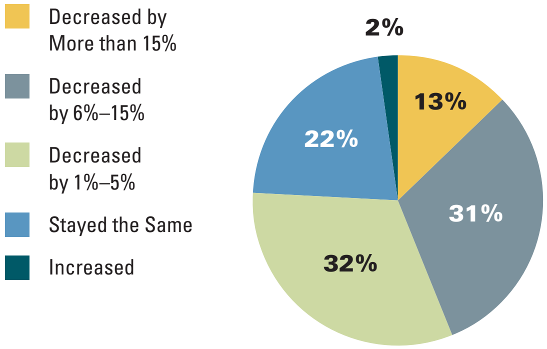
The impact of construction on the environment is significant. The US EPA estimates more than 135 million tons of debris from construction sites end up in landfills in the U.S. each year. According to the industry, that waste can be effectively minimized through the use of prefabrication/modularization.

According to Current Users

76% of current users report that prefabrication/modularization decreases the amount of their construction site waste, with 41% reporting decreases of 5% or more. Not only are these gains environmentally beneficial, but they also are financially beneficial, with less waste translating to cost savings and higher ROI.

Impact of Prefabrication/Modularization on Amount of Construction Site Waste

Source: McGraw-Hill Construction, 2011



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According to Current Non-Users

Non-users of prefabrication/modularization also recognize the green benefits that it can offer.

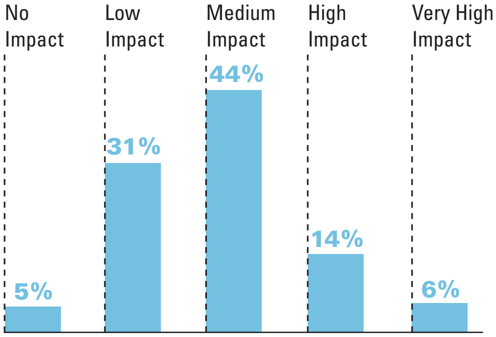
Nearly all (95%) non-users believe prefabrication/modularization can lead to a greener construction site, with a fifth reporting it can have a high or very high impact on creating a greener site.

VARIATION BY PLAYER

Architects have the most positive perception on the impact prefabrication/modularization can have on creating a greener construction site—33% of architect non-users believe it has a high or very high impact. Engineers lag, with 16% believing the same.

Impact Prefabrication/Modularization Can Have On Creating a Greener Construction Site
(According to Non-Users)

Source: McGraw-Hill Construction, 2011



Materials

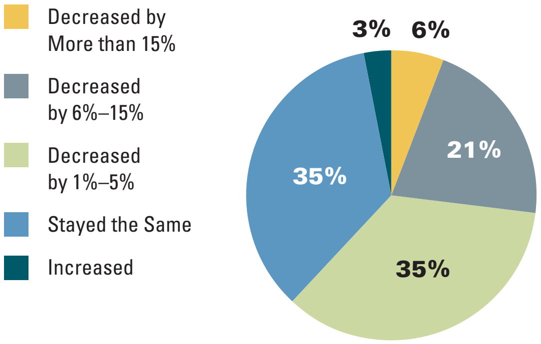
Not only does prefabrication help mitigate construction waste and lead to a greener construction site, it can also reduce material use, increase recycling and allow for greener material selection.

Materials Use

Currently, a majority (62%) of the industry recognizes that prefabrication/modularization can help decrease the use of construction materials, with over a quarter (27%) reporting decreases of 5% or more. The precise measurement possible in an offsite facility prevents wasted material, and the remnants of metals and other material can frequently be directly recycled back into the manufacturing process. However, more education is needed, given that over a third do not perceive a change in material use for prefabrication/modularization versus onsite construction.

Impact of Prefabrication/Modularization on Project Material Use

Source: McGraw-Hill Construction, 2011



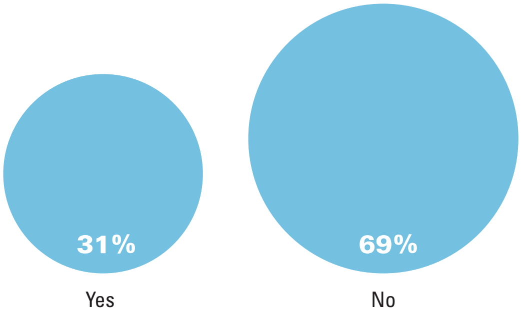
Greener Material Selection

Nearly a third (31%) of firms find that prefabrication/modularization also enables greener building material selection.

However, it is clear that more education is needed in making the connection between prefabrication/modularization and green from a materials perspective. Given the increase in green building activity, firms that understand this connection can gain a market advantage.

Percentage Finding that Prefabrication/Modularization Enables Greener Building Material Selection

Source: McGraw-Hill Construction, 2011



Data: Model-Driven (BIM)

Prefabrication

Usage

The use of Building Information Modeling (BIM) by industry professionals is on the rise, and this trend, in turn, is expected to drive high levels of use of model-driven prefabrication over the next two years.

Use of BIM

Nearly three-quarters of survey respondents (73%) indicated that they are using BIM on some projects, with nearly a third of BIM users (32%) indicating that they are using BIM on more than 50% of their projects.

Notably, prefabrication and modular construction users are significantly more likely to also be users of BIM. 78% of prefab/modular adopter respondents use BIM on some projects compared with only 48% of non-adopter respondents.

Use of Model-Driven Prefabrication

Model-driven prefabrication, where BIM models are provided to building product manufacturers to prefabricate building elements off-site, is projected to increase dramatically in the next two years.

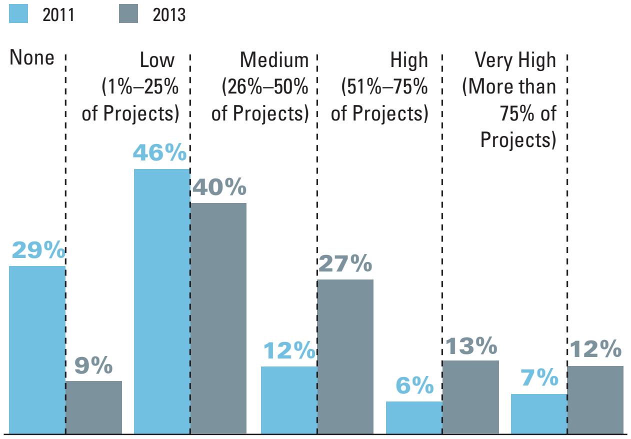
Currently, 71% of prefabrication and modular construction users are doing model-driven prefabrication on some projects. However, this activity is expected to grow to 91% by 2013—with a quarter of users (25%) doing model-driven prefabrication on more than 50% of their projects.

Contractors are doing the most model-driven prefabrication today (76%) with nearly all (95%) expected to be doing some model-driven prefabrication in 2013.

Use of Model–Driven (BIM) Prefabrication

(by Percentage of Respondents)

Source: McGraw-Hill Construction, 2011

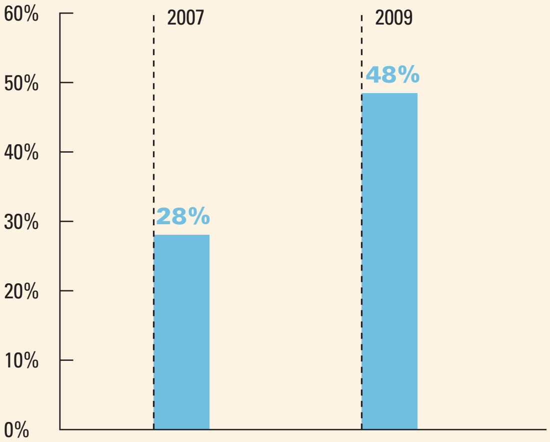


Sidebar:

McGraw-Hill Construction research conducted in 2009 (*The Business Value of BIM SmartMarket Report*) indicated that BIM use was growing rapidly with nearly half of survey respondents (48%) reporting use of BIM or BIM-related tools—a 75% increase in use compared with 2007 data. Further, in the 2009 study, one of the primary perceived future benefits, and driver of future BIM use, was the ability to do prefabrication on larger and more complex parts of projects.

Growth in BIM Use for Industry Players

Source: The Business Value of BIM SmartMarket Report, McGraw-Hill Construction, 2008



Drivers

Primary Reasons for Doing Model-Driven Prefabrication

Respondents report doing model-driven prefabrication for a number of nearly equally important reasons:

PRODUCTIVITY REASONS

- **17% of users indicated that saving money was the primary reason for doing model-driven prefabrication. This was a particularly important reason for contractors (22%).**
- **16% of users report that saving time was their primary motivation for implementing BIM-driven prefabrication. This was slightly more important for architects (18%).**
- **15% of users report that improving quality was their primary driver to using model-driven prefabrication. This was a particularly important reason for architects (23%).**
- **Somewhat surprisingly, making the construction site/process safer (2%) and greener (1%) were considered much less influential reasons for doing model-driven prefabrication.**

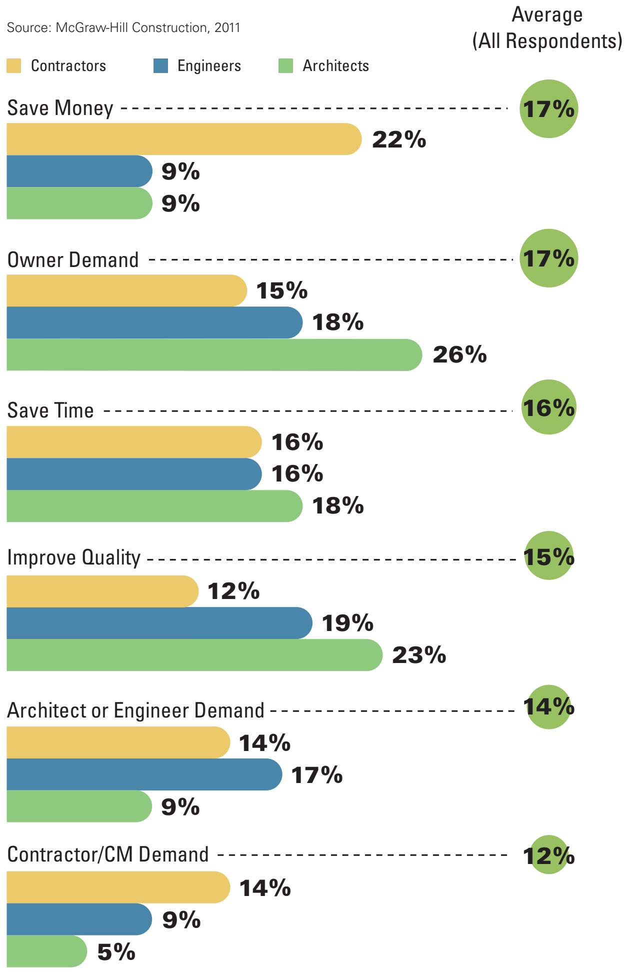
PLAYER DEMAND REASONS

- **Owner demand for model-driven prefabrication was a highly rated reason for doing model-driven prefab. 17% of users indicated this was their primary reason, and it was particularly high among architects (26%).**
- **The architect or engineer specifying model-driven prefabrication was the second highest player demand reason (14%) with slightly more engineers (17%) indicating this was their primary reason.**

Primary Reason for Using Model–Driven Prefabrication

(By Player)

Source: McGraw-Hill Construction, 2011



Drivers Behind Owner Adoption of Prefabrication and Modularization

Propelled by new advancements in technology and the offer of potential significant cost savings compared to stick build construction, prefabrication/modularization has reemerged as an important construction option for building and plant owners.

As the data in this report points out, the reduced cost of off-site labor combined with the increased productivity of the fabrication shop is translating into compressed schedules and cost reductions, which owners are starting to recognize.

In-Depth Interviews of Owners with Commercial and Institutional Buildings and Industrial and Energy Plants

In February 2011, McGraw-Hill Construction conducted in-depth interviews with 15 leaders in firms that own commercial and institutional buildings and energy and industrial plants. (See the Profile of Owners box on page 45 for more information.) The respondents overall have favorable views regarding the use of prefabrication/modularization and expect its use to increase in the future as a result of the benefits being observed.

The interviews reveal the owners' perceptions of the drivers and the benefits as well as the various challenges facing the use of prefabrication/modularization across the industry.

Use of Prefabrication and Modularization

Over 90% of the owners interviewed report having used prefabrication/modularization in their projects during the past two years. They report levels of use ranging from 5% to 80% in their project portfolios.

COMMERCIAL AND INSTITUTIONAL BUILDING OWNERS

Sectors of use:

- **Offices**
- **Hotels**
- **Schools and campus buildings**
- **Retail and entertainment**
- **Mixed-use/multifamily residential**
- **Commercial warehouses**

Most commercial and institutional building owners state that prefabrication/modularization lends itself well to building projects where stacking unit types and repetition is involved, which is where owners get the greatest benefits.

INDUSTRIAL AND ENERGY PLANT OWNERS

Sectors of use:

- **Power generation facilities (fossil-fuel thermal and nuclear power)**
- **Oil refineries**
- **Chemical plants**
- **Control buildings**

Industrial and energy plant owners indicate that prefabrication and modularization is used most commonly in the building of pipe racks, skid mounted units and combined cycle projects (gas turbine, front end, heat recovery steam generators).

Prefab/Modular in Action

Example: Schedule Reduction

A commercial building owner states: "When we used modularization on a recent building project, it took 18 months from inception to in-service. If it were conventional construction, it would have taken 24 or 25 months."

