SmartMarket Report

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Prefabrication and Modular Construction 2020

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Prefabrication and Modular Construction 2020 SmartMarket Report

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About Dodge Data & Analytics

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Introduction

Prefabrication and modular construction are both experiencing a significant expansion of interest and use as the construction industry seeks to improve safety, productivity, quality, cost, schedule and sustainability performance while continuing to face workforce shortages, cost uncertainties and other challenges. While major advances have been made in both prefabrication and modular construction since Dodge Data & Analytics published its first SmartMarket Report on these topics in 2011, many of the underlying drivers and benefits of these approaches remain powerfully consistent in this new research study. Then, as now:

- **Improved productivity and quality are top benefits driving usage.**
- **Positive impacts on budget and schedule performance are widely experienced.**
- **Construction sites are greener due to less waste being generated, and safer due to working with assemblies and modules produced offsite.**

While practitioners in both studies forecast ambitious plans to increase the amount of prefabrication and modular construction they will do over the next few years, the top obstacles they cite to achieving those goals are also familiar:

- **Contractors continue to say that architects and engineers are not adequately enabling prefabrication and/or modular construction in their design solutions.**
- **Meanwhile design professionals point to a shortage of prefabrication facilities close to their project sites and to owners' lack of understanding of the value of modular construction as the main reasons they do not design in these approaches from the beginning of a project.**

To help address this, one of the main objectives of Dodge's new study is to provide all industry participants with more quantification of the benefits of prefabrication and modular construction, especially the latter, which has experienced dramatic growth since the previous study. Because of the differences in how, when, where and why each approach is being applied on projects, respondents to the survey were routed into separate lines of inquiry about either prefabrication or modular construction based on their experience level, and this report presents the resulting data in two separate sections.

Key findings reveal both commonalities and contrasts between the two approaches. For example, over three quarters of current users of each are receiving a significant level (medium, high or very high) of these seven valuable benefits from their use:

- **Improved Cost Predictability**
- **Improved Productivity**
- **Improved Quality**
- **Improved Safety Performance**
- **Increased Client Satisfaction**
- **Increased Schedule Certainty**
- **Reduced Waste Generated by Construction**

But interestingly, the percentages are higher among the users of modular construction for each of these benefits than from the group responding about their use of prefabrication.

This study also examines the positive impact of BIM on the achievement of benefits related to these approaches.

- **Less than a quarter (22%) of respondents who report using no BIM claim that they experience schedule performance improvement from the use of prefabrication, whereas among the companies that use BIM on half or more of their projects a significant majority (61%) cite improved schedule performance.**
- **Similarly, with modular construction, only 21% of non-BIM users report cost performance improvement compared with 46% of those using BIM frequently.**

Clearly the future is bright for continued growth in use of both prefabrication and modular construction, and this report will serve as a benchmark of our recent progress and a baseline against which to track exciting future expansion. Dodge wishes to thank Bradley Corporation, the Modular Building Institute, Pinnacle Infotech, the Mechanical Contractors Association of America and Skender for supporting this research.

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Stephen A. Jones leads DD&A's Industry Insights Research division. He is active in numerous industry organizations and frequently speaks at industry events around the world. Before DD&A, Jones was vice president with Primavera Systems (now part of Oracle), a global leader in project management software. Prior to that, he was principal and a Board of Directors member with Burt Hill, a major A/E firm (now merged with Stantec).

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Donna Laquidara-Carr currently provides editorial direction, analysis and content to DD&A's *SmartMarket Reports*. Prior to this position, she worked for nearly 20 years with DD&A's Dodge division, where she gained detailed insight into the construction industry.

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Cover Image Courtesy of Skender; Adjacent Page: Image courtesy of Pyatok Architects

At Right:
Coliseum Connections, a modular 110-unit housing development in Oakland, Calif.

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Executive Summary

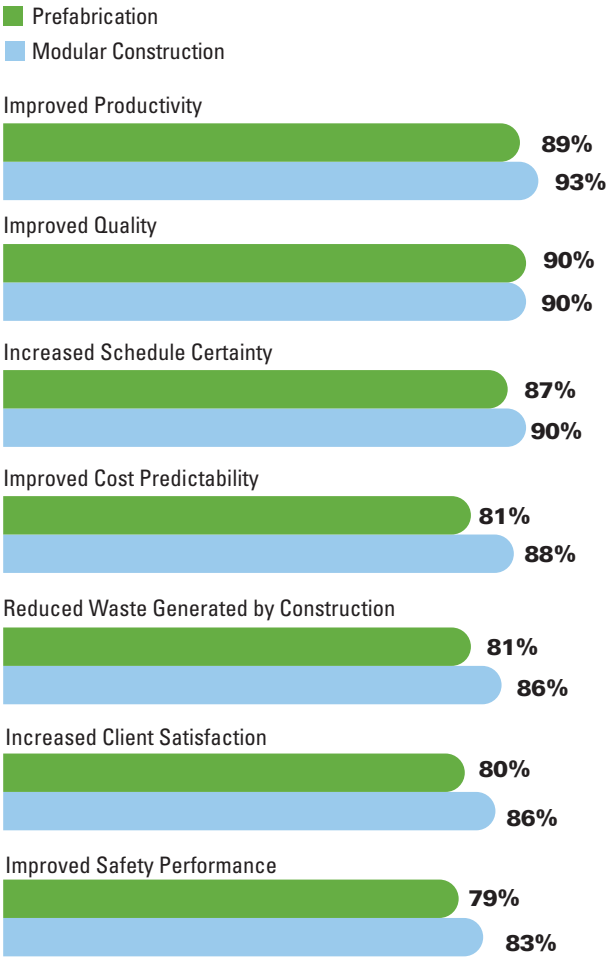
Design firms and contractors agree that both prefabrication and modular construction are providing significant improvements to cost, schedule, quality and safety performance, productivity, client satisfaction and their ability to reduce waste. These companies are forecasting expanded use of both approaches over the coming years as the benefits are more widely measured, owners become increasingly comfortable with the process and the outcomes, and the industry develops more resources to support innovative applications.

Benefits of Using Prefabrication and Modular Construction

Users report receiving many important benefits from both prefabrication and from modular construction. The chart below shows the percentages reporting significant (medium, high or very high level) positive impacts from the use of each on seven key metrics.

Benefits From the Use of Prefabrication and Modular Construction (Percentage of Users Citing Medium, High or Very High Levels)

Dodge Data & Analytics, 2020

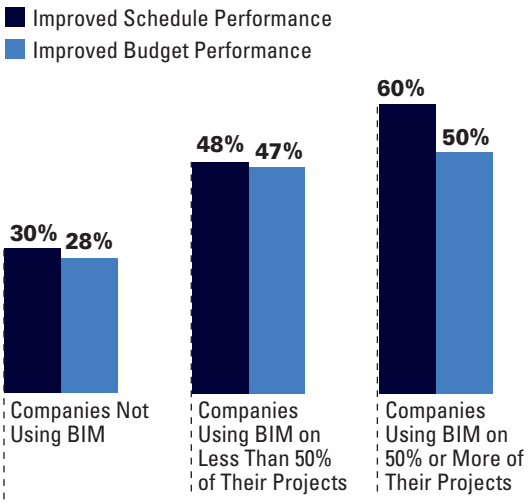


Impact of BIM on Budget and Schedule Performance When Using Prefabrication or Modular Construction

Modeling technologies are impacting all aspects of the design and construction industry. This study reveals a strong correlation between companies' BIM use and the degree to which they enjoy improved schedule and budget performance from using prefabrication or modular construction. The findings are similar for both users of prefabrication and of modular construction, so percentages in the chart below reflect their combined reporting of positive impacts, differentiated by their level of BIM implementation.

Impact of BIM on Schedule and Budget Performance When Using Prefabrication or Modular Construction (Percentage of Companies by BIM Usage Reporting Improved Performance)

Dodge Data & Analytics, 2020

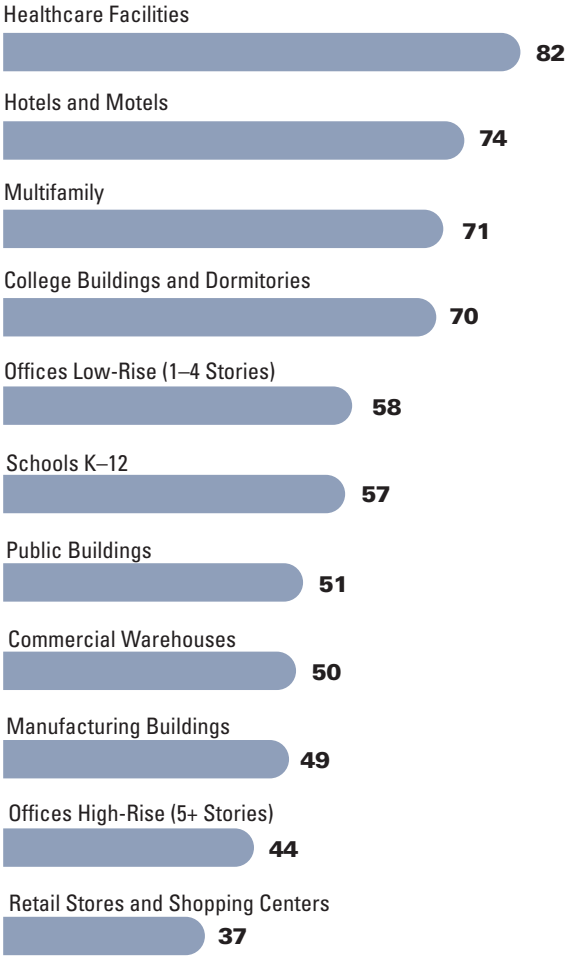


Forecast for Building Types With Most Frequent Use of Prefabrication and Modular Construction in the Next Three Years

Survey participants predict a high frequency of prefabrication and of modular construction over the next three years on many major building types. The summary chart below is based on an index combining their forecasts for each. (See the Prefabrication Trends and the Modular Construction Trends sections of this report for more detail on the specific forecast for each.)