Example: Cost Reduction

One energy plant owner points out: "Once we were able to get the pipe rack modularized, delivered and [installed], we saved ourselves 25% on cost. And now we have a better quality pipe rack in place as a result."

Biggest Influence Factors on Decision to Use Prefabrication or Modularization

All of the owners expect to use prefabrication/modularization in their projects over the next two years at either current levels or increased levels of use.

The owners indicate that schedule and cost are the biggest drivers in their decision to use prefabrication/modularization, followed by safety. They see prefabrication/modularization positively affecting their projects in each of these areas.

SCHEDULE

All owners report reductions in their project schedules ranging from 10% to 30% as a result of using prefabrication/modularization.

CONTINUED

Overall, owners state that the on-site construction duration can be substantially shortened as a result of more work for a project being completed off-site. Prefabrication/modularization can to lead to a compressed schedule because off-site work contains fewer inherent risks such as conflicting crews, weather delays or interference with ongoing operations.

COST

Owners report project cost reductions ranging from 2% to 40% as a result of using prefabrication or modularization.

Several reasons for these reduced costs include:

- **Local labor for onsite work may be very expensive or inefficient.**
- **Unfavorable onsite conditions and weather problems may lead to costly delays.**

Several owners report that since some or all of the work is relocated to an off-site location, costs associated with onsite infrastructure and overhead can be reduced. Additionally, they mention that fewer workers onsite translate to fewer costs for accommodations, scheduling onsite work and other onsite logistics.

SAFETY

Almost all owners agree that overall project safety is improved through the use of prefabrication and modularization. The risk to owners from worker accidents and lost time is reduced when construction work is transferred away from the job site and into a controlled manufacturing environment.

Prefab/Modular in Action

Example: Structural Assembly
One owner mentions: "Structural steel assembly for a refinery that was once constructed a hundred feet in the air is now fabricated at ground level. The assembly will later be hoisted as a whole into place, requiring only a few connections."

Example: Reduced Scaffolding
A building owner states: "On our projects in New York City, reducing scaffolding is an important issue due to lack of space. Prefabrication/modularization helped us to reduce congestion and the cost of extra scaffolding permitting."

Types of safety addressed by prefabrication/modularization include less exposure to:

- **Weather**
- **Heights**
- **Hazardous operations**
- **Congested construction activities**

Advantages Offered by Prefabrication and Modularization

Overall feedback from owners on the advantages of prefabrication/modularization confirms the responses from the other industry players reported in the data sections. Most owners believe quality can be improved through off-site work as a result of controlled factory and production conditions and repetitive procedures handled by automated machinery.

LABOR

- **Skills**

Owners indicate that it is not uncommon to encounter a lack of available skilled labor onsite, which becomes exacerbated the more remote the location of the site. This is a key factor in the decision to use prefabrication/modularization and a primary advantage according to owners. Owners can shift work to an off-site location where the supply of skilled labor is better.

- **Costs**

Labor costs can also be a driver for prefabrication/modularization. Owners state that in areas where the local labor costs are very high, prefabrication/modularization offers a less costly alternative. Owners are able to shift some of the work to an off-site location and take advantage of cheaper labor costs.

QUALITY

Quality is cited by almost all owners as a significant advantage of prefabrication/modularization. Owners state that fabricating components away from the site allows higher quality due to the controlled environment provided by the manufacturing facilities.

OTHER ADVANTAGES MENTIONED

Less disruption of existing onsite operations was cited by several owners as an important advantage.

Several owners also emphasize the advantage of just-in-time delivery of building components. It allows for

CONTINUED

less site disruption and less degradation of materials being stored onsite waiting to be constructed.

Challenges of Using Prefabrication and Modularization

While the drivers and advantages mentioned above help make the case, the decision to implement is determined by the owners weighing the benefits against the challenges of using prefabrication/modularization. Primary challenges listed by owners are: early commitment to engineering and design work, increased transportation requirements and the limited number of providers.

EARLY COMMITMENT TO ENGINEERING AND DESIGN WORK

Owners indicate that with prefabrication/modularization, the engineering and design work have to be completed before onsite construction can begin, as opposed to conventional construction where only a portion has to be completed. Since this requires a well-defined scope early in the planning stage, some owners see this commitment as inflexible and a constraint on their delivery strategy.

INCREASED TRANSPORTATION LOGISTICS REQUIREMENTS

Owners cite the key role of transportation logistics in determining the feasibility of using prefabrication/modularization. Size and weight limitations, route restrictions, permitting requirements and the need for lifting equipment are factors that all need to be planned and coordinated before construction begins.

Owners emphasize the need to pay attention to transportation costs. Several owners cited cases where miscalculations were made up front which resulted in a substantially costlier project in the end.

LIMITED NUMBER OF PROVIDERS

The universe of providers of components via prefabrication/modularization is fairly small compared to the universe of providers of other kinds of components. This limited range of sourcing options is seen as a constraint and a risk factor.

Perceptions of the Role of Prefabrication and Modularization in Green Projects

At least half of the owners interviewed report having a green component to some or all of their projects, including both commercial and industrial projects. While a majority of owners believe that the use of prefabrication/modularization leads to less waste onsite and as a result less energy use, many do not yet see green as a primary reason for choosing it, and only two owners are currently pursuing LEED certification for their projects. For examples of how prefabrication/modularization can be effective on green projects, see page 39.

Feedback from owners illustrates that more awareness is needed on the environmental benefits of using prefabrication/modularization: namely, fewer onsite environmental impacts because of reductions in material waste, air and water pollution, dust and noise, and lower overall energy costs. ■

Profile Of Owners

Commercial and Institutional buildings (5 firms)

- Headquarters: AL, IN, NJ, NY
- Portfolios: Include Office, Education, Healthcare, Retail and Mixed-Use/Multifamily Residential

Industrial and Energy plants (10 firms)

- Headquarters: CT, MI, NC, NV, NY, TN, VA , (UK, Canada)
- Portfolios: Including Oil and Gas, Chemical and Power Generation (Thermal and Nuclear)

Prefab/Modular in Action

Example: Early Commitment
One plant owner states: “Dimensions are sometimes dictated by transportation. The size of a module may be constrained by the capacity of a truck. These engineering and transportation considerations need to be resolved up front.”

Example: Limited Providers
One owner reports: “If we were building onsite, we would get a thousand responses to our RFP. However, after putting in all the codes and deciding to use prefabrication, we were left with only a handful of options.”

Data: Contractors

Usage

The adoption of prefabrication and modular building processes is not a new activity for most contractors. 57% of contractors surveyed have been using these processes for five years or more.

Current and Future Usage

Given that prefabrication/modular construction has been around for many years, it is not unexpected that 84% of contractors today are using these processes on some projects. Further, by 2013, nearly all contractor respondents (98%) expect to be doing some prefabrication and modularization on a least some portion of their projects:

- **By 2013, 73% of all contractors expect to be using these processes at a medium to very high level (more than 25% of projects). Two-thirds of mechanical contractors (66%) expect they will be using these processes on over 50% of their projects by 2013.**
- **94% of large contracting firms (more than $100 million in annual revenue) have adopted these processes compared with only 76% of smaller firms (less than $25 million per year in revenue).**
- **Among contractors, design-builders (96%) are the highest adopters of prefabrication and modular processes, followed by construction managers (89%) and mechanical contractors (87%).**

Building Sectors

Contractors are using prefabrication and modular building processes on a wide variety of commercial building projects. In particular, contractors today are using it on healthcare facilities (61%), university buildings and dormitories (50%) and public buildings (46%).

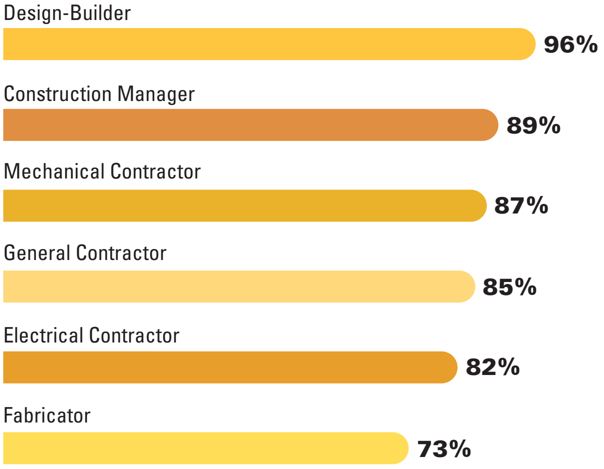
- **Over 50% of mechanical contractors are using prefabrication on high- and low-rise offices and manufacturing buildings.**
- **Contractors see the most future opportunity in healthcare facilities (19%), hotels and motels (13%), high rise offices (10%), commercial warehouses (9%) and other building types (7%) including data centers, prisons, power plants and oil refineries.**

Building Elements

As part of commercial building projects, contractors most regularly use prefabricated/modular MEP systems (62%), exterior walls (39%) and interior rooms (31%).

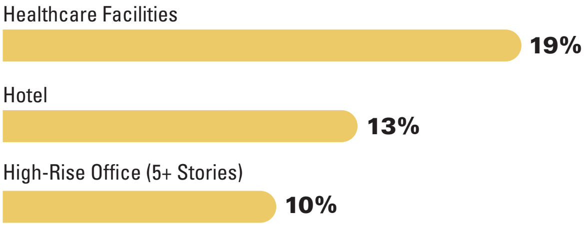
Current Use of Prefabrication/ Modularization by Contractor Type

Source: McGraw-Hill Construction, 2011



Top Building Sectors for Prefabrication/ Modularization Opportunity (Contractors)

Source: McGraw-Hill Construction, 2011



- **Apart from expected occupational preferences (e.g., MEP systems for mechanical and electrical contractors), design builders (38%), fabricators (30%) and general contractors most often use prefabrication (24%) on the building superstructure.**

Reasons for Not Using

The primary reasons contractors do not use prefabrication and modularization on projects is that the architect did not design it into the project (48%), followed by the recognition that the process was not applicable for the project (33%).

- **Construction managers (49%) and general contractors (30%) also rated the lack of a local prefabrication shop as a key reason for non-usage.**

Productivity

More than any other player group, contractors (92%) believe that prefabrication/modular construction processes can improve productivity.

Project Schedule

72% of contractors surveyed believe that use of prefabrication and modularization decreases project schedules by more than a week, with over one third (37%) believing that usage can decrease schedules by more than four weeks.

- **All contractor types agree on the positive impact that prefabrication/modularization is having on project schedules, ranging from 65% of electrical contractors to 79% of mechanical contractors.**
- **43% of construction managers believe that these processes can decrease project schedules by four weeks or more.**

Project Budget

Nearly three-quarters (74%) of contractors surveyed believe that prefabrication/modularization can help decrease project budgets, and nearly a quarter (23%) believe it can decrease project budgets by 11% or more.

- **Mechanical (85%) and electrical (81%) contractors are particularly convinced that it can reduce project budgets.**
- **Design-builders are the most optimistic about prefabrication's potential, with 18% believing that it can reduce project budgets by 20% or more.**

Site Safety

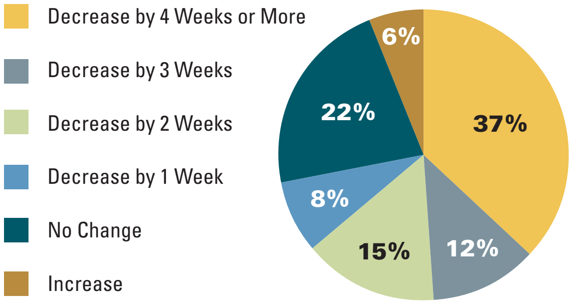
Contractors have very mixed views on the impact of prefabrication/modularization onsite safety. More than any other player, 37% believe that these processes improve site safety. However, more contractors (12%) than other players believe that it reduces site safety. Possibly this is due to the size of components and the need to have more cranes or other heavy equipment onsite to place these components. A majority of contractors believe that site safety stays about the same.

- **Mechanical contractors (46%) and fabricators (42%) believe that these processes improve site safety.**
- **Interestingly, a large percentage of fabricators (26%) believe that these processes decrease site safety, followed by design-builders (18%).**

Decrease in Project Schedule Due to Prefabrication/Modularization

(According to Contractors)

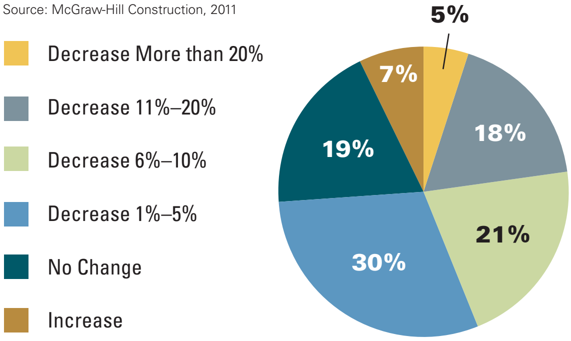
Source: McGraw-Hill Construction, 2011



Decrease in Project Budget Due to Prefabrication/Modularization

(According to Contractors)

Source: McGraw-Hill Construction, 2011



Purchase Price and Installation of Materials

Nearly half of contractors (47%) believe that the purchase and installation costs for prefabricated materials are lower than for regular building products. Over 10% of contractors believe that such costs are lower by 10% or more.

- **More than half of construction managers (53%) believe that purchase and installation costs are lower.**
- **Over a quarter of electrical contractors (28%) and design-builders (27%) believe that purchase and installation costs are higher.**

Drivers

Current Drivers

Contractors, like other industry players, are using prefabrication and modularization today because of the perceived productivity improvements (92%) and the belief that it gives them a competitive advantage (85%).

- **Nearly all mechanical contractors (98%) and electrical contractors (97%) see productivity improvements as the primary driver.**

Future Drivers

Contractors believe that by 2013 the primary drivers to future prefabrication/modular use will be their ability to employ these processes to decrease construction costs (85%) and produce improvements in project schedules (84%).

- **More than other contractors, construction managers (84%) and mechanical contractors (83%) believe that measurable improvements in project quality will be a key driver to future use.**

Model-Driven Prefabrication

Over three-quarters of contractor prefabrication and modularization users (76%) are also doing model-driven prefabrication. Most (50%) are doing it on only a low percentage of their projects. However, over half of contractors (55%) believe they will be doing it on more than 25% of their projects in 2013.

- **The primary reason why contractors are doing model-driven prefabrication is to save money (22%).**

Green and Sustainability

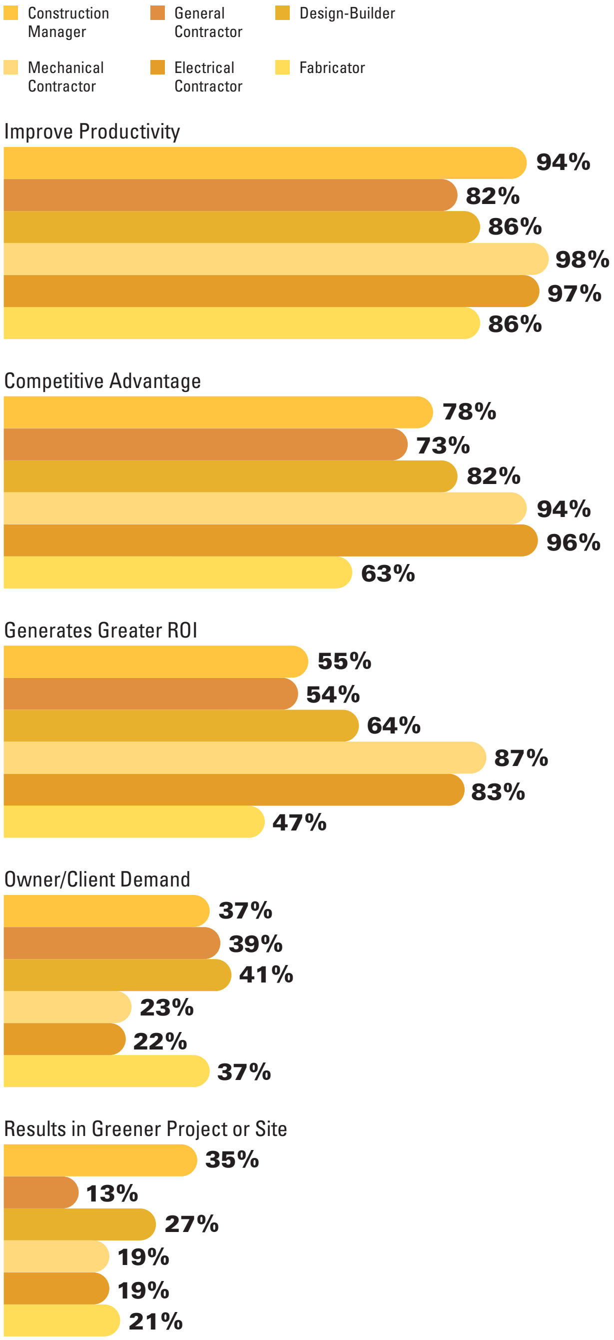
Results show that contractors are not particularly aware of the overall green benefits of prefabrication. Less than a quarter (22%) view green as a key driver to prefabrication and modularization usage. However, when specific green aspects are considered, a somewhat different picture on green benefits emerges.

- **Reducing Onsite Waste: 83% of contractors believe that prefabrication reduces onsite waste. Nearly 40% believe it reduces onsite waste by 5% or more. Less than 1% believes that it increases onsite waste.**
- **Project Materials: Two-thirds of contractors (66%) also believe that prefabrication/modularization reduces the amount of material used on a project—over a quarter (29%) believes it reduces material use by 5% or more.**

Current Drivers to Use of Prefabrication/Modularization

(By Contractor Type)

Source: McGraw-Hill Construction, 2011



Data: Architects and Engineers

Usage

Like contractors, architects and engineers are familiar with prefabrication and modular building processes. 64% of architects and 77% of engineers surveyed have been using prefabrication and modularization on some projects for five years or more.

Current and Future Usage

The long-term familiarity of architects and engineers with prefabrication and modularization translates into high current usage. 90% of engineers and 76% of architects are using these processes on some projects today. Further, nearly all architects (98%) and engineers (99%) expect to be doing some prefabrication and modularization on at least some portion of their projects by 2013.

- **By 2013, 38% of architects and 43% of engineers that use prefabrication and modularization today expect to be using it on more than 50% of their projects.**
- **97% of large engineering and 84% of large architectural firms (more than $10 million in annual revenue) have adopted these processes, compared with only 76% of smaller engineering and 70% of smaller architectural firms (less than $500,000 per year in revenue).**

Reasons for Not Using

The primary reason that architects do not use prefabrication/modularization on a project today is because the owner does not want it (39%). The primary reason engineers are not using it on specific projects is because the architect didn't design it into the project (44%). Thus, there is a need for the industry to better educate owners on the benefits of prefabrication/modularization so that architects will include it when designing projects.

Building Sectors and Elements

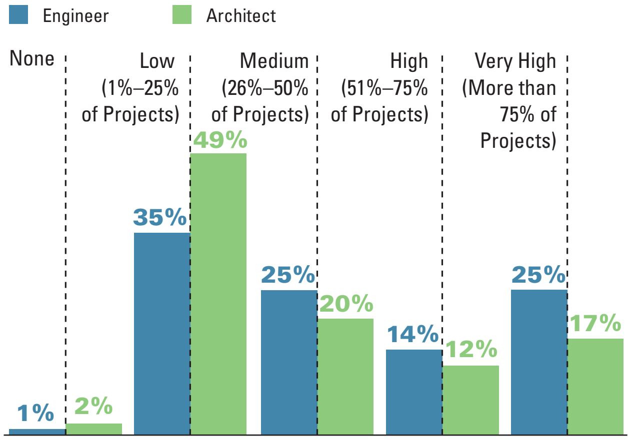
Today, both architects and engineers are using prefabrication/modularization on a wide variety of commercial building projects. Architects are currently using it most frequently on low-rise office buildings (43%) and healthcare facilities (36%). Engineers use it most frequently on manufacturing buildings (46%) and warehouses (43%).

In terms of future sectors of opportunities, architects and engineers report the following:

- **Architects see equal future opportunity in hotels (14%), K–12 schools (14%) and multifamily housing (14%).**
- **Engineers see the most future opportunity in commercial warehouses (17%), and manufacturing buildings (15%).**

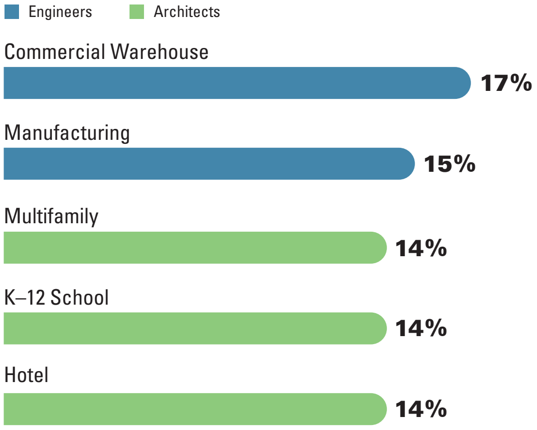
Percentage of Future (2013) Prefabrication/ Modularization Use (for Engineers and Architects)

Source: McGraw-Hill Construction, 2011



Top Building Sectors for Prefabrication/ Modularization Opportunity
(According to Engineers and Architects)

Source: McGraw-Hill Construction, 2011



- **As part of commercial building projects, over two-thirds of architects (68%) and engineers (71%) are most likely to utilize prefabrication/modularization in the building superstructure. Over half of architects and engineers surveyed also use it in exterior walls and for roof construction.**

Drivers and Productivity

Current and Future Drivers

Just like contractors, architects and engineers see the primary drivers for using prefabrication/modularization today to be productivity improvements and competitive advantage.

- **68% of architects and 70% of engineers are primarily driven by productivity improvements.**
- **60% of engineers and 52% of architects believe that these processes give them a competitive advantage.**

Architects and engineers are also closely aligned with contractors in the belief that the primary drivers to future usage will be the improvements that prefabrication and modularization can provide to project schedule, cost and quality.

- **90% of architects and 79% of engineers believe that in the future these processes will result in measurable improvements in project schedule.**
- **Over 80% of both architects (83%) and engineers (82%) believe these processes will reduce future construction costs.**
- **70% of architects and 66% of engineers believe that prefabrication and modularization will result in measurably higher quality on future projects.**

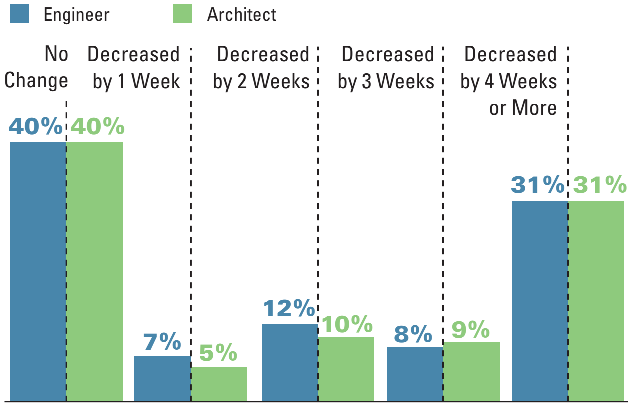
Productivity

As noted above, both architects and engineers see productivity improvements as being the primary driver of current prefabrication/modularization usage and elements of productivity, including improving schedules and decreasing costs, as being primary drivers to future usage.

- **Project Schedule—Both architects and engineers see prefabrication/modularization as having a positive impact on projects schedules, but less so than contractors.**
  - 60% of both architects and engineers believe that the use of these processes reduces project schedules by one week or more, versus 72% of contractors.
  - 31% of both architects and engineers believe that it reduces project schedules by four weeks or more.
- **Project Budget—42% of architects and 52% of engineers believe that prefabrication/modularization has a positive impact on project budgets. This can be compared to 74% of contractors.**

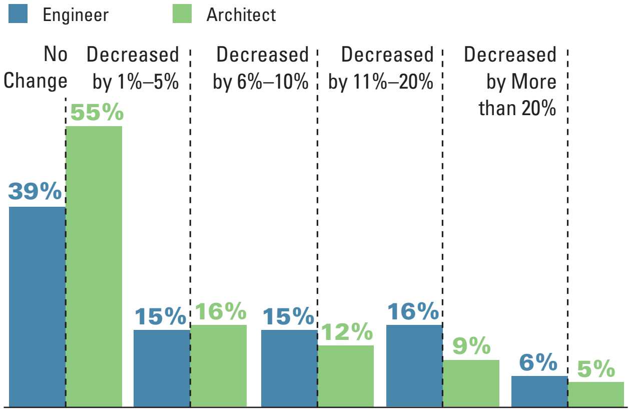
Level of Decrease in Project Schedule Due to Prefabrication/Modularization
(According to Engineers and Architects)

Source: McGraw-Hill Construction, 2011



Level of Decrease in Project Budget Due to Prefabrication/Modularization
(According to Engineers and Architects)

Source: McGraw-Hill Construction, 2011



- Most architects (55%) believe that prefabrication/modularization is budget neutral, while 26% see it reducing project budgets by 6% or more.
- 39% of engineers believe that project budgets are unaffected by use of prefabrication/modularization, while 37% see it reducing project budgets by 6% or more.

- **Site Safety—Most architects (77%) and engineers (62%) believe that site safety stays about the same. Very few architects (3%) and engineers (6%) believe that prefabrication/modularization reduces site safety.**

Glossary:

Definition of Terms Used

Building Information Model (BIM):
A BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility and forms a reliable basis for decisions during its lifecycle from inception onward. BIM also refers broadly to the creation and use of digital models and related collaborative processes between companies to leverage the value of the models.

Building Superstructure:
All parts of the building above the foundation, including the building frame, roof and exterior walls.

Green Building:
A building constructed to LEED or other green building standards, or one that involves numerous green building strategies across several categories, including energy, water and resource efficiency and improved indoor air quality. Projects that only involve a few green building products are not included in this definition.

Integrated Design Process:
Active participation in all stages of design for all disciplines involved in the design, construction and, at times, the operation of the building. An integrated design team usually includes an owner's representative; architect; mechanical, electrical and structural engineer; and construction manager and/or general contractor. It can also include future building occupants, facility managers and maintenance staff, subcontractors and building product manufacturers.

Integrated Project Delivery:
The delivery of a construction project according to a contract that calls for an integrated design process and that clarifies the legal responsibilities and risks born by all members of the project team.

Lean Construction:
The Associated General Contractors of America (AGC) defines lean construction as a set of ideas based in the holistic pursuit of continuous improvements aimed at minimizing costs and maximizing value to clients in all dimensions of the built and natural environment: planning, design, construction, activation, operations, maintenance, salvaging and recycling.

Modularization/Modular Construction:
The manufacture and remote assembly of major interior or exterior sections of a building (e.g., wall, floor, roof) of one or multiple material types which may include portions of a system (e.g., electrical, plumbing). Examples include curtain wall, structural insulated panels and entire building modules.