Most Likely Building Types for High Frequency of Prefabrication and/or Modular Construction (Index Based on Respondent Forecasts for the Next 3 Years)

Dodge Data & Analytics, 2020

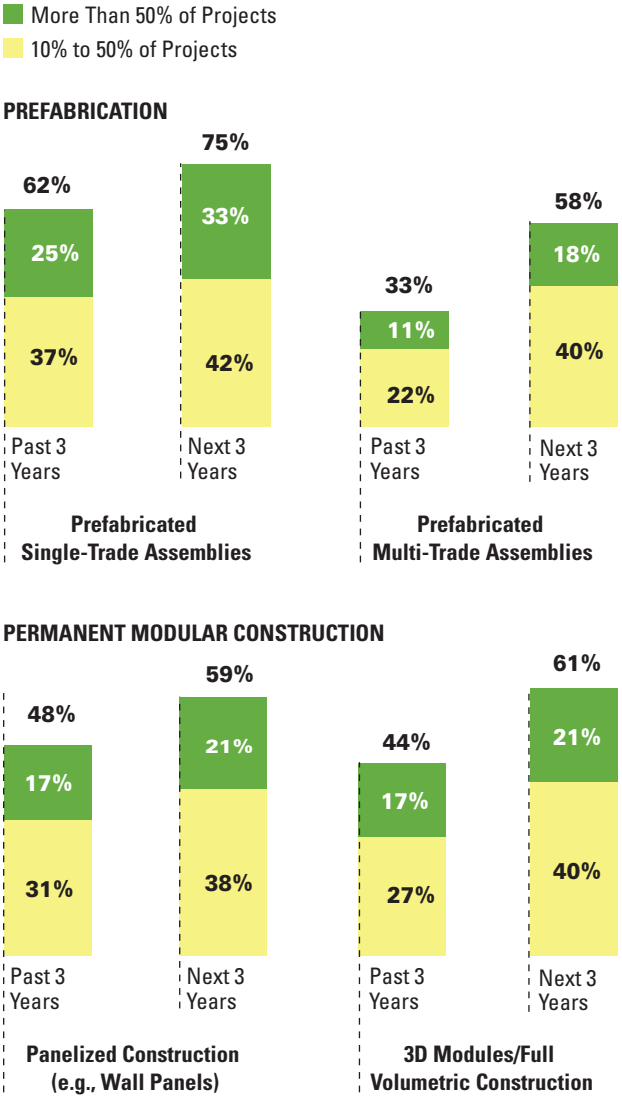


Forecast for Increased Use of Prefabrication and Permanent Modular Construction in the Next Three Years

Current users forecast increased engagement over the next three years.

Forecast for Increased Use of Prefabrication and of Permanent Modular Construction in the Next 3 Years (Percentages Reporting Use on at Least 10% of Projects Over the Past 3 Years and Forecasting That Level of Use in the Next 3 Years)

Dodge Data & Analytics, 2020

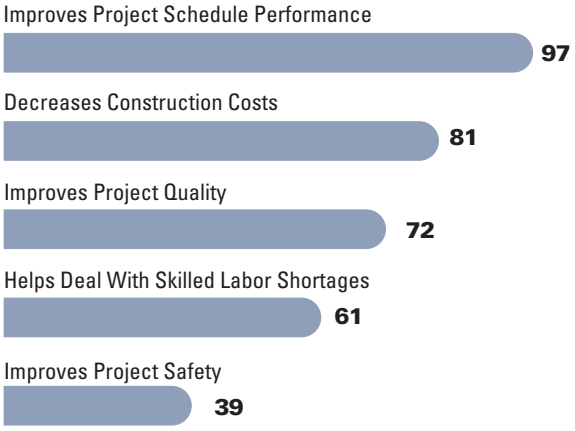


Most Important Drivers for Increased Future Use of Prefabrication and Modular Construction

The survey probed design firms and contractors to identify the most compelling benefits or process improvements that would drive them to increase their implementation of prefabrication and of modular construction over the next three years. The chart below shows the top five reasons that will be most impactful to spur deeper engagement with both approaches, based on an index that combines the findings for each.

Benefits That Would Most Encourage Increased Use of Prefabrication or Modular Construction in the Next 3 Years (Index Based on Respondent Forecasts for Next 3 Years)

Dodge Data & Analytics, 2020

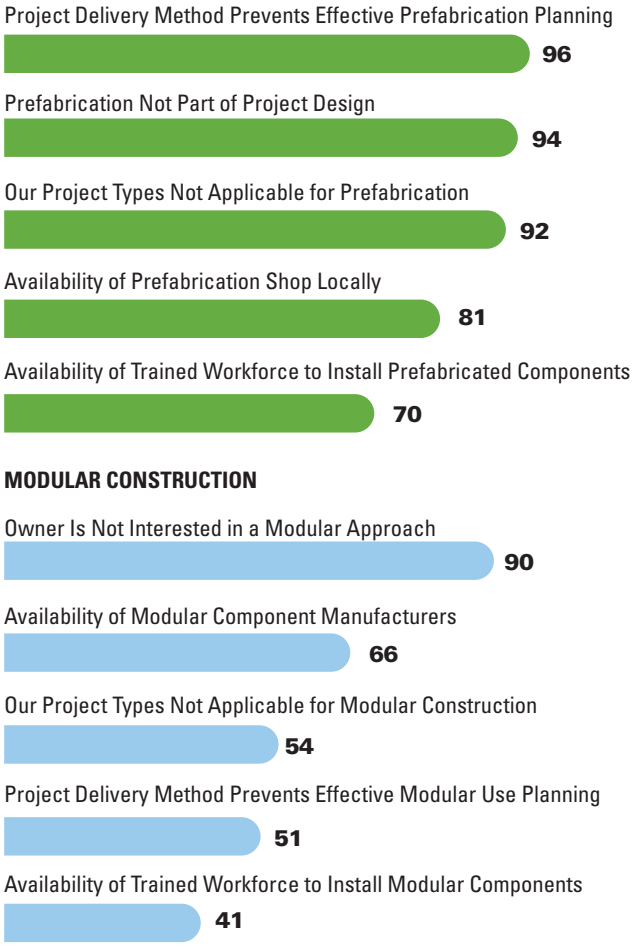


Top Obstacles Preventing Increased Future Use of Prefabrication and Modular Construction

Survey participants selected their top three most important from a list of factors that are preventing increased future use of prefabrication and a separate list for modular construction. Numbers in the charts at right reflect an index created from those responses.

Impact of BIM on Schedule and Budget Performance When Using Prefabrication or Modular Construction (Index Based on Responses for Next 3 Years)

Dodge Data & Analytics, 2020



Data: Introduction

Prefabrication and Modular Construction

This SmartMarket Report is a follow-up to a study originally conducted by Dodge Data & Analytics (when part of McGraw Hill Construction) and published in 2012 as the *Prefabrication and Modularization: Increasing Productivity in the Construction Industry SmartMarket Report*. Its purpose is to establish the current and likely future use of both prefabrication and modular construction, quantify users' benefits and challenges related to each, and increase industry understanding of which factors will most effectively drive growth and expand future use.

About Prefabrication and Modular Construction

Although each can be considered as part of a larger category of offsite construction, there are meaningful differences between prefabrication and modular construction. For example, they are at very different stages of maturity in the US construction market:

- 94% of survey respondents cite experience with prefabrication over the last three years.
- 38% have used permanent modular construction.
- 28% have used relocatable modular construction.

They also require different planning approaches and implementation strategies, provide different types of benefits and will require different drivers to spur their future growth.

For these reasons prefabrication and modular construction are each analyzed and reported on independently in the body of this study.

Definitions From the Modular Building Institute That Are Used in This Survey

- **PERMANENT MODULAR CONSTRUCTION**—A design and construction process performed in a manufacturing facility that produces building components or modules that are constructed to be transported to a permanent building site.
- **RELOCATABLE BUILDING**—A partially or completely assembled building that complies with applicable codes or state regulations and is constructed in a building manufacturing facility using a modular construction process. Relocatable modular buildings are designed to be reused or repurposed multiple times and transported to different building sites.

Analysis in This Report

To support this separate analysis approach, Dodge created an online survey with two lines of inquiry, one for prefabrication and the other for modular construction. 66% of total respondents to the study, including architects, engineers, GCs/CMs, trade contractors and modular builders/manufacturers, responded to the prefabrication line of inquiry and the remaining 34% responded to the modular ones. See the Methodology on page 64 for more information.

The findings reported in the Prefabrication Trends section of this report represent the respondents to the prefabrication line of inquiry, and those in the Modular Construction Trends section reflect those that responded to the modular construction line of inquiry. Because of the unique nature of their perspectives, the responses provided by the modular builders/manufacturers in both lines of inquiry were aggregated and are reported on in a separate section of this report.

Most Frequent Building Types for Use of Prefabrication

Prefabrication of single and multi-trade assemblies can be used on a wide variety of building types. This section of the report compares the recent experience of the designers, GCs/CMs and trade contractors designated for the prefabrication line of inquiry with their respective forecasts for the next three years.

Architects' and Engineers' Perspectives

The chart at right shows the top 10 building types (from an overall list of 14) that architects and engineers believe will have frequent use of prefabricated single and/or multi-trade assemblies over the next three years. To evaluate the dynamics of the market, the chart also compares those forecasts with this group's experience with prefabrication frequency over the past three years on those same 10 types of projects.

OFFICE BUILDINGS

While nine of the top 10 show forecasted growth over the next three years, low-rise office buildings (1–4 stories) stand out, surging from less than a quarter of firms (22%) citing high frequency in the past to nearly half (48%) forecasting it in the near future. That building type was already the second most common, so this prediction of strong organic growth suggests that prefabrication is well on its way to becoming a standard practice in that market.

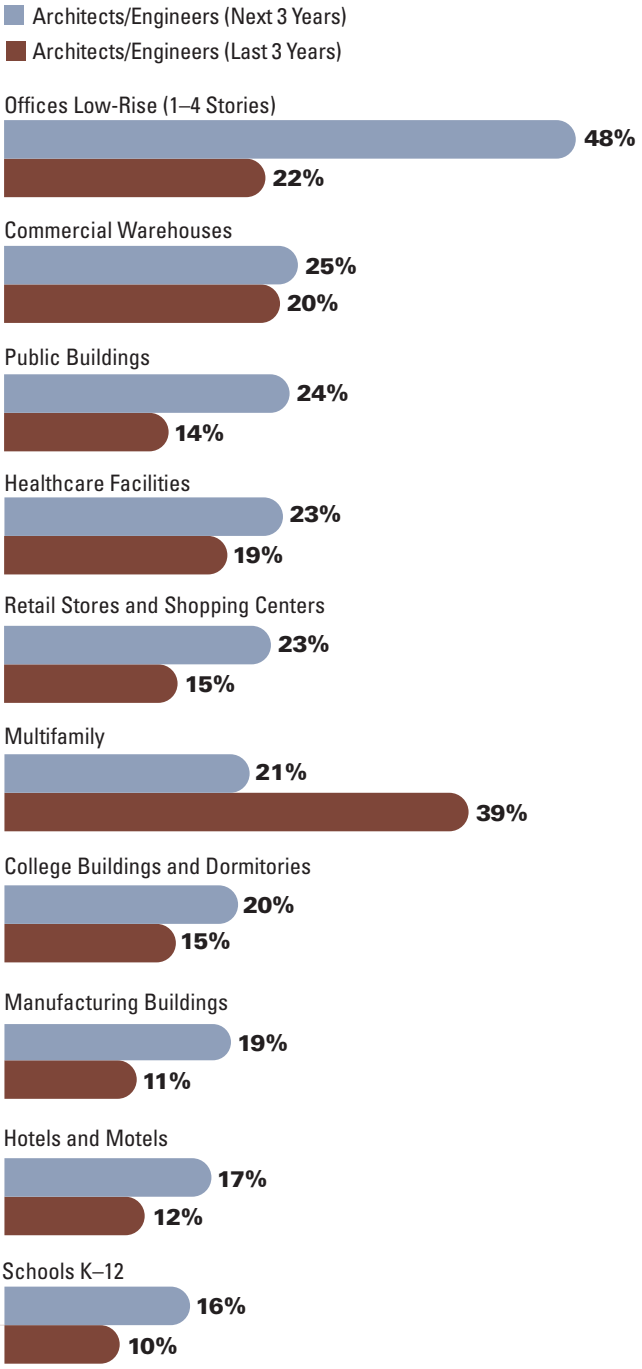
By contrast, high-rise office (five or more stories) ranked 11th among the 14 with only 13% of design firms predicting high frequency of prefabrication. (High-rise office is not included in the chart at right since it did not rank in the top 10.) This may be due to the greater complexity of lifting and installing single and multi-trade assemblies on these projects.

MULTIFAMILY RESIDENTIAL

Contrasting with design firms' generally positive prefabrication forecast, multifamily residential shows a dramatic decrease in the predicted level of prefabrication. This contrasts with their bullish forecast for the use of permanent modular construction in this market (see page 35), so it may be a matter of replacing prefabrication with modular in their view.

Architects/Engineers' Top 10 Most Frequent Building Types for Using Prefabrication
(Forecast for Next 3 Years Compared With History of Last 3 Years)

Dodge Data & Analytics, 2020



Most Frequent Building Types for Use of Prefabrication CONTINUED

General Contractors' and Construction Managers' Perspectives

The forecast by GCs/CMs for which building types will have frequent use of prefabricated single and multi-trade assemblies over the next three years differs from the design professionals' view, as does their reported experience. The chart at right shows the top 10 building types (from an overall list of 14) that they believe will show the most prefabrication activity.

HEALTHCARE FACILITIES TOP THE LIST

GCs/CMs predict growth of prefabrication in each of these top 10 building types. Among them, healthcare facilities rank as both the most frequent over the past three years and, with nearly half (49%) including it among their top predicted building types going forward, the top future market as well. By comparison, only 23% of design firms agree with that forecast.

MULTIFAMILY RESIDENTIAL SHOWS GROWTH

Contrasting with the negative perspective of design firms, GCs/CMs rank multifamily residential as second most frequent in their prediction for future usage of prefabrication.

LOW-RISE OFFICE (1–4 STORIES) SEE SOFTER GROWTH PREDICTIONS

Though both groups see future growth, GCs/CMs are more muted, with less than one third (32%) predicting a hot future market compared with almost half (48%) of design firms.

HOTELS AND MOTELS LOOK PROMISING

Almost one third (30%) of GCs/CMs are bullish on the future demand for prefabrication in this building-type compared with just 17% of design firms.

RETAIL STORES AND SHOPPING CENTERS SEE LITTLE EXPECTED ACTIVITY

This building type does not even rank in the top 10 for GCs/CMs, whereas it ranks fourth for design professionals, with almost a quarter (23%) of design professionals including it in their three-year forecast of high prefabrication activity.

GCs/CMs' Top 10 Most Frequent Building Types for Using Prefabrication (Forecast for Next 3 Years Compared With History of Last 3 Years)

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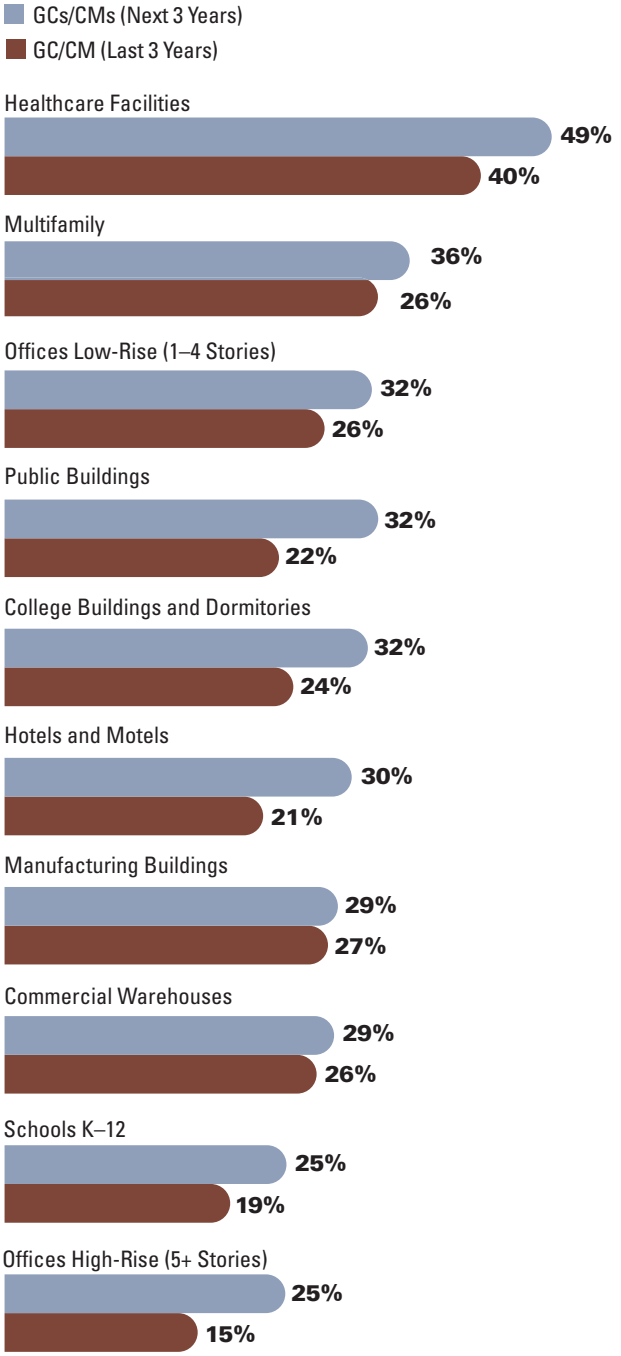


Most Frequent Building Types for Use of Prefabrication CONTINUED

Specialty Trade Contractors' Perspectives

The findings from specialty trade contractors are similar to GCs/CMs in seeing healthcare as the top project type that has and will feature frequent prefabrication. They also rank multifamily second, with over twice as many (47%) including it in their forecast as those who cited it in their history (23%).

But interestingly, trade contractors differ from GCs/CMs in that low-rise office projects (1–4 stories) are not even in their top 10 (among 14 possible building types), and high-rise office buildings (5+ stories) are fourth in their forecast, compared with 10th for GCs/CMs and 11th for design firms.

Impact of BIM Use on Prefabrication Forecasts by Building Type

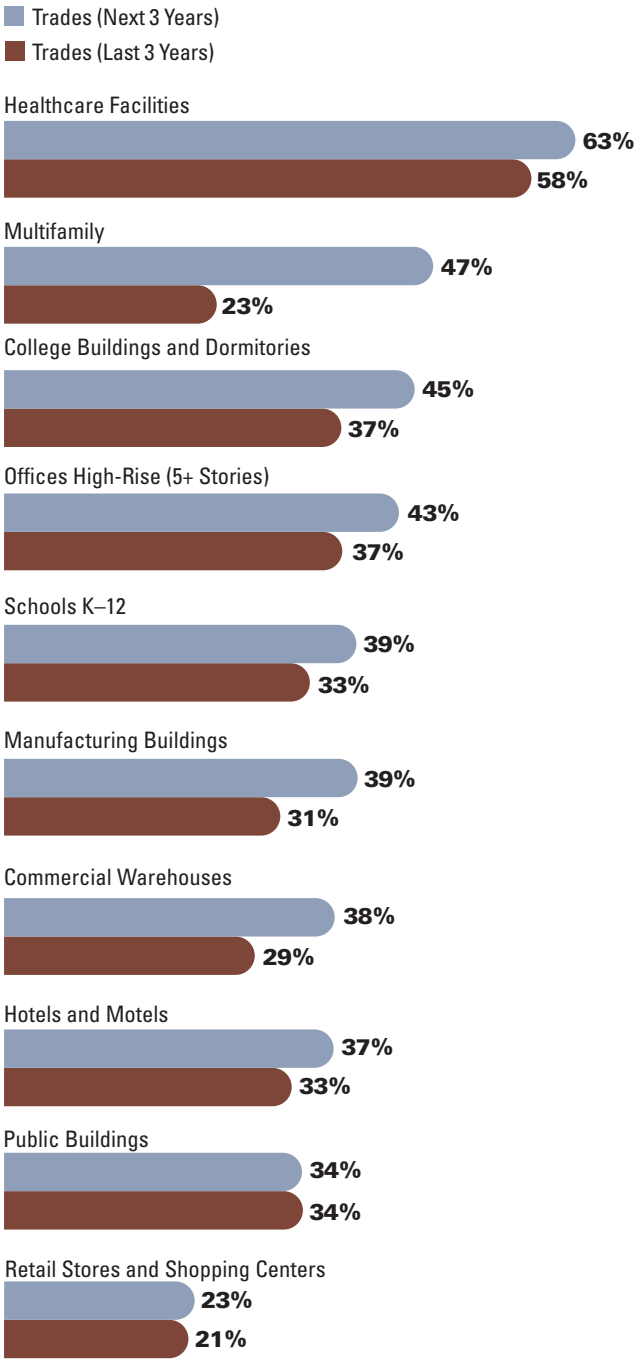
The data show a strong correlation between the use of BIM by design firms, GCs/CMs and trade contractors and the frequency with which they all predict a high frequency of prefabrication, especially on commercial and institutional projects where BIM use is increasingly common. The matrix below demonstrates that direct relationship for six of the top 10 building types. This underscores the powerful role of BIM in enabling model-driven prefabrication. (See page 22 for more findings related to model-driven prefabrication.)

Percentage of All Respondents Predicting Frequent Use of Prefabrication (by Level of BIM Usage)

Building Types	No Projects Use BIM	Use BIM on Less Than 50% of Projects	Use BIM on 50% or More of Projects
Healthcare Facilities	24%	44%	57%
Public Buildings	20%	25%	39%
College Buildings and Dormitories	18%	33%	45%
Hotels and Motels	20%	34%	38%
Schools K–12	13%	30%	31%
Offices High-Rise (5+ Stories)	9%	23%	41%

Trade Contractors' Top 10 Most Frequent Building Types for Using Prefabrication (Forecast for Next 3 Years Compared With History of Last 3 Years)

Dodge Data & Analytics, 2020



Most Frequently Prefabricated Assemblies

Prefabrication can be carried out by a single trade on their part of the work such as behind-the-wall plumbing assemblies for headwalls or large public bathrooms, or by several trades working together to create multi-trade assemblies such as above-the-ceiling corridor racks in hospitals. This part of the report explores current and future use of both types of assemblies.