Off-Site Fabrication:
The fabrication or assembly of components (no manufacturing processes) off-site or on the construction site but at a location other than the point of installation. The process is usually completed by specialty contractors (e.g., finish carpentry).

Permanent Modular Construction (PMC):
A design and construction process performed in a manufacturing facility, which produces building components or modules that are constructed to be transported to a permanent building site.

Prefabrication:
Manufacturing processes generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation. Examples include trusses, joists, structural steel and precast concrete. Model-driven prefabrication describes the use of the BIM model to enable prefabrication and assembly of building components both off and on the construction site.

Productivity:
Productivity is the ratio of output to all or some of the resources used to produce that output. Resources can include labor, capital, energy, raw materials, etc.

Project Budget:
The project owner or client will generally determine the construction project budget. It is the task of the project team to deliver a finished project to the owner maximizing project value within the budget.

Project Schedule:
The time for the events related to the project planning and construction. A construction schedule may also address the resources required to accomplish the tasks as well as the dependencies of the tasks to one another.

Methodology:

Methodology

McGraw-Hill Construction conducted the 2011 Prefabrication and Modularization Study to assess the level and scope of use of prefabrication and modularization construction processes and analyze how these processes can impact perceived productivity both now and in 2013.

The research in this report was conducted in two ways. The primary method was through an Internet survey of industry professionals between January 20 and February 22, 2011. This survey had 809 complete responses. The "total" category displayed throughout the report includes 101 architects (13%), 190 engineers (23%), and 518 contractors (64%). In addition, MHC conducted fifteen in-depth-interviews (IDIs) of owners between February 18 and March 7, 2011, to collect detailed information on their perceptions and use of prefabrication and modularization and perceived impact on productivity on their construction projects.

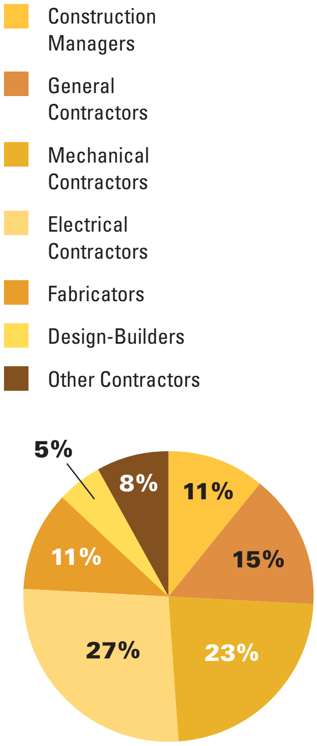
The use of a sample to represent a true population is based on the firm foundation of statistics. The sampling size and technique used in the Internet study conform to accepted industry research standards expected to produce results with a high degree of confidence and low margin of error.

The total sample size (809) used in this survey benchmarks at a 95% confidence interval with a margin of error of less than 5%.

For the architects and engineers, the confidence interval is 95%, with a margin of error of less than 10%; and for the contractors category the confidence interval is 95%, with a margin of error of less than 5%. In addition, for the Contractors Perceptions section, all contractor categories, including general contractor (79), construction manager (55), mechanical contractor (119), electrical contractor (141), fabricator (59) and design-builder/other (65), benchmark at 90% confidence interval with margins of error of less than 12%.

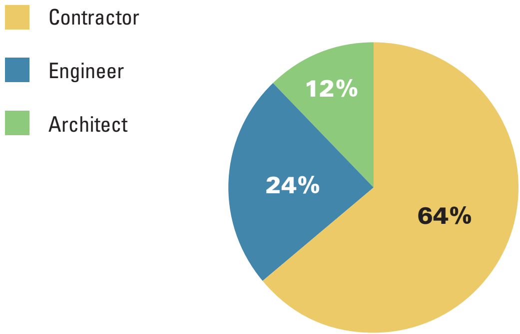
Contractor Respondents

Source: McGraw-Hill Construction, 2011



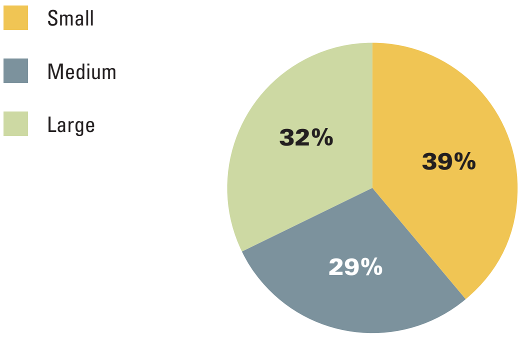
Respondents by Firm Type

Source: McGraw-Hill Construction, 2011



Respondents by Firm Type

Source: McGraw-Hill Construction, 2011



Resources

Organizations, websites and publications that can help you get smarter about prefabrication and modular construction.

McGraw_Hill
CONSTRUCTION

McGraw Hill Construction
Main Website: **construction.com**
GreenSource: **greensourcemag.com**
Research & Analytics:
construction.com/market_research
Achitectural Record: **archrecord.com**
Engineering News-Record: **enr.com**
Sweets: **sweets.com**
Green Reports:
greensource.construction.com/resources/SmartMarket.asp

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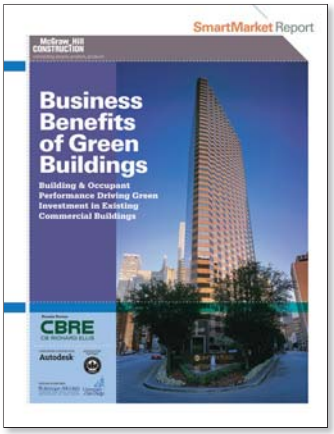
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ISBN: 978-1-934926-35-2

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AGC of America THE ASSOCIATED GENERAL CONTRACTORS OF AMERICA Quality People. Quality Projects.
AIA
AISC
ASCE American Society of Civil Engineers
CURT THE CONSTRUCTION USERS ROUNDTABLE
DBIA
ICC INTERNATIONAL CODE COUNCIL
Mechanical Contractors Association MCAA of America
NECA NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION
NSCA BUILDING CONNECTIONS
SMACNA
SMPS Society for Marketing Professional Services

Exhibit C:

Modular Building Institute – Permanent Education Structure Award Winners 2015 – 2019

Exhibit C-1

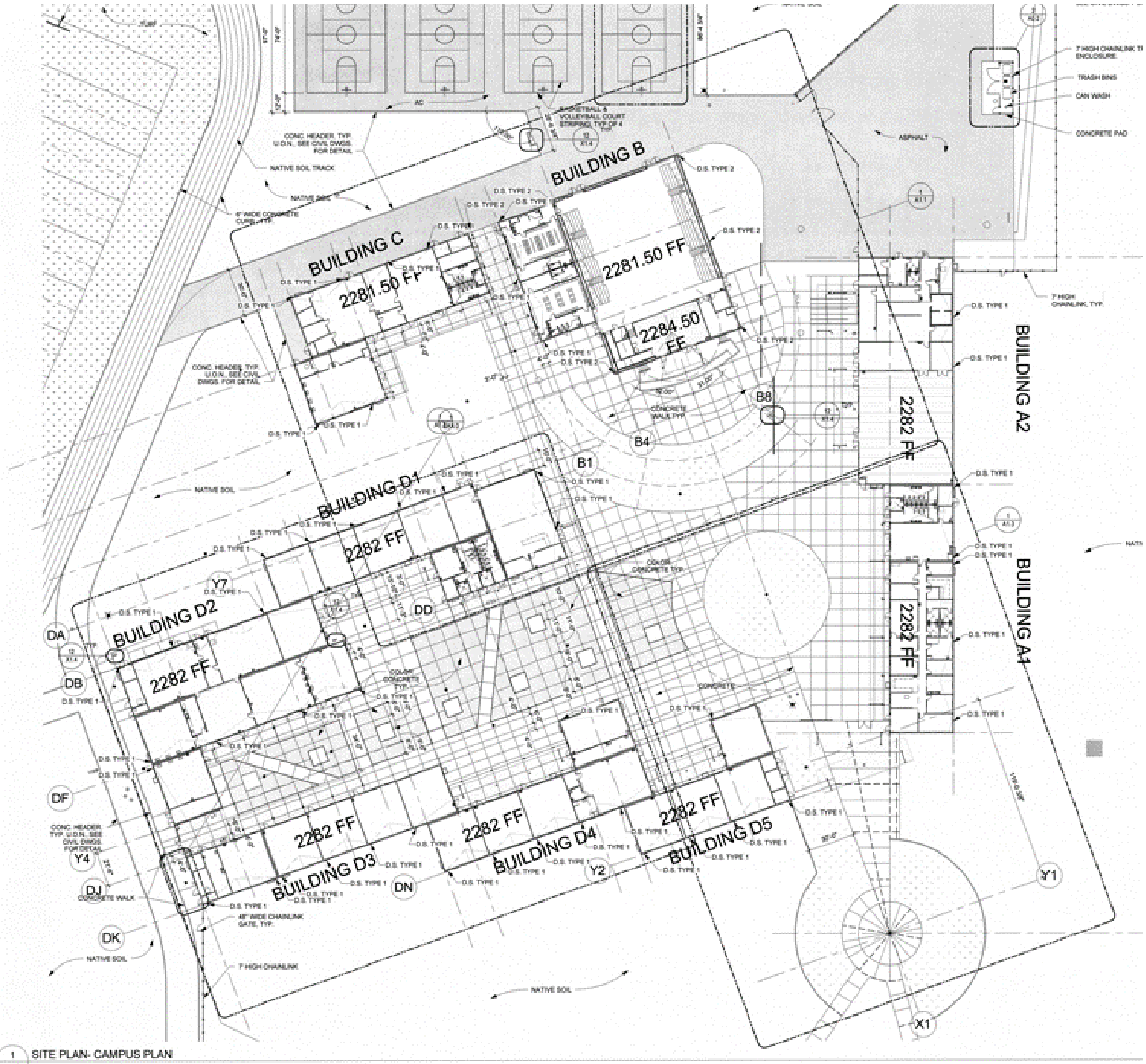
2019 First Place

Murray Middle School

- Main Category: Modular Building Design
- Company: Meehleis Modular Building Inc
- Location: Ridgecrest, California
- Building Use: Middle School
- Gross Size of Project: 68,243 Square Feet
- Days to complete: 319

Exterior Image

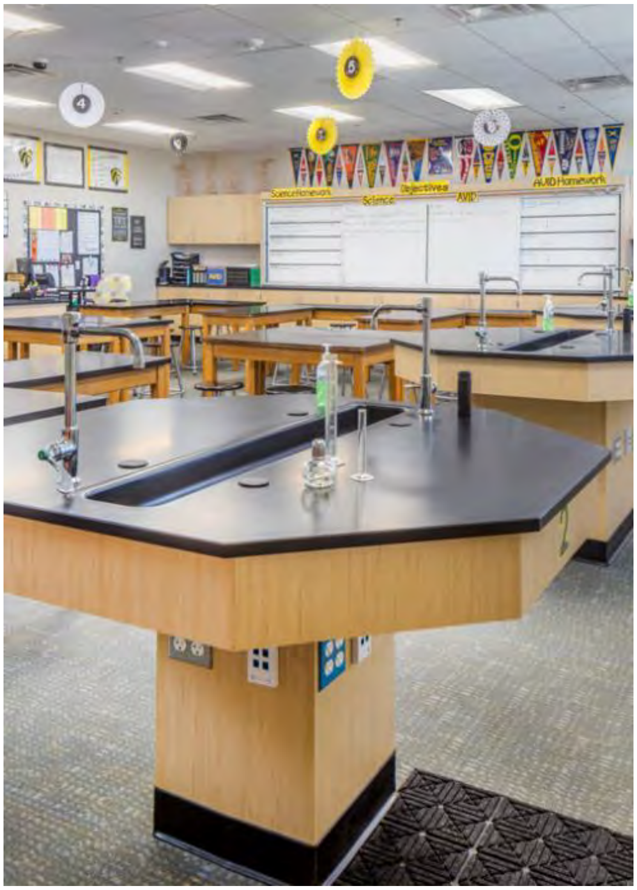
<u>Floor Plan Image</u>



1 A1.0 SITE PLAN- CAMPUS PLAN
Scale: 1/32" = 1'-0"

Horizontal Interior Image

Vertical Interior Image



Award Criteria

Architectural Excellence

A joint project between Sierra Sands School District, the Department of Defense and the Navy, Murray Middle School is a complete campus that includes standard classrooms as well as science classrooms, a media center, gymnasium, cafeteria plus kitchen, and administration facilities. With the site so close the Naval Weapons Station China Lake the campus also needed to meet Anti-Terrorism Force Protection (ATFP) standards. Designed with protection in mind the campus layout, while doubling as environmental protection, provides a defensible space and the simple exterior features reduce damage from potential threats. The site was planned to provide not only protection for students but protection from the harsh climate Ridgecrest and neighboring Death Valley are known for. The horseshoe layout of the campus shields the students from the winds which can be high during certain parts of the year and ample shade structures were employed to combat the heat which can reach over 115 degrees.

Technical Innovation & Sustainability

A groundbreaking achievement, the campus at Murray Middle pushes what modular construction can do. Meehleis Modular partnered with Protective Technologies and EXL Structural Engineers to design a structure that meets Division of State Architects (DSA) requirements but also the Department of Defense's ATFP (UFC 4-010-01) blast requirements. The result is one of the first blast resistant modular campuses in California. Roof overhangs were omitted to reduce blast forces on the buildings and specialty doors and windows were implemented to provide the upmost security. Murray Middle School’s site was also carefully selected to provide the greatest distance from nearby structures allowing for a large "defensible space" around the campus required in blast protection. Additionally, special care was taken to choose materials that will not only look good but will provide longevity in the harsh climate of the high desert.

Cost Effectiveness

Originally designed to be a site-built conventional project, Murray Middle School came in astronomically over budget resulting in a reassessment and redesign. Meehleis Modular stepped forward to undertake this immense challenge and after a short period of time was able to significantly reduce costs and bring the budget back under control. By fabricating large portions of the project in our Lodi facility we can nearly eliminate material waste, and increase quality control directly resulting in cost savings. The remote location of this campus also influenced the original pricing, our off-site construction methods enabled us to limit travel time and work in tough field conditions resulting in the drastically reduced budget versus site built.

Exhibit C-2

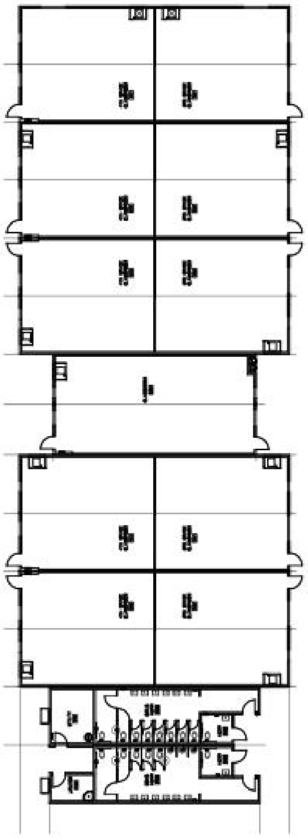
2019 Second Place

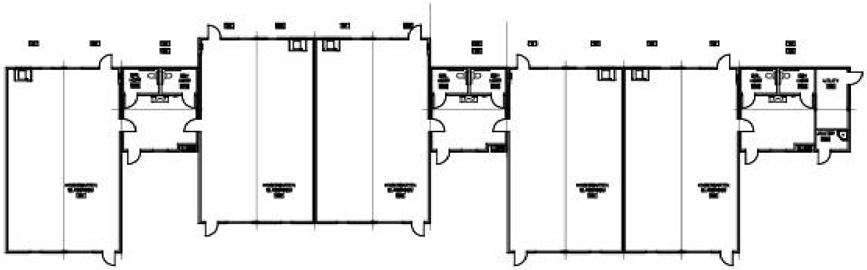
Wonderful College Prep Academy

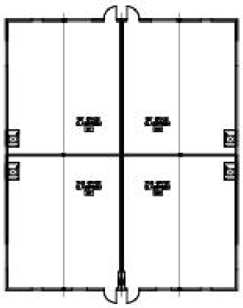
- Main Category: Modular Building Design
- Company: Blazer Industries, Inc.
- Affiliate: Design Space Modular Buildings
- Location: Delano, CA
- Building Use: Kindergarten and Elementary School
- Gross Size of Project: 29,079 Square Feet
- Days to complete: 43

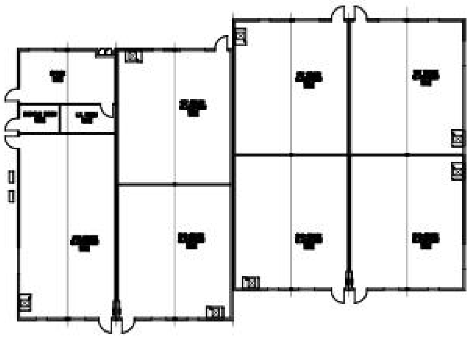
Exterior Image

Floor Plan Image









Horizontal Interior Image

Additional Exterior Image

Award Criteria

Architectural Excellence

This educational complex was designed to integrate the new kindergarten through fourth grade classrooms into a larger existing campus. Design features including low slope roofs, offset modules, varying color schemes, window pop-outs, and siding treatments all were used to lend interest and identity to the buildings. Four buildings consisting of forty-two modules ranging in size from 14’x18’ to 14’x64’ were assembled in groups of four, eight, fourteen, and sixteen modules to result in buildings of 3,507, 7,013, 7,266, and 11,293 square feet respectively.

Technical Innovation & Sustainability

We had a very tight construction schedule to allow for occupancy prior to the August start of the school year. This gave us approximately 6 months from initial notice of the bid to when the modules needed to be on site. There were several materials and/or items selected for increased sustainability reasons including Armstrong Dune Second Look ceiling tile, Dunn Edwards ultra-low VOC paint, drinking fountains with bottle fillers, tankless water heaters and an LED lighting system. The placement of the overhangs, the window pop-outs and the orientation of the modules all played a part in reducing the uninvited heat gain from direct sunlight into the classrooms.

Cost Effectiveness

The client was able to obtain the price they desired for the project due to the fact that they began the process prior to the beginning of the calendar year which allowed for materials to be ordered prior to annual price increases. Despite some of the high-end materials selected, the design we were able to produce allowed for savings in other areas including transportation and site work costs. The project went together easily on site, and fulfilled the required time line and budget for the project.

Exhibit C-3

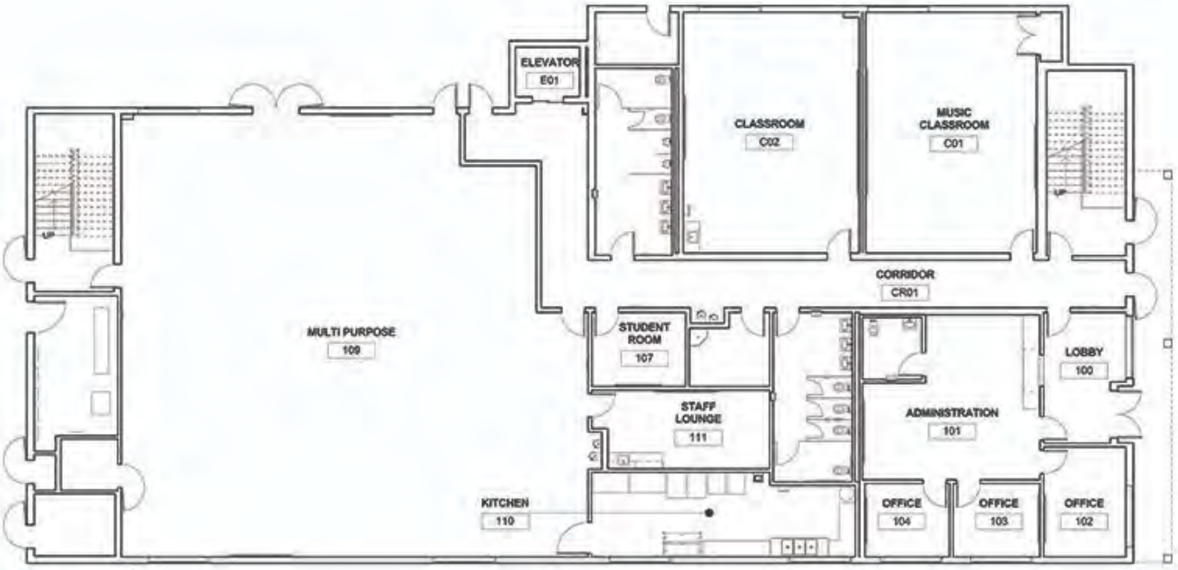
2018 First Place

KIPP LA

- Main Category: Modular Building Design
- Company: Silver Creek Industries
- Location: Los Angeles, California
- Building Use: Charter Middle School
- Gross Size of Project: 27,429 Square Feet
- Days to complete: 241

Exterior Image

Floor Plan Image



Horizontal Interior Image

Vertical Interior Image

Award Criteria

Architectural Excellence

Due to the design-build project delivery approach utilized on this project Silver Creek was able to collaborate directly with the client on design considerations during the conceptual phase of the project to ensure modular construction systems selected would support the design intent. The project consists of a three story structure which houses an entire charter school campus and the related functional spaces. The building contains 18 classrooms, a kitchen, multipurpose space, administrative spaces, interior corridors, an interior elevator, and interior stairs. The building exterior features plaster with a bright color palette and aluminum glazing systems. The finished building reflects the coordinated efforts of all team members to provide a design focused experience.

Technical Innovation & Sustainability

The program developed with the client required the building to utilize a central corridor system with interior stairs and elevator. The client also required 9’-6” high ceilings in most spaces and an open ceiling in the multipurpose spaces. Additionally, the site constraints required offsets at the rear of the building and cantilevered modules on the 2nd and 3rd levels. To meet these requirements Silver Creek developed a series of specialized building frames which utilized a mixture of module sizes (with widths up to 12’-10” and lengths up to 71’-0”) and 13’ floor to floor heights. The delivery of the modules to the project site required the preparation of specialized shipping systems in order to accommodate the size and weight of the modules. Special planning was used to organize the interior spaces in a manner which minimized the amount of “close-up” work that would be done on site at the module joint locations.

Cost Effectiveness

Due to the complexity and scope of the project, the ability to perform the work in a factory environment provided the opportunity for significant cost reductions and increased quality control measures. Larger than typical modules were utilized to maximize the factory scope of work. The careful placement of the restrooms allowed those spaces to be enclosed on all sides within a single module and to leave the factory fully finished. Spaces that could not be enclosed due to size or location were partially finished in the factory and wherever possible the remaining finishes were pre-cut in order minimize the duration of work on site. The electrical distribution system was designed to utilize larger conductors and conduits to reduce the number of electrical connections made in the field. Where possible the ductwork was designed to be installed within a single module which eliminated the need for horizontal connections in the field.

Exhibit C-4

2018 Second Place

Arkansas Lane Campus Expansion

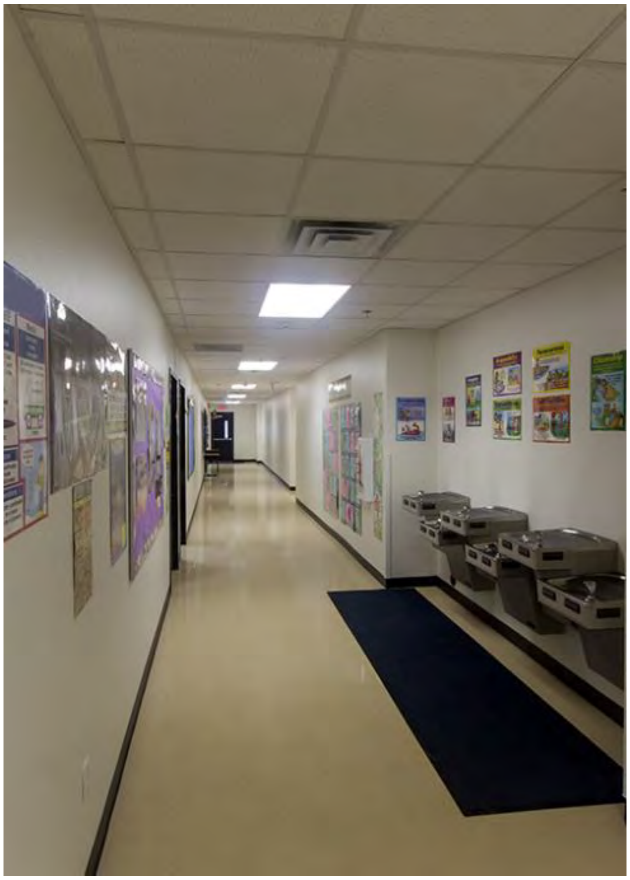
- Main Category: Modular Building Design
- Company: Ramtech Building Systems, Inc.
- Location: Arlington, TX
- Building Use: New Campus Building for Grades 3-5
- Gross Size of Project: 37,329 Square Feet
- Days to complete: 235

Exterior Image

Floor Plan Image

Horizontal Interior Image

Vertical Interior Image



Award Criteria

Architectural Excellence

This project provides space for 24 standard classrooms to accommodate up to 528 additional students. The building has five special use classrooms for the school's art, music, speech, and special education programs. It also includes a cafeteria with a warming kitchen, administrative offices, a library, tutoring center and learning lab, and a 3,000 square foot multipurpose exercise room with athletic flooring and a 14 foot ceiling height. We incorporated a mix of masonry and EFIS that complimented the existing structures and provided a cohesive appearance to the campus. The elevations also had to comply with city ordinances for architectural requirements that called for specific ratios in the placement of vertical and horizontal articulations all while being within the constraints of the project budget. Interior finish selections were largely driven by the educational use and included painted gypsum, resilient and ceramic tile as well as an acoustical drop ceiling.

Technical Innovation & Sustainability

Using Ramtech's Slab-On-Grade PMC System, the floorless building sections were crane-set directly onto a five inch 4,000 psi reinforced concrete slab foundation with 18' deep drilled belled piers. The slab was cast with weld-plate embeds at all steel column points, allowing the structure to be welded to the finished slab. The slab's design and necessary soils remediation was dictated by a geo-tech's report. Steel clear-span trusses are used throughout the building allowing for unlimited future configurations of the space. All interior partitions are full height to the roof deck aiding sound attenuation. In the multipurpose exercise area, the roof modules were constructed atop a clearstory knee wall that was supported by the adjacent modules allowing a 14' clear ceiling height. Use of recycled materials was incorporated throughout the structure. All materials were manufactured within 500 miles of the project site.