Frequency of Using Single-Trade Assemblies by Company Type

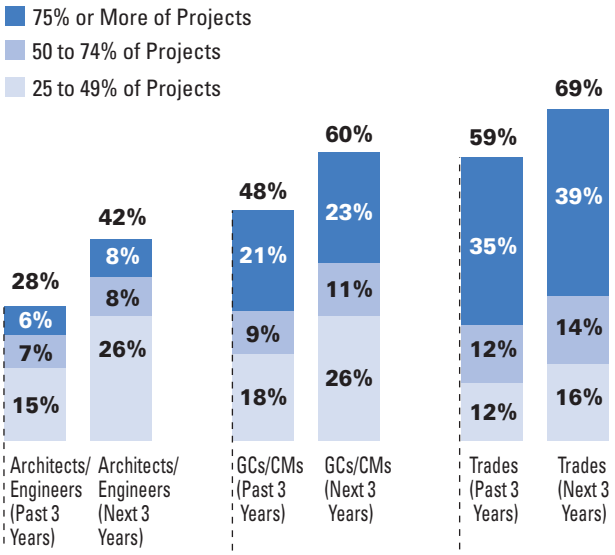
To explore the current usage and future growth of single-trade prefabricated assemblies, respondents identified the percentage of projects where they have been used over the past three years, and the percentage on which they are likely to be used over the next three years.

The chart at right shows that all three company-types that participated in the survey predict significant growth in the use of single-trade assemblies over the next three years.

- **Trade contractors are the most enthusiastic,** with 53% predicting that they will employ single-trade assemblies on half or more of their future projects.
- **GCs/CMs are similarly positive,** with over one third (34%) predicting that a majority of their projects will include single-trade assemblies.
- Although predicting a strong increase over the next three years, **design professionals forecast the lowest overall percentage,** with only 16% anticipating usage on most of their projects. This indicates a need for them to become more engaged with designing in a way that enables contractors to implement prefabrication.

Percent of Projects With Prefabricated Single-Trade Assemblies (Past 3 Years and Next 3 Years By Type of Company)

Dodge Data & Analytics, 2020



Most Frequently Prefabricated Assemblies

CONTINUED

Frequency of Using Specific Types of Single-Trade Assemblies

The companies that reported using single-trade assemblies were asked to indicate how many specific types they have used. The chart at right shows those results.

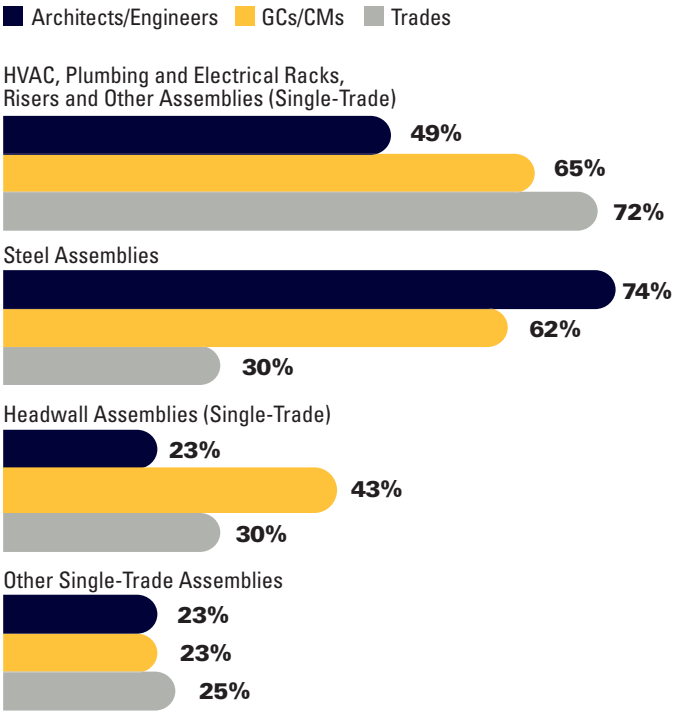
- **The growth of prefabrication in healthcare and similarly MEP-intensive projects gives rise to the high percentage of all respondents citing racks, risers and other single-trade assemblies,** especially among trade contractors who can often make the decision to prefabricate their trade's part of the work without significantly impacting or involving other trades.
- **Steel assemblies are a well-established use of single-trade prefabrication,** as demonstrated by the high percentage of architects (74%) indicating experience with them.
- **Single-trade headwall assemblies are a healthcare specialty, frequently involving piping for medical gases. The relatively low percentage of trade contractors citing their use (30%) is more a reflection of the fact that this is most frequently done by mechanical contractors,** which represent only a portion of all trade contractors participating in this study.

The "Other" category of single-trade assemblies identified by respondents includes aluminum storefront, a variety of precast concrete elements, millwork, wood framing and trusses, subfloor systems, equipment skids and racks for conduit or equipment.

Percentage of Companies Using Specific Prefabricated Single-Trade Assemblies

(Past 3 Years, By Type of Company)

Dodge Data & Analytics, 2020



Frequency of Using Multi-Trade Assemblies by Company Type

Similar to the question about single-trade prefabricated assemblies, respondents identified the percentage of projects where they have used multi-trade assemblies over the past three years, and the percentage on which they are likely to use them over the next three years.

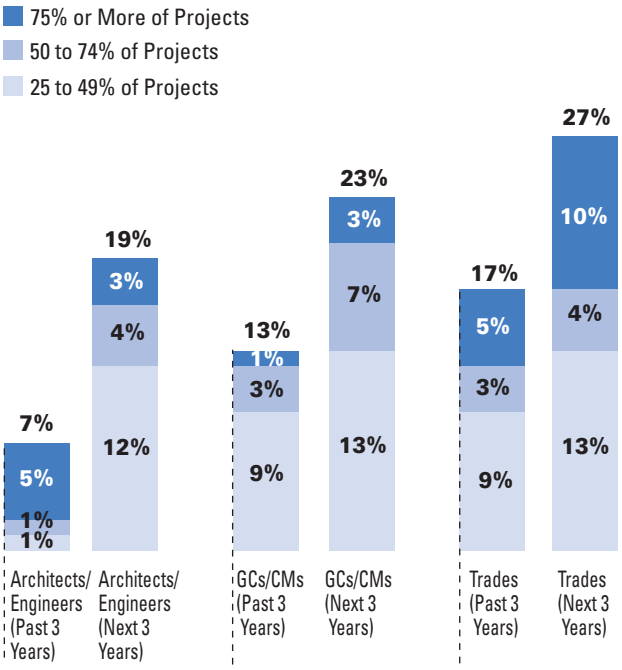
The chart at right shows that, although the total percentages predicting use of multi-trade assemblies on over half of their projects is notably smaller than with single-trade ones, all respondents are predicting very strong growth over the next three years.

- **Trade contractors have the highest level of use** currently of multi-trade assemblies.
- **A 10-point increase is expected in the next three years among both GCs/CMs and trade contractors** in this area. Trade contractors in particular see the most dramatic growth on the high end of the scale.
- Designers lag in their use of these approaches, but the **participation is expected to more than double** in the next three years.
- **Design professionals will need to enable multi-trade assemblies in their design solutions** in order to support the ambitious targets all of these groups are setting.

Percent of Projects With Prefabricated Multi-Trade Assemblies

(Past 3 Years and Next 3 Years by Type of Company)

Dodge Data & Analytics, 2020



Most Frequently Prefabricated Assemblies

CONTINUED

Frequency of Using Specific Types of Multi-Trade Assemblies

The companies that reported usage were asked to indicate how many specific types they have used. The chart at right shows those results.

- **Like the findings for single-trade assemblies, two thirds of GCs/CMs and three quarters of trade contractors report experience over the past three years with MEP-oriented multi-trade assemblies.** Coupled with the overall strong forecasts for growth by these groups, this suggests that these assemblies are well on their way to becoming standard practice for MEP-intensive projects.
- **Also like the findings for single-trade steel assemblies, over half of design firms cite experience with multi-trade curtainwall and exterior wall assemblies,** which also bodes well for future growth.
- **Past experience using interior wall or soffit panels also scores well and should increase as the overall market for prefabricated assemblies continues to mature.** This familiarity among nearly half of designers and GCs/CMs also may presage a rapid adoption of modular versions of these types of assemblies.

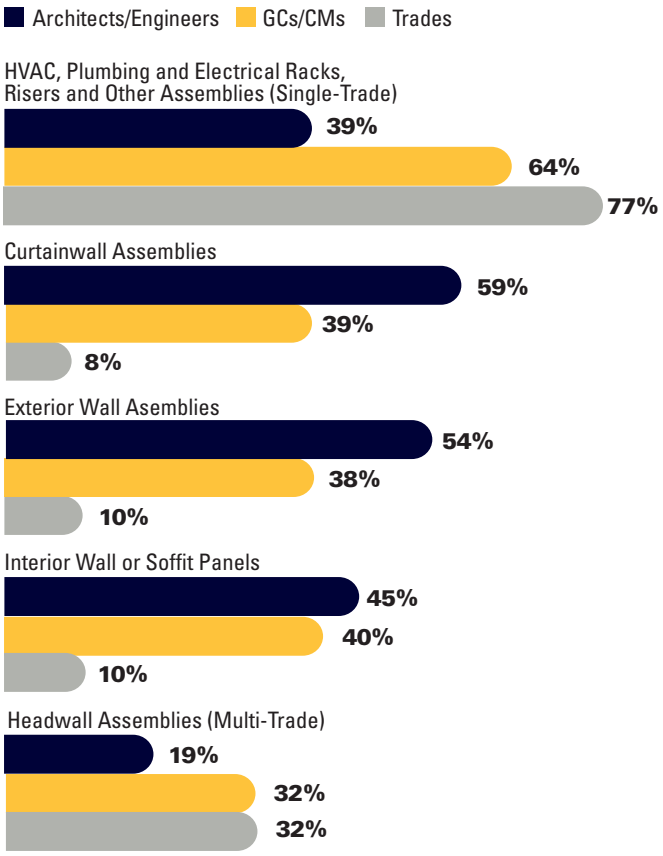
BIM Use Has a Strong Impact

As the matrix below demonstrates, the level of BIM use impacts the predicted frequency of both single and multi-trade assemblies, further reinforcing the powerful role of model-driven prefabrication.

Percentage of Companies Using Specific Prefabricated Multi-Trade Assemblies

(Past 3 Years by Type of Company)

Dodge Data & Analytics, 2020



Percentage of All Respondents Predicting Frequency of Prefabricated Assemblies

(by Level of BIM Usage)

Predicted Use of Assemblies on Projects in Next 3 Years	No (0%) Projects Use BIM	Use BIM on Less Than 50% of Projects	Use BIM on 50% or More of Projects
Over 50% Single-Trade	27%	27%	51%
Over 11% Multi-Trade	16%	41%	55%

Impact of Prefabrication

On Schedule and Cost Performance

Compliance with the project schedule and the construction budget are two of the most important metrics in the construction industry. This page of the report examines the positive impact of prefabrication on schedule and cost performance.

Schedule Performance

The chart at upper right shows the percentage of schedule performance improvement that respondents experienced over the past three years by engaging in prefabrication.

- **Trade contractors experience the greatest positive impact** with half citing better than 5% schedule compression.
- Although only 31% of design firms report a schedule benefit from prefabrication, **most of those (21%) indicate it has a very strong impact.**

Cost Performance

The chart at lower right shows the percentage of cost performance improvement that respondents experienced over the past three years by engaging in prefabrication.

- **Trade contractors are even more enthusiastic about improved cost performance (82%),** with well over half (55%) citing better than 5% budget impact.
- **Design firms are also far more positive about cost impact,** even slightly exceeding GCs/CMs in the top category.
- **GCs/CMs are about equal** with their positive evaluation of both cost and schedule improvement from prefabrication.

BIM Use Enhances Improvements

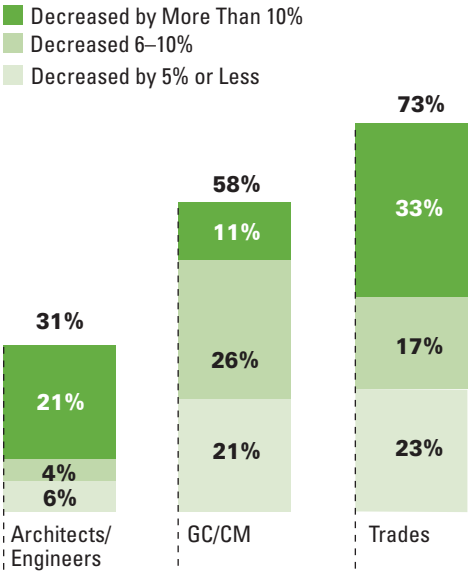
As shown in the matrix below, higher percentages of the companies that use BIM report schedule and cost performance improvements over the last three years from prefabrication.

Percentages Reporting Improved Schedule and Cost Performance From Prefabrication (by Level of BIM Usage)

	Companies That Do Not Use BIM	Companies That Use BIM on Less Than 50% of Projects	Companies That Use BIM on 50% or More of Projects
Percentage Reporting Improved Schedule Performance	22%	49%	61%
Percentage Reporting Improved Cost Performance	31%	49%	52%

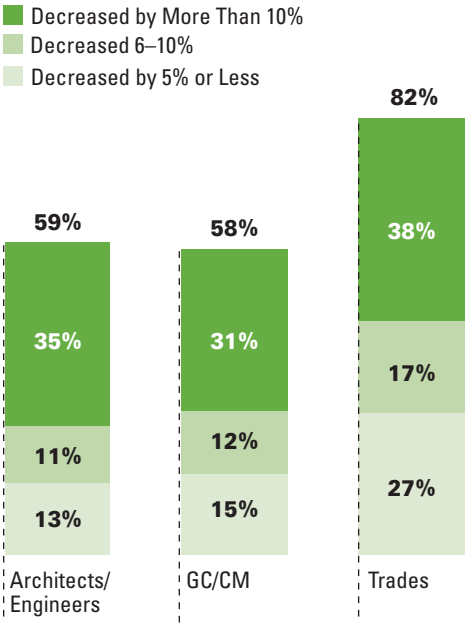
Impact of Prefabrication on Project Schedule Performance (Percentages Reporting Each of Three Levels of Improvement)

Dodge Data & Analytics, 2020



Impact of Prefabrication on Project Budget Performance (Percentages Reporting Each of Three Levels of Improvement)

Dodge Data & Analytics, 2020



Impact of Prefabrication on Seven Specific Benefits

In addition to improved compliance with project schedule and construction cost, the survey examined the impact of prefabrication on seven other specific aspects of project delivery.

RESPONSES BY COMPANY-TYPE

To examine contrasts and commonalities between their perspectives, the charts in this section of the report separately show the findings from the three main respondent groups (Architects/Engineers, GCs/CMs, Trades). In each, the order reflects the sum of their medium, high and very high rating levels.

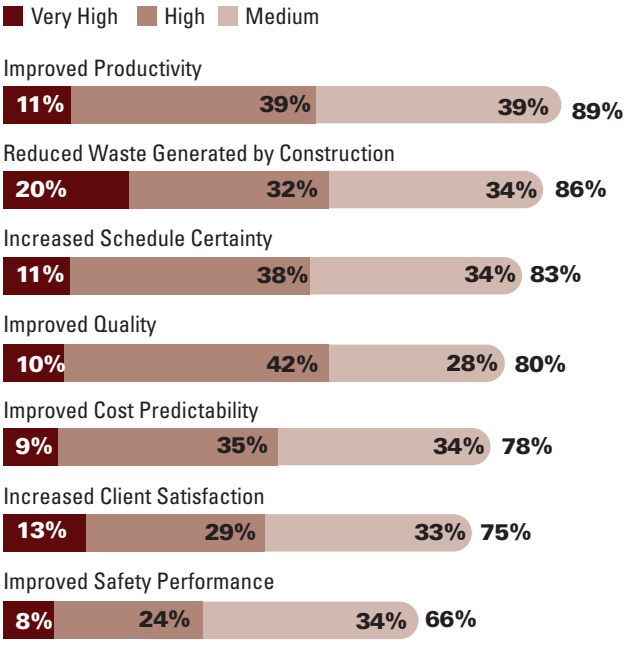
Architects/Engineers

The chart at right shows the responses from design firms in the survey.

- Although improved productivity scores first overall (89%), **reduced waste generated by construction is the second-highest rated, and, importantly, it garners the most very high impact votes (20%),** demonstrating this group's strong interest in green.
- **Two thirds (66%) cite improved safety performance,** even though design firms are less directly involved in that aspect. This finding is encouraging for the potential growth of Prevention Through Design and other means by which design solutions can actively enhance safety.
- **Three quarters (75%) report increased client satisfaction** and it earns the second-most number of first-place rankings. This should increase in the future as prefabrication usage grows, its benefits are quantified and owners are more engaged in the process of deciding what to prefabricate, all of which will contribute to their appreciation of its positive impact on project delivery.

Architects/Engineers: Impact of Prefabrication on Seven Key Performance Factors (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Impact of Prefabrication on Seven Specific Benefits CONTINUED

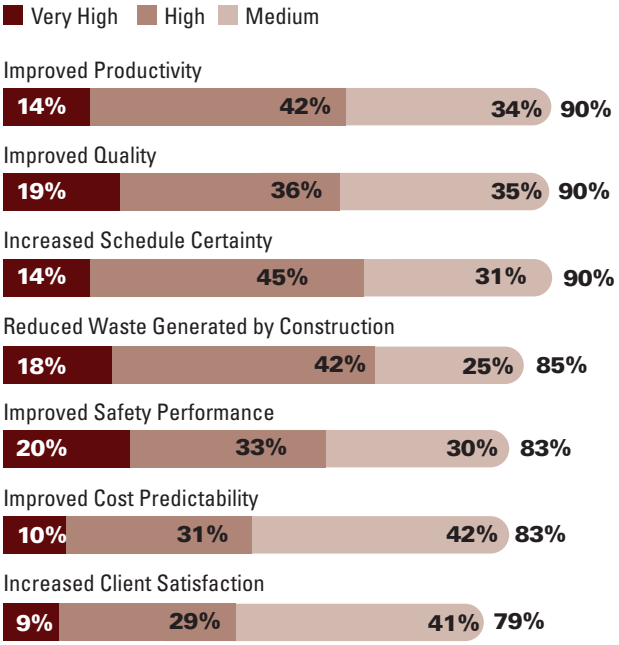
GCs/CMs

Compared with design firms, the responses from GCs/CMs shown at right are generally higher and the combined totals of medium, high and very high scores fall in a narrower overall range (79% to 90%), indicating more widespread support among these practitioners for all seven benefits.

- **Improved productivity again is highly rated (90%),** which is particularly meaningful because it is such a critical metric for GCs and CMs.
- **The impact of prefabrication on improved quality scores noticeably higher with GCs/CMs than with design firms,** both for total score (90% compared with 80%) and very high impact (19% compared with 10%).
- **90% cite increased schedule certainty**, which is a different type of schedule-related benefit than schedule reduction (see page 15). Regardless of whether an overall project is ahead, behind or on schedule, this finding suggests that prefabrication improves certainty by reducing risk of schedule variances.
- **Among the very high impact responses, improved safety ranks first (20%),** providing perhaps the most compelling reason to increase the use of prefabrication.
- **The strong very high impact score for reduced waste generated by construction (18%),** reflects an appreciation for the importance of green construction practices.

GCs/CMs: Impact of Prefabrication on Seven Key Performance Factors (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Impact of Prefabrication on Seven Specific Benefits CONTINUED

Trade Contractors

Scoring highest among all respondent groups (range of 81% to 93%), trade contractors' responses (shown in the chart at upper right) reveal meaningful differences from those of design firms and GCs/CMs.

- **The percentages of trades giving very high impact scores is significantly larger for every aspect studied,** as much as tripled over other groups.
- **Improved quality ranks first overall,** compared with second place for GCs/CMs and fourth place for design firms.
- **Their strong rating for improved safety (31% very high and 86% overall)** is especially meaningful because it is the trade contractors that provide jobsite labor.
- Even trade contractors' lowest rated benefits among the seven, **reduced waste generated by construction and increased client satisfaction both show strong very high ratings (25%) and perfectly respectable overall ratings of 81%.**

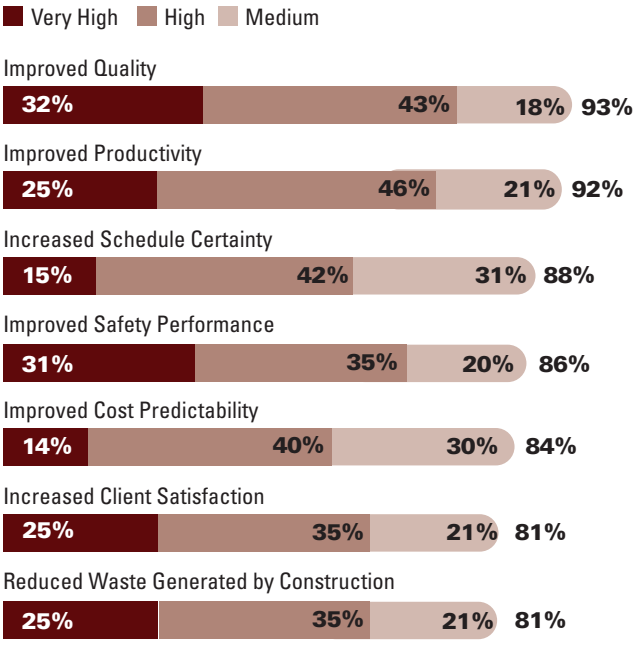
The Impact of BIM on Performance Factors

To see the impact of BIM on those receiving the top levels of benefits, the chart at lower right shows, on average across all seven of these factors, the percentage of all respondents who report high or very high positive impact from their use of prefabrication, broken down by their level of BIM usage.