Cost Effectiveness

Ramtech developed our Slab-on-Grade PMC System as an efficient means to provide concrete floors while deal with the highly expansive soils found throughout Texas. Conventional pier and beam PMC installations require a grade-beam or stem-wall foundation supported typically by under-reamed drilled piers. Then a conventional block pier supports a steel modular floor system with a corrugated steel deck and three inches of poured light-weight concrete. This redundancy of structures (expense of foundation and a modular floor system) adds considerable cost to the project. By utilizing a poured-in-place conventional concrete slab as prescribed by the geotechnical engineer, then placing a floorless module directly atop the slab, three things are achieved at a lesser cost: Better floor acoustics due to more mass (quiet floors); A grade level entry is provided at all exterior doors; There is no crawlspace to ventilate, greatly reducing the possibility of poor indoor air quality.

Exhibit C-5

2017 First Place

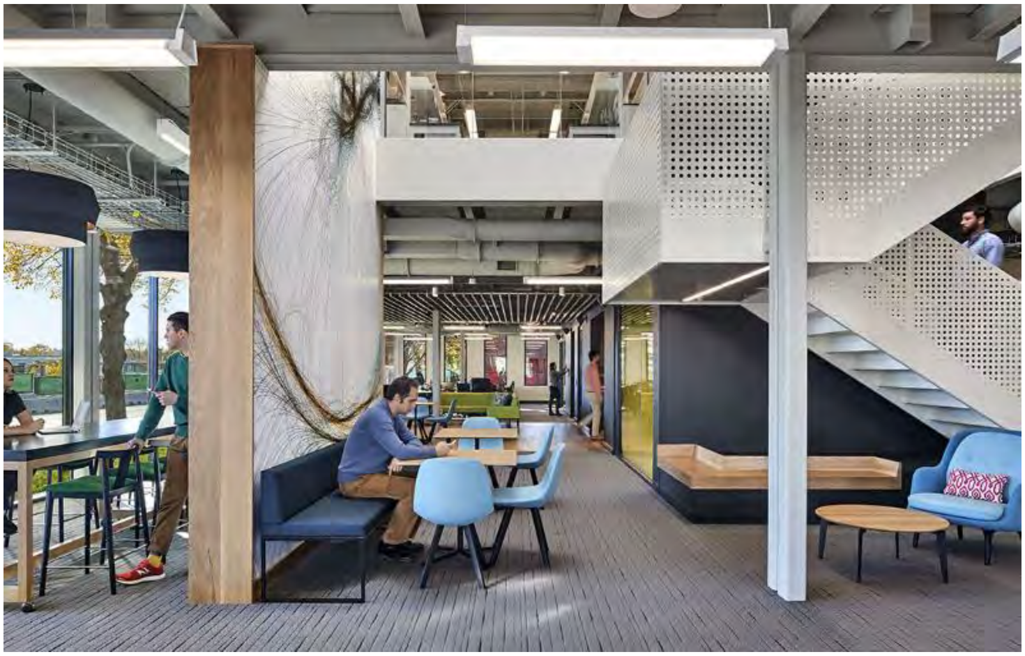
Pagliuca Harvard Life Lab

- Main Category: Modular Building Design
- Company: NRB, Inc.
- Affiliate: Triumph Modular
- Location: Allston, MA
- Building Use: Life Sciences Wet Laboratory
- Gross Size of Project: 15,000 Square Feet
- Days to complete: 205

Exterior Image

Floor Plan Image

Horizontal Interior Image



Vertical Interior Image

Award Criteria

Architectural Excellence

The Harvard University Pagliuca Life Lab, designed by Shepley Bulfinch, is a state-of-the art facility offering students, faculty and alumni the vital resources needed for life science related ventures. The upper level wet lab areas have 30 lab benches, tissue culture rooms, freezer, fume hoods and cold room. Below, the beautifully appointed space is a flexible open concept, designed to nurture teamwork, including write-up lab areas, lounge spaces, meeting rooms, a walk-through kitchen and even a 21st century version of a "phone booth" for quiet conversations. The extensive use of glazed partition walls on both floors, with the large ornamental staircase space and two story mural further fosters team connectivity both physically and visually. Inside, the walls are stunningly bold, floors are laminate, tile and carpet and ceilings are a wood slat system or exposed cable trays, ductwork and pipe. Outside is a combination of architectural aluminum panels and unique cement board siding.

Technical Innovation & Sustainability

The steel building is non-combustible construction with pre-poured concrete floors. Achieving the remarkable design characteristics and configuration for this two-story building presented some challenges. The upper wet lab area with its heavy equipment cantilever approx. 12' over the fully glazed entrance below to provide a covered, lighted patio area. This, along with the floor to ceiling windows wrapping around the corner of the building required some careful consideration for structural design and module layout. All interior floor to ceiling glass partitions on the upper and lower floors were preinstalled at the plant prior to shipping and due to the structural design, could travel without movement. The building was constructed inside the plant in a static form with the modules joined together vertically and horizontally to allow NRB to pre-install and pre-test systems and to ensure precision fit and finish to minimize the on-site time for final installation by the Contractor.

Cost Effectiveness

The building envelope design features continuous insulation on the roof and walls and the crawlspace below is conditioned. Windows that provide the desired daylighting and views, were insulated glass in thermally broken aluminum frames and feature a Solar ban coating. Interior light fixtures were LED type for reduced energy consumption. One of the most critical factors on this project however, was to have the Life Lab built in less time as the life science venture teams were already lining up to prequalify, and those selected would be ready to take their seats at the lab benches as soon as it was up and running. From start to finish, the Life Lab was ready to go in just 7 months, much less time than if it had been conventionally built. Harvard was also looking to have the building completed to the highest possible degree prior to shipping so they could significantly reduce the amount of on-site time, cost and disruptive activity to the surrounding campus and community.

Exhibit C-6

2017 Second Place

St Joseph's School

- Main Category: Modular Building Design
- Company: Metric Modular
- Location: Kelowna, British Columbia
- Building Use: School expansion
- Gross Size of Project: 19,680 Square Feet
- Days to complete: 133

Exterior Image

Floor Plan Image

Horizontal Interior Image

Vertical Interior Image

Award Criteria

Architectural Excellence

When St Joseph Catholic Elementary School outgrew their existing school space they came to Britco to help with their expansion. With the addition of 12 classrooms, a student lounge, boys' and girls' washrooms on both floors, wheelchair accessible washrooms on both floors, an elevator and a main entry hall, the students were thrilled with their new space. Since this was an expansion on the existing school, Britco strategically designed the new space to complement the existing elementary school. A highlight of this project for both Britco and the folks at St Joseph's was inviting students and teachers to tour the factory while their modules were being built.

Technical Innovation & Sustainability

The Barrier Free design enables accessibly for disabled students and faculty, with an elevator and wheelchair accessible washrooms on both floors. To reduce noise distractions, extra measures were taken to sound proof the walls between classrooms and hallways, and between floors. This building meets the green building rating of ASHRAE 90.1 – 2010 due to the natural gas heating, multi-zone high-efficiency furnaces and air conditioning. As well, LED lighting was used in lieu of fluorescent lighting.

Cost Effectiveness

The most challenging aspect of this project was the very tight schedule - we couldn't start any site work until the previous school year had come to an end in June and completion was required in time for the start of the 2016/2017 school year. Because we were able to achieve this, the school did not incur the additional costs of placing these students elsewhere during the school year.

<u>Exhibit C-7</u>

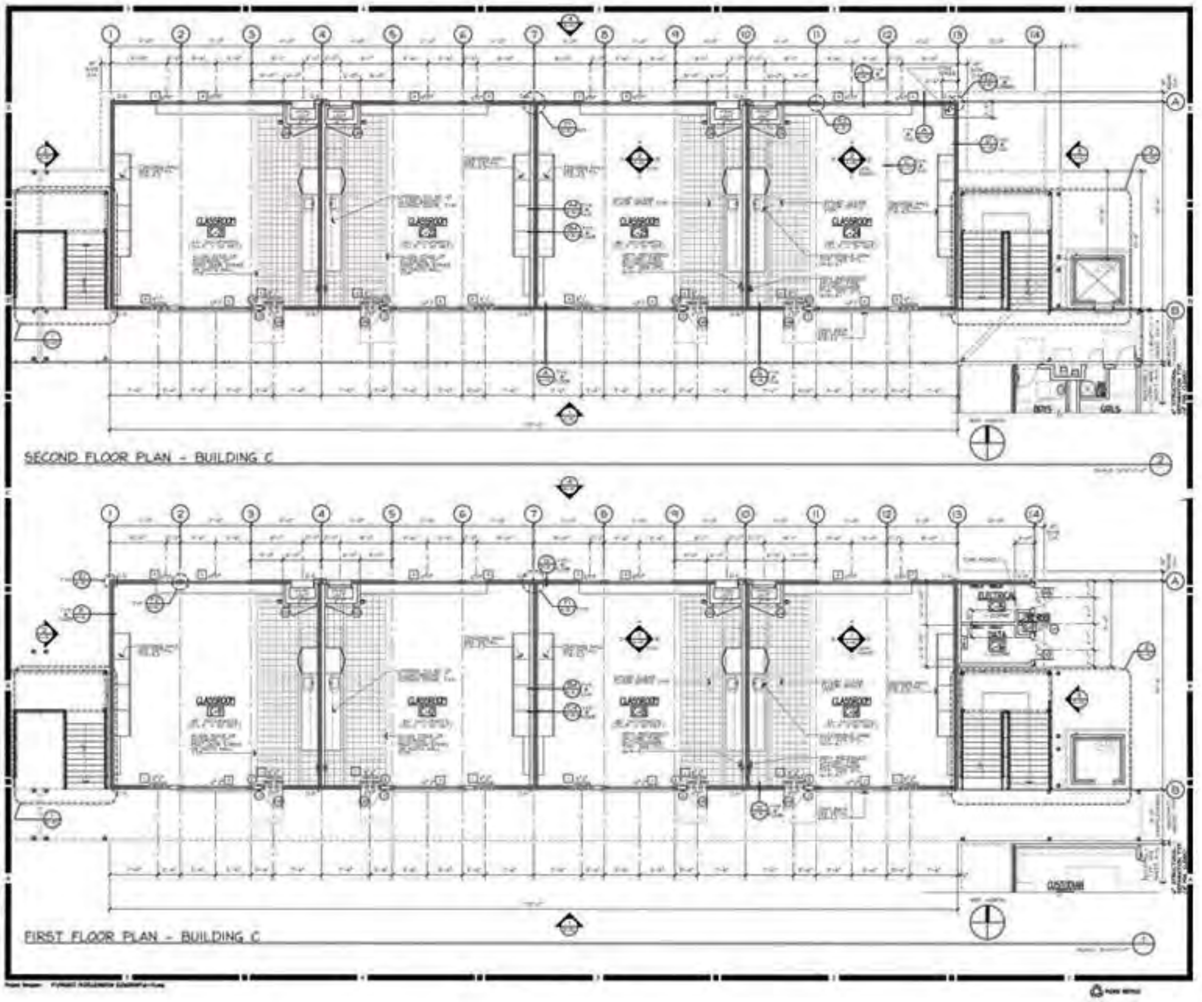
2015 First Place

Lexington Elementary School

- Main Category: Modular Building Design
- Company: Meehleis Modular Building Inc
- Location: Los Gatos, California
- Building Use: Education,Administration,Library
- Gross Size of Project: 25,767 Square Feet
- Days to complete: 259

Exterior Image

<u>Floor Plan Image</u>



Horizontal Interior Image

Vertical Interior Image

Award Criteria

Architectural Excellence

The modular portion of the construction was designed to match the accompanying site built multi-use building. The exterior finishes of cement plaster (stucco), and HardiePanel siding were chosen to maintain consistency. Additionally, all of the custom guardrails and stair systems were fabricated at the Meehleis Modular plant allowing for ease of access and safety while keeping the desired aesthetic. The administration building boasts an expansive glass fascia, wood textures, and clean lines. Creating a stunning focal structure for the campus.

Technical Innovation & Sustainability

Located just 10 miles from the 6.9 magnitude Loma Prieta earthquake epicenter, Lexington required a hefty, 20 inch thick, slab-on-grade design to acount for the possibility of large scale earthquakes. Additionally our unique sher wall construction and use of sound deadening materials produced quiet classrooms. Receiving a CHPS (Collaberative for High Performance Schools) certification for background noise under 45 dBA.

Cost Effectiveness

Constructed in our grid neutral facility with a 190kv photovoltaic system, the project shaved off the normal operating costs associated with construction as well as being environmentally conscious. With the site built multi-use building occupying the campus our off-site process allowed all structures to be constructed simultaneously. Reducing not only construction cost versus the site built building but also minimizing the total construction time.