- **Significantly less than half (44%) of the companies currently not using BIM report they are receiving this high level of benefit from prefabrication.**
- **By contrast, almost two thirds (64%) of those who report using BIM frequently are enjoying high levels of these performance improvements from prefabrication,** and companies still growing their BIM implementation are outperforming those that have not yet adopted, with well over half (54%) seeing improved performance.

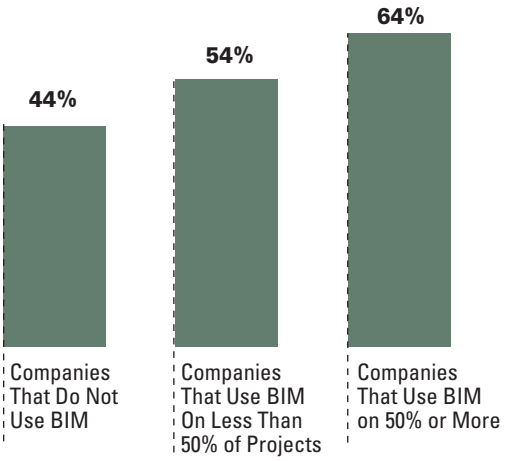
Trade Contractors: Impact of Prefabrication on Seven Key Performance Factors (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Percentages Reporting Improved Project Delivery Performance From Prefabrication
(Average Percentage Reporting High or Very High Contribution Across All Factors, by Level of BIM Usage)

Dodge Data & Analytics, 2020



Impact of Project Delivery Method on Prefabrication

Frequency of Project Delivery Method

Participants were asked how frequently various project delivery methods were in use on their projects that involved prefabrication over the past three years. The chart at upper right shows these broken out by the percentages of all respondents who cited each method as having been either first, second or third most frequent.

- As the most common project delivery method currently in use, it is not surprising that traditional design-bid-build shows the highest correlation to prefabrication projects, with 42% citing it as the most frequent.
- Design-build ranks as the second most frequent method. And when its first and second place rankings are added together, they surpass that combination for design-bid-build, certainly identifying it as a highly conducive environment for prefabrication.
- The other two methods are each included among the three most frequent by nearly half of respondents, so both have a meaningful correlation to the use of prefabrication, especially when compared with the total for design-bid-build, which occurs in the market at a far greater proportional frequency than this comparison would indicate.

Degree to Which Delivery Method Supports Prefabrication

Respondents indicating prefabrication experience with any of the methods shown in the chart at lower right were asked how much they believe that method enabled the use of prefabrication.

While all three methods garner very positive ratings, integrated project delivery and design-build both score especially well, with 30% and 26%, respectively citing significant help with their use of prefabrication.

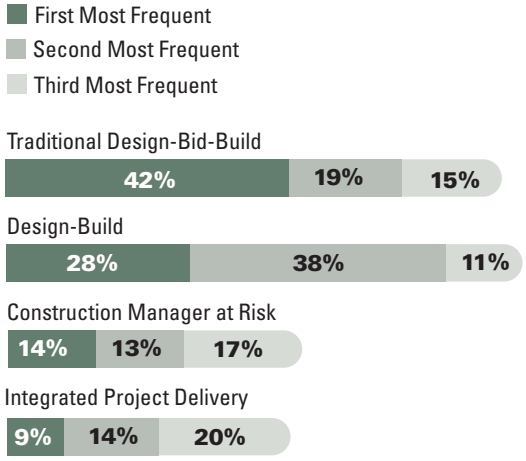
DESIGN-BID-BUILD HINDERING PREFABRICATION

Participants were also asked the degree to which they believe traditional design-bid-build hinders prefabrication. Importantly, only 18% stated that belief, so the fact that it may be in place on a project is not a legitimate reason to assume prefabrication cannot be successfully deployed.

Frequency of Project Delivery Method When Prefabrication Was Used in the Last 3 Years

(Top 3 Most Frequent Methods)

Dodge Data & Analytics, 2020



Degree to Which Prefabrication Was Enabled by the Project Delivery Method

(By Company Type)

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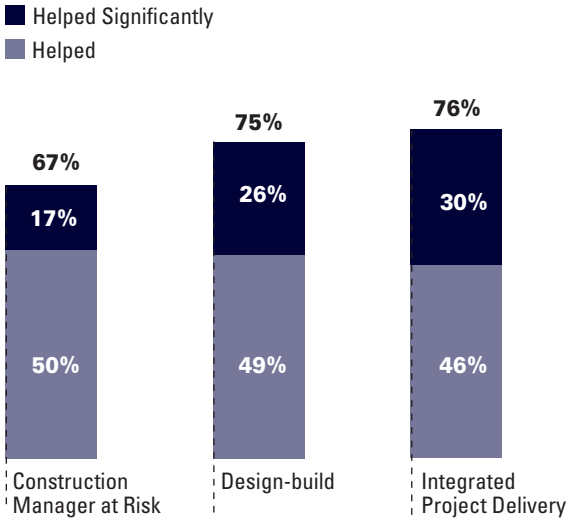


Prefabrication Suppliers and Procurement

The survey examined how participants learn about and select prefabrication suppliers and what channels they most frequently use to procure products for prefabrication projects. This part of the report addresses those findings.

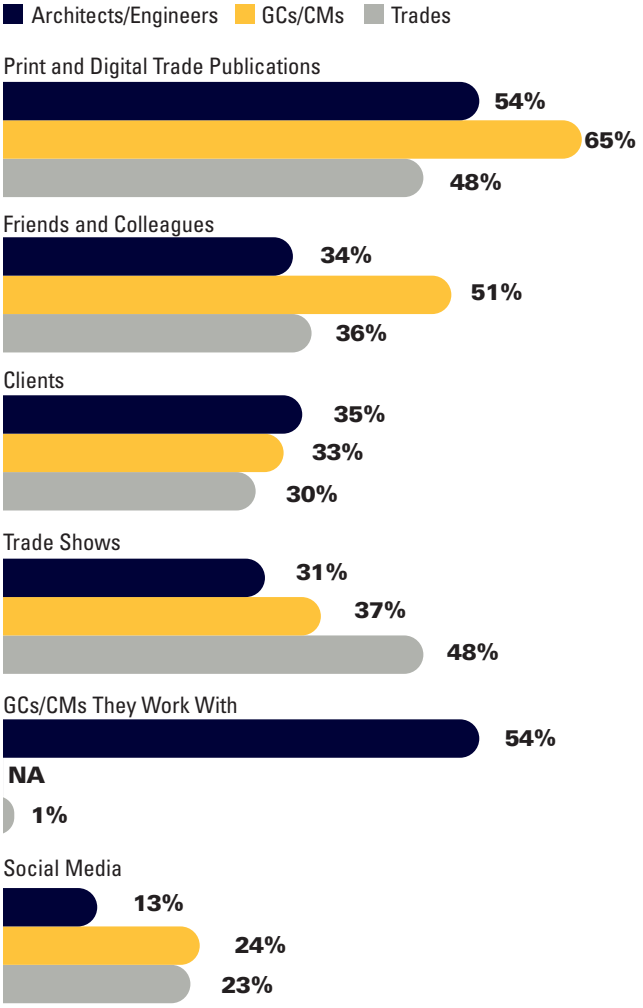
Learning About Prefabrication Suppliers

The chart at right shows where they have heard about prefabrication companies in the last six months.

- Design firms are most frequently informed through industry publications (54%) and the GCs/CMs they work with (54%).
- The GCs/CMs rely more than any other group on industry publications (65%) but are also strongly influenced by friends and colleagues (51%).
- In addition to publications (48%) trade contractors learn more than others from trade shows (48%).
- Social media is still an emerging source but can be expected to grow as its use expands in the construction industry.

Top Sources of Information About Prefabrication Companies (Percentages Citing Each Source Over the Last 6 Months)

Dodge Data & Analytics, 2020



Selection of a Prefabrication Supplier

Participants identified the one factor among six that is the most influential in selecting a supplier of prefabrication services on their projects. The chart at right shows the top four responses.

- Design firms and GCs/CMs value expertise far more than low price, owner input or any internal criteria they may have.
- Design firms are much more influenced by owners than GCs/CMs or trades, perhaps because they are not as knowledgeable about alternatives available to them.
- About half of the trade contractors that participated in this part of the survey report that they self-perform prefabrication, so they were deducted from the responses shown in the chart.

The other two options ("We use the same prefabrication company for all of our projects" and "We use whoever is closest to the project (distance-wise)") are much less influential.

Procuring Products for Prefabrication

Contractors were asked if they most often go through traditional distribution channels to procure products for their prefabrication projects or if they primarily buy directly from manufacturers.

As the matrix below indicates, while nearly two thirds (59%) of GCs/CMs and over three quarters (76%) of trade contractors report primarily going through traditional distributor channels, over one third (37%) of GCs/CMs are mostly buying direct.

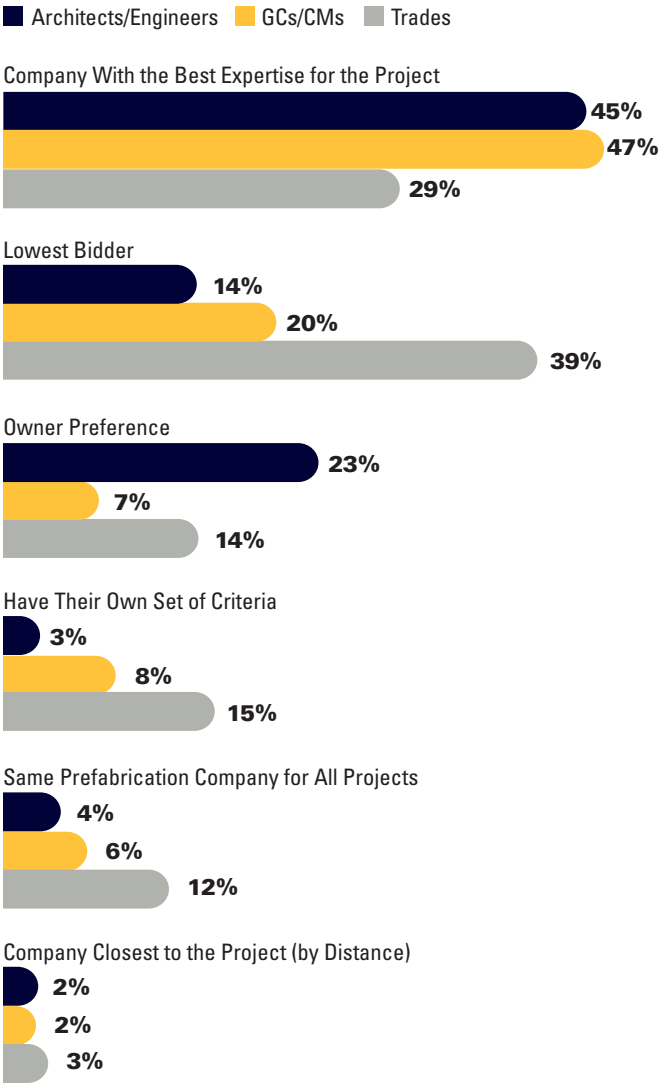
(Note that the percentages for each company type do not add up to 100% because a small percentage (4%) of each group indicated they are procuring through other methods, such as owner-procured or locked-in purchasing agreements.)