Exhibit C-8

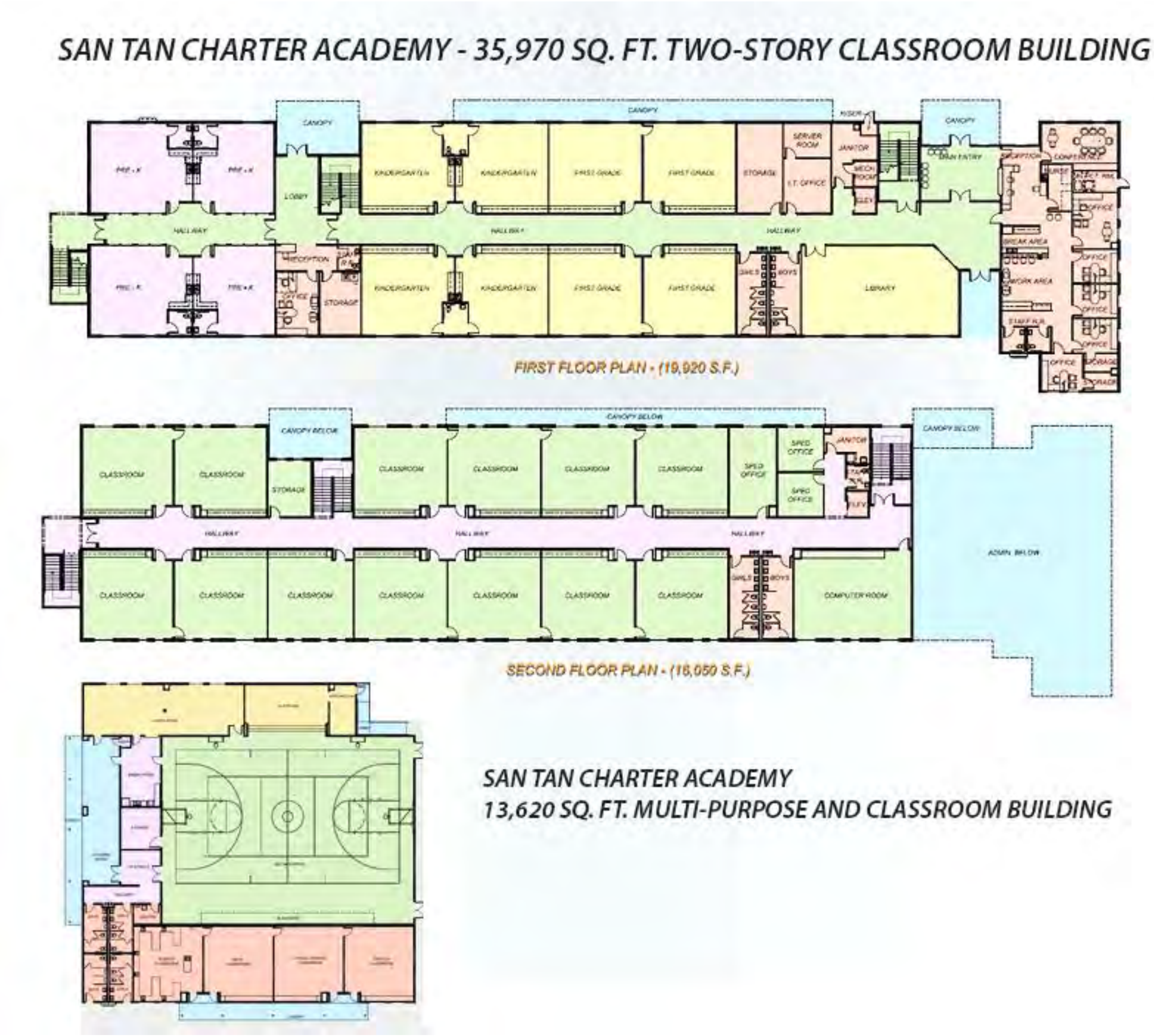
2015 Second Place

San Tan Charter Academy

- Main Category: Modular Building Design
- Company: Accelerated Construction Technologies
- Affiliate: Accelerated Construction Technologies
- Location: Gilbert, AZ
- Building Use: Public Charter School, Grades K-8
- Gross Size of Project: 49,090 Square Feet
- Days to complete: 228

Exterior Image

Floor Plan Image



Horizontal Interior Image

Vertical Interior Image

Award Criteria

Architectural Excellence

This project presented several challenges from a design point of view. Chief among them were meeting the design standards for Morrison Ranch. As the selected site was located in the master planned community of Morrison Ranch in Gilbert, Arizona, the project needed to conform to the stringent design standards set by the community. The floor plan focused on the building as a tool, providing a total teaching environment with student safety, separation of student age groups, and movement around the campus being paramount. In practice, the buildings house three separate schools; a preschool, k through 6th elementary, and middle school. Interior finishes were selected based on durability in a heavy use environment as well as meeting the client's ideas in creating warm and inviting interior spaces that create an atmosphere conducive to learning. Much effort was put into color selections, lighting levels, sound levels, and technological infrastructure. The results speak for themselves.

Technical Innovation & Sustainability

This building features a concrete second floor deck. This system was selected to provide greater noise control between the floors and disturbance in the classrooms.

Cost Effectiveness

While this project used several elements, such as building orientation and placement on site, high performance fixed windows, low maintenance floor coverings, and minimized exterior finishes while detracting from the buildings appearance to achieve cost effectiveness, it was the modular approach and the time savings it provided that really provided the big return for the owner. As a school, it is imperative that this project was completed on time and budget. The students were coming no matter what. In the early days, this project suffered a significant time delay in the financing and property acquisition process. Had it not been for our ability to build offsite while the financing and property segments came together, this project could not have been completed prior to the expected start of classes. The owner found our unique ability to open the school on time under these circumstances to be extremely cost effective.

Exhibit D:

Whitley-Evergreen Case Studies

WM
WHITLEY
MANUFACTURING

CASE STUDY

The Thea Bowman Leadership Academy was founded on the belief that "educated citizens emerge as the true leaders of a community." The school offers a full curriculum for all grade levels and is based in Gary, Indiana. Enrollment growth and long waiting lists necessitated the school's curriculum to expand from K-8 to a full K-12 program. The new building would need to serve both programs and address site issues.

KEY ACHIEVEMENTS

Exterior covering: split-face block masonry. Cost effective and deadens exterior noise.

The building features non-combustible construction and a full fire-suppression system.

Solid floor structure composed of a cementitious sub-floor cast on a welded steel deck.

The building features 2 story classroom sections separated by common areas & offices.

Construction begins January 15th and ready for classes to begin in August

Less material waste and environmental impact than conventional building

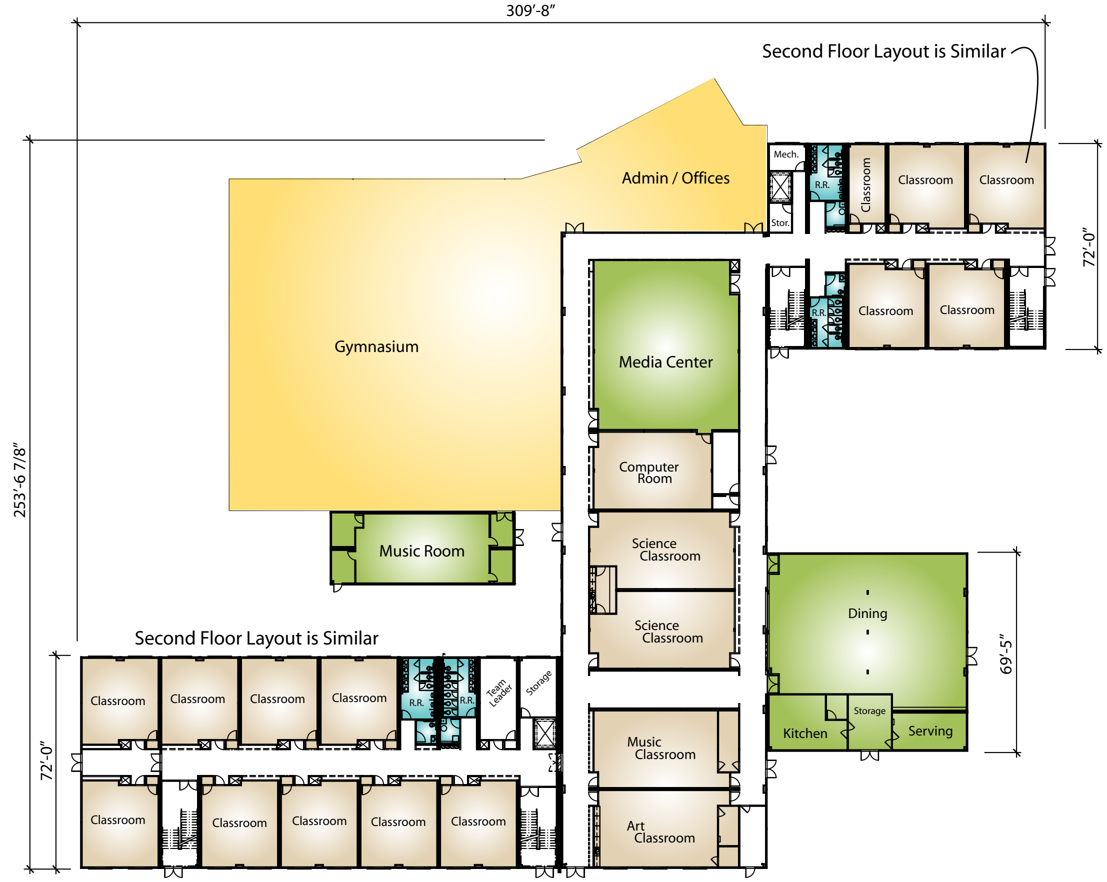
THEA BOWMAN LEADERSHIP ACADEMY

The building was to be sited in an area designated with protected status and needed to have minimal environmental impact. In addition, it needed to address noise: from car traffic, a nearby airport and railway lines.

Whitley Manufacturing was selected by Innovative Modular Solutions to construct the modular portions of the structure. The junior high and high school facilities are separated, while sharing support offices. The building features non-combustible construction, an elegant masonry facade, high-efficiency HVAC systems and solid cementitious-cast floors. The offices are shared between grades and the masonry exterior effectively deadens outside noise.

WHITLEY
MANUFACTURING

Thea Bowman Leadership Academy



Floor Plan

KEY FACTS

PROJECT NAME
THEA BOWMAN LEADERSHIP ACADEMY

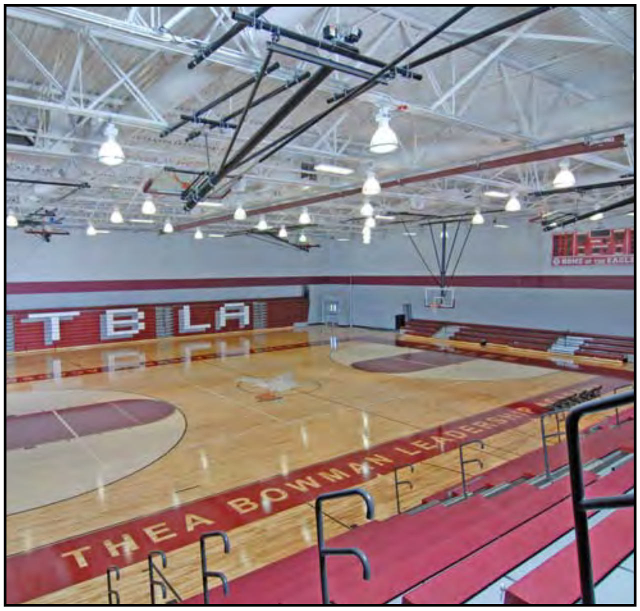
LOCATION
GARY, INDIANA

PARTNER
INNOVATIVE MODULAR SOLUTIONS
FMK ARCHITECTS

PROJECT TYPE
PERMANENT SCHOOL BUILDING

BUILDING SIZE:
58,520 SQ. FT.

BUILDING UNITS:
55 MODULAR UNITS
SITE BUILT GYMNASIUM & ADMIN OFFICES



WHITLEY MANUFACTURING

Cesar-Chavez is a new charter school formed in Detroit. The charter serves a predominantly Latino population base and was formed to instill a sense of community, as well as encouraging academic and social pride amongst an at-risk youth population

CASE STUDY

KEY ACHIEVEMENTS

- *8 month construction time*
- *Two story*
- *Ceramic lavatories*
- *Recessed lockers*
- *Energy efficient heating system*
- *Spacious classrooms*

CESAR-CHAVEZ SCHOOL

In February of 2005, the Cesar Chavez School saw an opportunity. They were paying high rent for space in a poorly retrofitted warehouse. They wanted an alternative that would provide a prime educational setting within the span of a few short months. Initially, they doubted that modular construction could provide the modern aesthetic that their urban surroundings.

Our distributor (Innovative Modular Solutions), told the Chavez board, to their surprise, that a new building could be ready in time for the fall semester. A new school would save a year's rent and could be custom designed to facilitate their unique educational goals. In a few short years, the building would have paid for itself in rent savings alone. The presentation drawings prepared by Whitley and Lee Stevens Architects allowed the board to "see" their new building and modify it to best suit their needs. The building now evokes pride in the neighborhood and in children who attend the gleaming facility.

WHITLEY
MANUFACTURING

Cesar-Chavez School

KEY FACTS

PROJECT NAME
CESAR-CHAVEZ SCHOOL

LOCATION
DETROIT, MI

DEVELOPER
INNOVATIVE MODULAR SOLUTIONS
OF NAPERVILLE, IL

ARCHITECT
LEE STEVENS (AIA)
OF PORT HERON, MI

PROJECT TYPE
PERMANENT-TWO-STORIES
NON-COMBUSTIBLE MATERIALS

BUILDING SIZE:
35,000 SQ.. FT.

MARYSVILLE SCHOOL OPENS WITH MODULAR BUILDING

CASE STUDY

The Marysville Art & Technology High School had outgrown their outdated leased, 21,000 ft^2, space. They were looking to increase their capacity to approximately 39,000 ft^2 and accommodate 400 students. The new campus (the Marysville Secondary Campus) would be located on the Tulalip Indian Reservation. It will include the Tulalip Heritage High School and the Tenth Street Middle School.