Most Frequent Method of Procuring Products for Prefabrication Projects

	Traditional Distribution Channels	Direct From the Manufacturer
GCs/CMs	59%	37%
Trade Contractors	76%	20%

Top Factor That Influences Selection of a Prefabrication Company (Most Influential From a List of 6 Factors)

Dodge Data & Analytics, 2020



Use of BIM for Model-Driven Prefabrication

Most companies (89%) that participated in the survey say that BIM is being deployed on at least some percentage of their projects (for more information on BIM engagement, see Methodology page 64). Within that group, the companies also designated for the prefabrication line of inquiry were asked about how BIM is being applied specifically to prefabrication (i.e., model-driven prefabrication). This part of the report addresses those findings.

Current and Future Implementation of BIM for Prefabrication

The chart at upper right shows the percentages of the BIM users described above that are currently engaged with model-driven prefabrication at several levels of implementation, and the percentages that believe they will be operating at those levels within the next three years.

- **The percentage using BIM for prefabrication on at least a quarter of their projects will grow dramatically,** from 44% to 75% in the next three years.
- **Within three years, virtually all BIM users (99%) will be engaged in model-driven prefabrication.**

High-Level Implementation by Company-Type

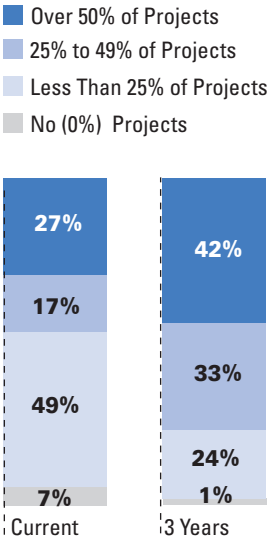
The chart at lower right shows the current and future percentages by company-type that use BIM for prefabrication on 50% or more of their projects.

- **Trade contractors are the most deeply engaged,** with over half (53%) predicting a high level of implementation in the next three years.
- Though currently the least active, **design firms will nearly double their current number of high-level implementers over the next three years,** which is a positive indicator that they will be doing more to actively enable prefabrication in their design solutions.

Percentage of BIM Users Engaged With Model-Driven Prefabrication

(Comparing Current Implementation Levels With Predicted Levels in 3 Years)

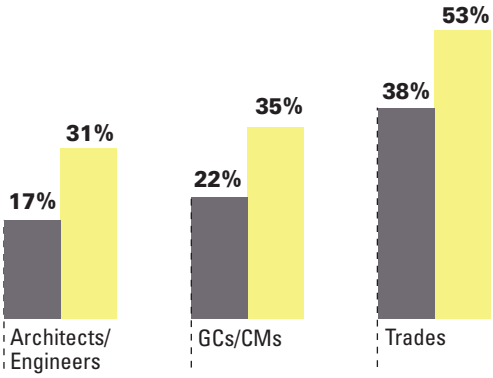
Dodge Data & Analytics, 2020



High-Level Implementation of BIM for Prefabrication by Company-Type

(Percentages Using BIM for Prefabrication on More Than 50% of Projects (Current and Next 3 Years)

Dodge Data & Analytics, 2020



Reasons to Use BIM for Prefabrication

To understand the drivers for its adoption and the expectations for its impact, current users of BIM for prefabrication were asked to select up to three reasons (from a list of 10) that they are engaging with it. The chart at right shows the leading eight reasons by company-type, with percentages indicating how many selected each to be among their top three most important. They are listed in order of the average percentage across all company-types.

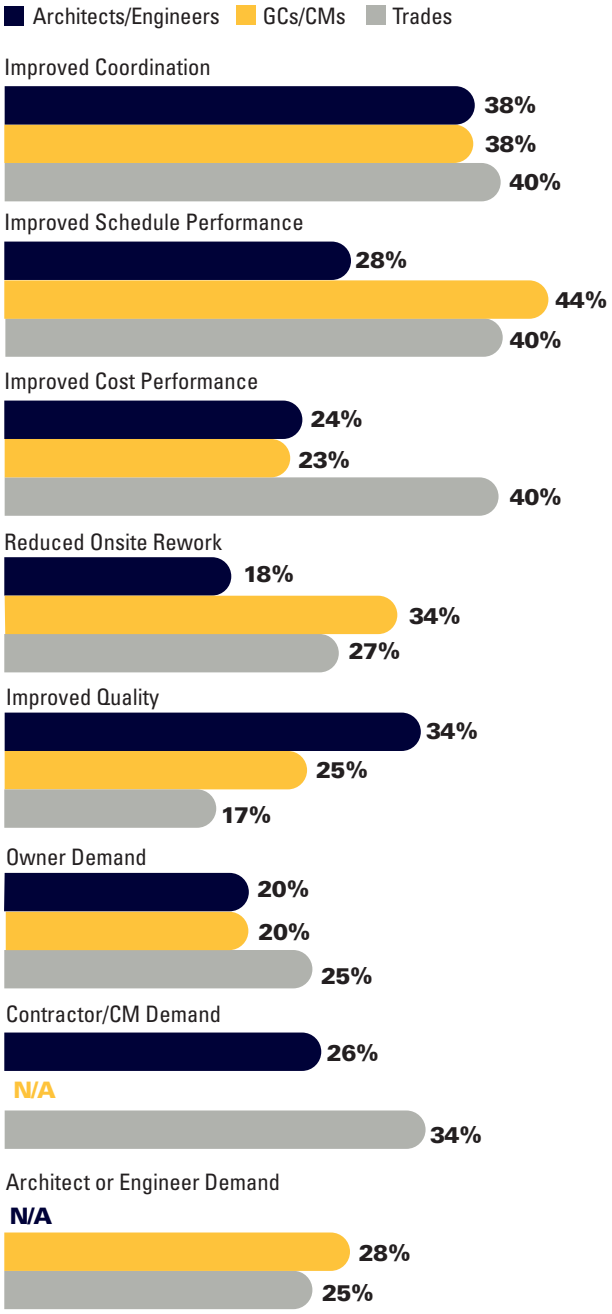
- Successful prefabrication requires comprehensive spatial coordination between systems and disciplines. These findings reinforce this by **the first-place ranking and the nearly equal acknowledgement by all the company-types of the value of BIM for improved coordination.**
- **Of equally high importance for trade contractors are improved schedule and cost performance (40% for each). GCs/CMs agree regarding schedule (at 44%, it is their top reason) but are less focused on expecting cost reductions.** This may be because trade contractors experience internal operational cost savings by prefabricating, but that may not always lower the overall construction cost, which is the concern of GCs/CMs.
- **Interestingly, twice as many design firms (34%) select improved quality compared with trades (17%),** which are more attentive to cost and schedule improvements.

MANDATING THE USE OF BIM FOR PREFABRICATION

Demand by another project team member shows significant influence in these findings, ranging from a low of 20% (from GCs/CMs citing demand from owners) to a high of 34% (from trade contractors citing demand from GCs/CMs). As the use of BIM for prefabrication grows and its benefits become more widely understood, it is reasonable to expect that its use will be mandated on an increasingly wide variety of projects.

Most Important Reasons to Use BIM for Model-Driven Prefabrication (Percentages by Company-Type Who Selected Each Reason to be Among Their Top Three)

Dodge Data & Analytics, 2020



Top Factors That Influenced Use of Prefabrication

(Last Three Years)

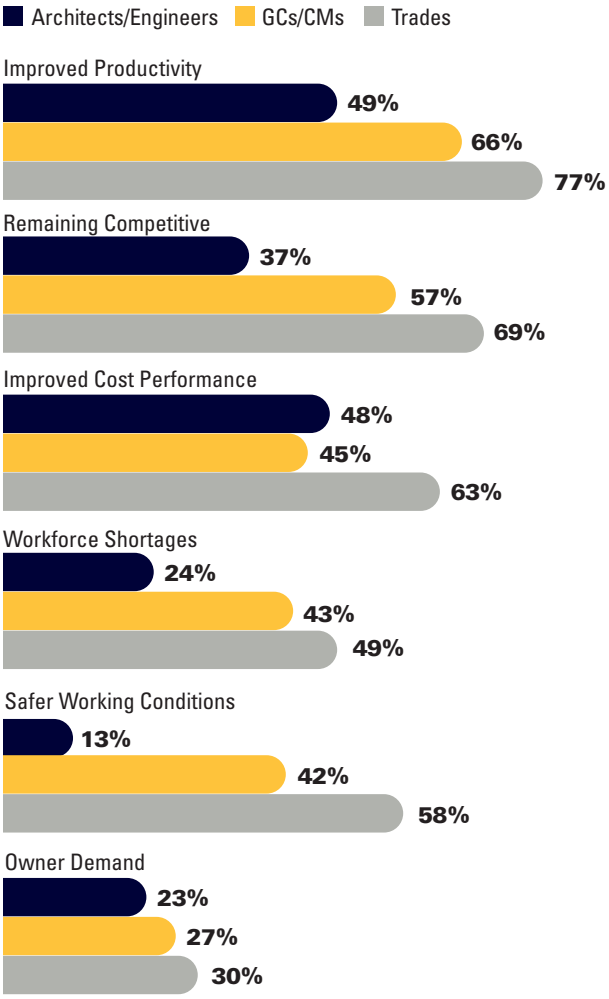
Respondents were asked to rate the level of influence that each of six factors had on their decision to use prefabrication over the last three years. The chart at right shows the percentages that cite either high or very high levels of influence, represented by company-type.

- **Larger percentages of trade contractors rate each of the factors as influential** than the other types of companies, underscoring their level of enthusiasm for prefabrication found throughout the survey results.
- **All three company types rate improved productivity highest for its influence,** reinforcing similar findings for the top benefits generated by using prefabrication (see pages 16, 17 and 18).
- **Remaining competitive is the second most influential factor for GCs/CMs and trades,** and it ranks third for design firms, indicating that prefabrication capability is becoming an expectation in the marketplace.
- **Improved cost performance ranks second highest with design firms,** even slightly outscoring GCs/CMs. This demonstrates that architects and engineers understand prefabrication can have a positive influence on cost control and should lead to more development of design solutions that consciously enable it.
- As with the evaluation of safety as a benefit of prefabrication (see page 18), **safety scores far higher with trade contractors because of its direct impact on their workforce.**
- Speaking of workforce, although **fewer than half of GCs/CMs and trades rate workforce shortages as a strong influence over the past three years,** this may change if the current workforce challenges continue.
- Owner demand has been the least influential factor, but this should change as they become more aware of the benefits, more familiar with the process and more comfortable with the outcomes.