KEY FEATURES

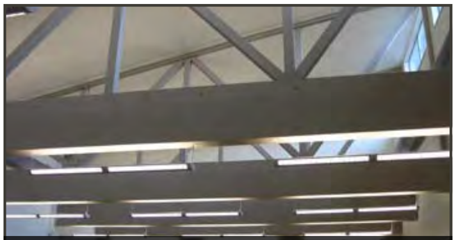
- *Built faster than conventional site built structure*
- *Clearstory windows provide plenty of natural light*
- *Flexible spaces to enhance student learning & adapt to changing needs*
- *Shared spaces (office, gym & lunchroom) save on costs*
- *Less environmental impact and minimal disturbance to site*
- *Reduced material waste by controlling inventory & recycling*

Marysville Art & Technology High School, Washington

Whitley-Evergreen completed this innovative project along with Williams-Scotsman. The building was produced in sections at Whitley-Evergreen, Marysville, Washington, a modern construction facility. Williams-Scotsman, a national leader in the distribution of modular space, then transported the sections to the site where the foundation had already been prepared (this "concurrent construction" saved a significant amount of time on the project). Under the watchful eyes of professional project managers and third-party inspection agencies the building was assembled and finished. Together, Whitley-Evergreen (Whitley Manufacturing) and Williams-Scotsman were able to complete a custom, modern building with architectural appeal on a shortened time line and a controlled budget.

W-E
WHITLEY
EVERGREEN

Marysville Arts & Technology High School, WA



Vaulted Ceilings with clearstory windows

KEY FACTS

PROJECT NAME
MARYSVILLE A&T HIGH SCHOOL

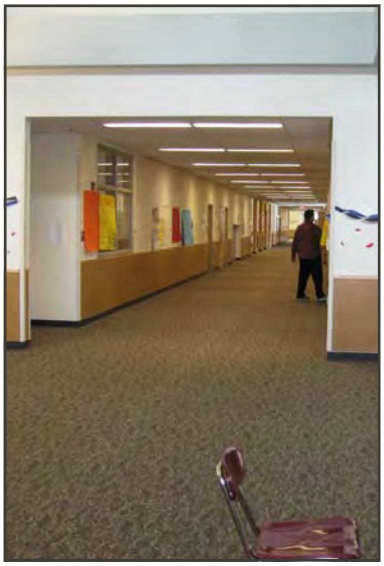
LOCATION
MARYSVILLE, WA

PARTNERS
WILLIAMS SCOTSMAN

PROJECT TYPE
PERMANENT MODULAR SCHOOL

BUILDING SIZE:
39,000 SQ. FT.

BUILDING UNITS:
120 MODULES



WHITLEY MANUFACTURING

CASE STUDY

Match Charter Public School (Match) is an innovative, high-performing free public school in Boston. It is widely recognized for its success in preparing students for college and careers. Match currently includes four campuses which span grades preK-12. With their achievements, Match is expanding to include an enrollment of 1,250 students. To accommodate, additional classroom space will be needed soon.

MATCH COMMUNITY DAY CHARTER SCHOOL MODULAR BUILT

To develop the classroom buildings needed, modular construction was the obvious choice. Through a collaborative effort, Commodore Builders, Pope Industries, Studio G Architects, and Whitley Manufacturing were able to accelerate the construction process and reduce time and costs.

Whitley Manufacturing built two classroom buildings (both two-story) totaling 60,000 sq. ft. (40,000 & 20,000) and a third building, single-story, 2400 sq. ft. gymnasium locker room, with a total of 82 modules. The layout consisted of both traditional classrooms along with smaller, more flexible meeting areas and conference rooms. Off-site modular construction included structural, framing, drywall, insulation, doors, windows, misc. finishes, plumbing, HVAC, and electrical.

KEY ACHIEVEMENTS

50% faster than a conventional building

Finished with 2 1/2 times less waste than traditional building

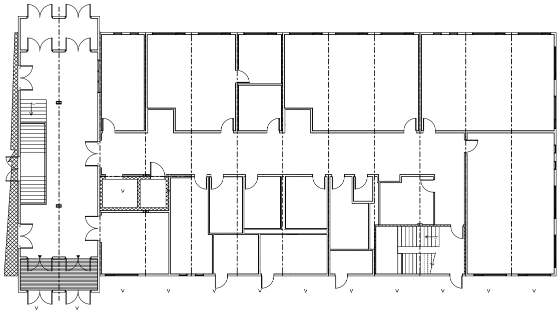
Steel framing consisted of 72% recycled material

Minimal disruption to the school campus

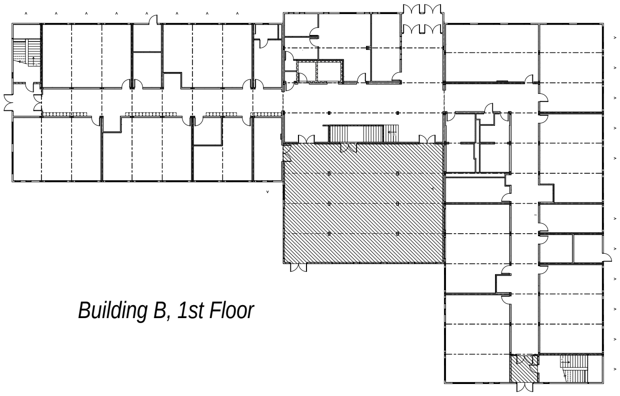
Less environmental impact.

Flexible design for changing needs.

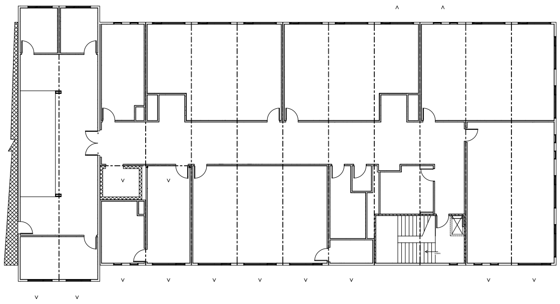
Match Community Day Charter School



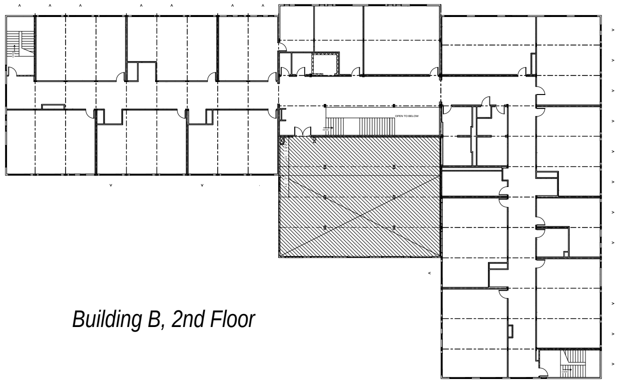
Building A, 1st Floor



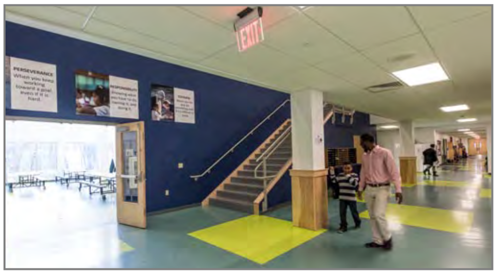
Building B, 1st Floor

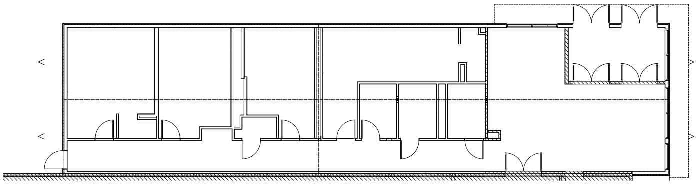


Building A, 2nd Floor



Building B, 2nd Floor





Locker Room Building

KEY FACTS

PROJECT NAME
MATCH COMMUNITY DAY CHARTER SCHOOL

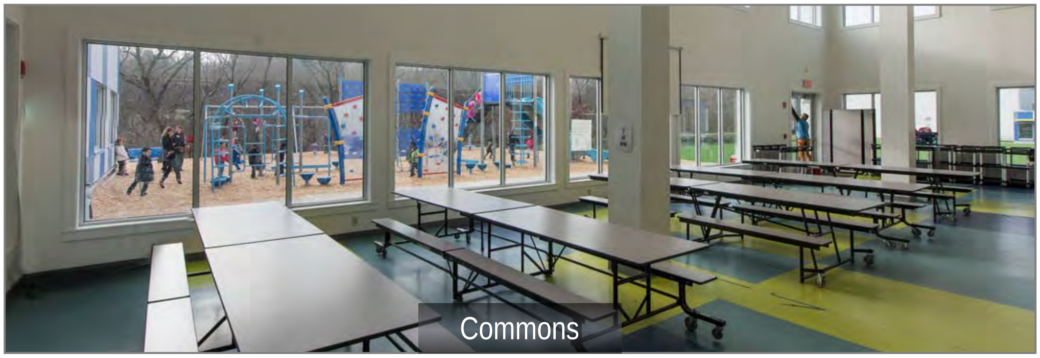
LOCATION
HYDE PARK, MA

PARTNERS
POPE INDUSTRIES
COMMODORE BUILDERS
STUDIO G ARCHITECTS

PROJECT TYPE
ELEMENTARY SCHOOL

BUILDING SIZE:
CLASS RM BLDG A: 20,000 SQ. FT.
CLASS RM BLDG B: 40,000 SQ. FT.
LOCKER RM BLDG: 2400 SQ. FT.

BUILDING UNITS:
BLDG A: 28 MODULES
BLDG B: 50 MODULE
LOCKER RM: 4 MODULES



Commons

Exhibit E:

Case Studies a Joint Report by the National Institution of Building Sciences, the Modular Building Institute, the Integrated Technology in Architecture Center, and the University of Utah - Permanent Modular Construction

OFF-SITE
STUDIES

PERMANENT MODULAR CONSTRUCTION

PROCESS
PRACTICE
PERFORMANCE

National Institute of BUILDING SCIENCES

MODULAR BUILDING INSTITUTE

ITAC
INTEGRATED TECHNOLOGY IN ARCHITECTURE CENTER
UNIVERSITY OF UTAH COLLEGE OF ARCHITECTURE + PLANNING

THE UNIVERSITY OF UTAH

HIGH TECH HIGH
SAN DIEGO, CA

Architect: Studio E Architects
Modular Builder: William Scotsman
Contractor: BYCOR
Structural Engineer: R & S Tavares Associates

ABOUT

The school is situated on an eight acre site in southeastern Chula Vista overlooking the Otay River Valley and Mexico to the south. The design of the school reflects the charter school's emphasis on three fundamental values – transparency, community and sustainability. The school is a combination of modular and site built construction. (Arch Daily)

GENERAL

EDUCATION BUILDING TYPE

2009 YEAR COMPLETED

61,445 SQUARE FEET

59 STEEL MODULES

1 STORIES TALL

COST

$7.9M CONSTRUCTION COST

$4M MODULAR CONTRACT

SCHEDULE

15 MONTHS FROM START TO FINISH

11 MONTHS UNDER CONSTRUCTION

4 MONTHS FOR DESIGN

2 MONTHS IN FACTORY

37 DAYS TO ERECT

$188.30 PER S.F.

40% MORE COST EFFECTIVE

10 MILES FROM FACTORY TO SITE

31% FASTER CONSTRUCTION

REFERENCES

Naslund, Eric. Studio E Architects. Interview with Talbot Rice on 6.17.14

Hudson, Valerie. BYCOR. Interview with Talbot Rice 6.11.14

http://www.archdaily.com/130879/high-tech-high-chula-vista-studio-e-architects/

Images: Studio E Architects, Jim Brady Architectural Photography, Christopher Gerber

	HIGH TECH HIGH	COMPARED PROJECT
CONSTRUCTION DURATION	11 MONTHS	17 MONTHS
STORIES AND CONSTRUCTION TYPE	1 STORY STEEL	4 STORIES STEEL
SQUARE FOOTAGE	61,445	73,000
COST	$11.57M	$22.8M
COST/SF	$188.30	$312.27

STEM SCHOOL
LAKE WASHINGTON, WA

Architect: Integrus Architecture
Modular Builder: M Space
Contractor: Absher Construction

ABOUT

The STEM school provides an efficient design for students and educators and represents the broad capabilities and limitless design opportunities when integrating permanent modular construction and traditional construction. (MSpace)

GENERAL

EDUCATION BUILDING TYPE

2010 YEAR COMPLETED

63,000 SQUARE FEET

160 STEEL + WOOD MODULES

2 STORIES TALL

COST

$15.6M CONST. COST

$10.2M MODULAR CONTRACT

SCHEDULE

15 MONTHS FROM START TO FINISH

12 MONTHS UNDER CONSTRUCTION

4 MONTHS FOR DESIGN

3 MONTHS IN FACTORY

3 WEEKS TO ERECT

$247.83 PER S.F.

21% MORE COST EFFECTIVE

200 MILES FROM FACTORY TO SITE

29% FASTER CONSTRUCTION

LESSONS LEARNED

Even though this project was a Design-Bid-Build, there was great collaboration between the trades. Several issues, such as structural alignment, point to the need for a design-build process in the future.

Images: Absher Construction

REFERENCES

Tiegs, Jeff. Absher Construction. Interview with Talbot Rice on 6.20.14

http://www.mspaceholdings.com/project/lake-washington-school-district

	STEM SCHOOL	COMPARED PROJECT
CONSTRUCTION DURATION	12 MONTHS	17 MONTHS
STORIES AND CONSTRUCTION TYPE	2 STORY STEEL	4 STORIES STEEL
SQUARE FOOTAGE	63,000	73,000
COST	$15.6 M	$22.8 M
COST/SF	$247.83	$312.27