Top Factors Influencing Use of Prefabrication in Last 3 Years

(Percentages Citing High or Very High Level of Influence)

Dodge Data & Analytics, 2020



Top Positive Impacts That Will Drive More

Prefabrication in the Next Three Years

To understand their future expectations, participants were asked to identify which benefits they believe will be the most influential to drive more prefabrication over the next three years. The percentages in the chart at right represent how many from each type of company predict a high or very high level of influence. The order reflects the averages of their scores.

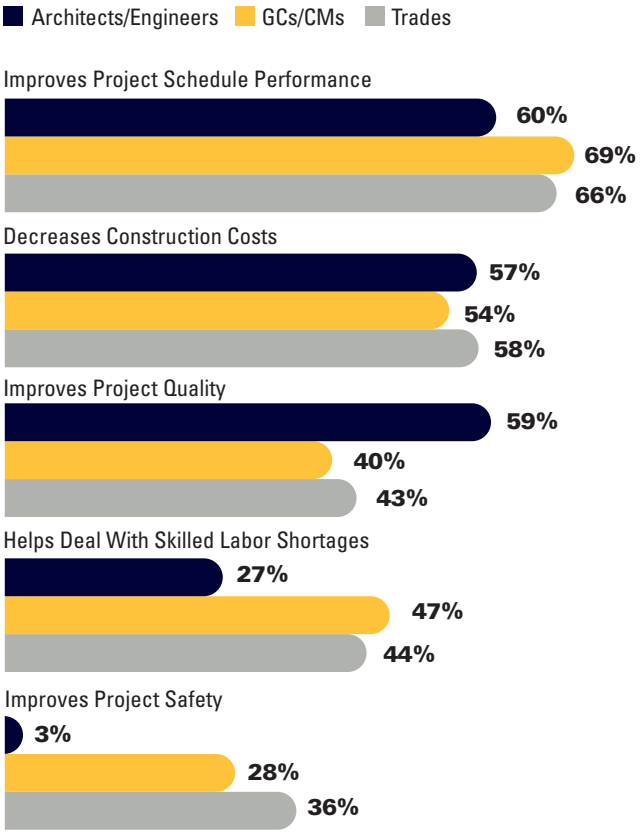
- All respondents agree that **improving project schedule performance will be the top future driver** for prefabrication.
- **Decreasing construction cost is almost as highly rated,** and, similar to the findings for past influences, it is even more influential with design firms than with GCs/CMs.
- **Improving project quality** is third-ranked overall and is a particularly high demand from design firms, which suggests these companies are ready to embrace prefabrication as a valid element of their design solutions.
- **GCs/CMs and trades will be very focused on prefabrication's positive impact on workforce and safety in the coming years.**

Impact of Industry Resources

As shown in the matrix below, about half the respondents believe externally developed resources would also help to drive future use of prefabrication.

Top Impacts That Will Influence Use of Prefabrication in the Next 3 Years
(Percentages Forecasting High or Very High Level of Influence)

Dodge Data & Analytics, 2020



Impact of Industry Resource on Use of Prefabrication (Next 3 Years)
Percentages Indicating High or Very High Level of Influence

	More Availability of Prefabricated Components	Design Guides or Standardization for Prefabrication	BIM Objects for Prefabricated Components
Architects/Engineers	58%	59%	41%
GCs/CMs	60%	47%	40%
Trade Contractors	46%	46%	47%

Top Obstacles Inhibiting More Use of Prefabrication

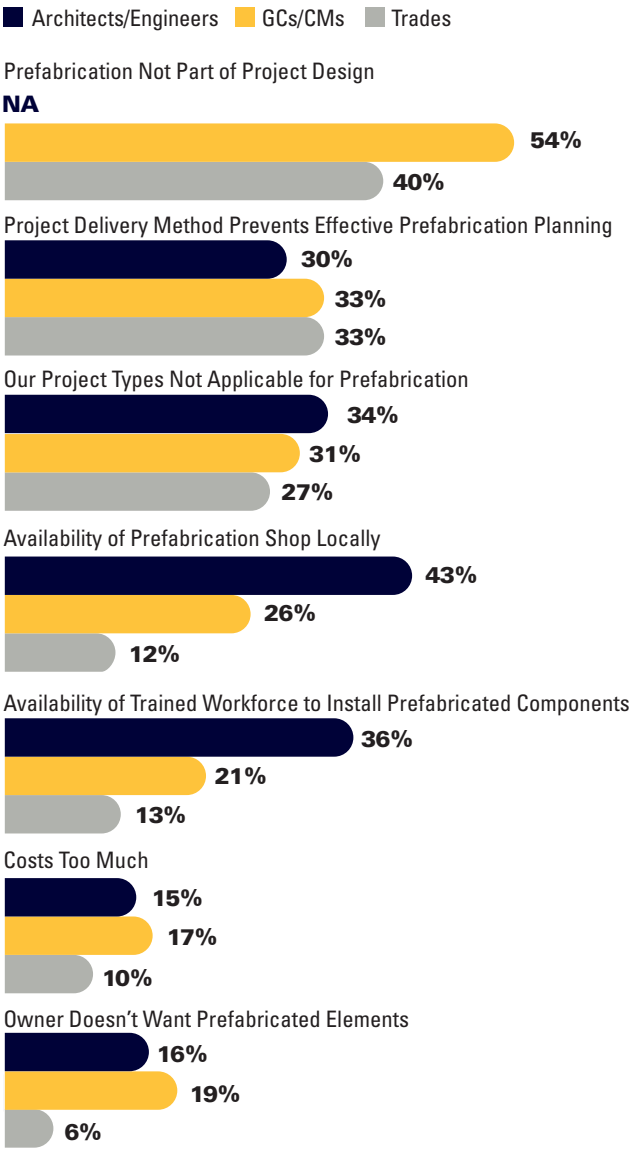
Having rated the benefits and the drivers, respondents also identified the three biggest obstacles (from a list of 10) that they believe are preventing their companies from doing more prefabrication. The percentages in the chart at right represent how many, by type of company, selected each obstacle among their top three. The order reflects the averages of those scores.

- **Prefabrication not being part of a project's design is the top obstacle for both GCs/CMs and trades.** Since design firms report experiencing significant benefits from prefabrication (see page 16), this should be a strong message that they need to develop design solutions that more effectively enable it.
- **Project delivery method and the type of project are both about equally cited by all company types.** These may improve as prefabrication becomes more of a standard practice regardless of delivery method and more types of assemblies are developed for use in a wider variety of project types.
- **Availability of local facilities and trained labor to implement prefabrication are not major obstacles for GCs/CMs and trades,** even though design firms identify them as their greatest concern.
- **Trades express very low concern about owners not wanting prefabrication,** perhaps because they often implement it as an internally driven business practice regardless of owner permission or awareness.

Very small percentages (average 10%) cite either of two other obstacles that were included in the survey: Inspection uncertainty and concern about quality.

Top Obstacles to Increasing Numbers of Projects That Use Prefabrication
(Percentages That Include Each Factor Among Their Top Three Out of 10)

Dodge Data & Analytics, 2020



Prefabricated and Modular Multifamily

Housing crises in multiple major US cities are driving interest and municipal support for prefab residential developments, but regulatory hurdles remain.

Despite some growing pains, factory-built housing is finally on an upswing. Faced with rising housing costs, cities in particular are beginning to invest in offsite construction as a way to deliver multifamily residential developments at a rapid pace.

Housing Shortages

Across the US, prefab and modular construction are being employed to help alleviate the housing shortages that plague metro areas such as San Francisco and New York City. Municipalities' embrace of offsite construction comes amid one of the greatest housing crises in American history. "We in the US have never had such a perfect storm of significant increases in labor rates, material costs, land costs and permit fees meeting diminished labor and increased demand," says Steve Glenn, the CEO of Plant Prefab, whose Nest LivingHomes concept won $1 million in the Los Angeles County Housing Innovation Challenge in 2018.

In San Francisco, where the average price of a two bedroom apartment is between $2,400 and $3,650, the city is exploring partnerships with modular builders in order to address the housing crunch, while New York City recently entered into an agreement with Brooklyn-based FullStack Modular to deliver 167 units of affordable housing in East New York. The support of local governments has meant growth for companies such as Plant Prefab, which has tripled its revenues and its workforce in the past year.

Time Savings

The primary financial benefit of offsite construction, from a developers' perspective, is the speed with which prefabricated building components—in some cases fully finished modules—can be assembled. A 2019 report from McKinsey & Company found that although early modular projects had a mixed track record of cost savings, more recent projects "have consistently been completed 20%–50% faster than traditional onsite builds."

Because building components are built inside a factory, oftentimes concurrently with sitework, when they arrive onsite, all that is left to do is crane them into place. In Oakland, a 110-unit apartment project led by Holliday Development and built by its sister company, Factory OS, was erected in 10 days. In Vancouver, the 52 units of M. Mitchell Place, a transitional housing development by Vancouver Affordable Housing Agency, were constructed offsite and craned into place in three days.

Continued Integration

For private housing developers, reducing onsite construction time means that units can be occupied more quickly, resulting in quicker returns, as well as less exposure to market cycle risks. At the same time, prefabrication often means increased upfront design and logistics costs, depending on the nature of the project.

For this reason, builders and manufacturers are increasingly integrating the roles of design, fabrication and construction through acquisitions or strategic partnerships. In 2018, CertainTeed, a leading materials manufacturer, partnered with Unity Homes to develop higher-performance assemblies and components for factory-built housing. "We are trying to connect the dots between the companies that design and build, and those that make and supply the materials and parts for those buildings," says Sarah Kossayda, the communications director for Bensonwood, the owner of Unity Homes. "We hope to establish the basis for a homebuilding operating system, leading to better industry cohesion."

Hurdles to Growth

Although the industry is poised for continued growth, challenges remain. The news that RAD Urban, an Oakland-based modular housing developer, would be laying off 170 employees at its factory in Lathrop, Calif., combined with concerns over the rapid growth of startups such as Katerra, which has raised more than $1 billion in venture capital funding and acquired several leading architecture firms, have fueled a sense of uncertainty.

States also need to amend building codes to better fit the realities of offsite construction, Kossayda says, citing California as a leader. "States, districts, cities and towns all have different codes and programs," she says, "or they don't have a program and they're not able to accept our third-party certification. Duplicate efforts are driving the price up and making it difficult for prefab and modular structures to be built." ■

Define Disruption

Enthusiasm for the benefits of prefabrication and modular construction is often also shadowed by concerns about whether they will be a disruption to the standard business of construction.

Nowadays it's a common point of view that construction is ripe for disruption, and prefabrication is one of the technologies to do it. But each of those three terms is wide, and participants in the conversation (researchers, consultants, industry practitioners and media pundits) often use them loosely, to the point where confusion arises about what's really going on. For developers, project delivery teams and manufacturers wanting to get ready for changes coming over the horizon, it may be helpful to get a clearer view of the landscape.

Coming to Terms

First, prefabrication. Based on input from our subject matter experts, this report distinguishes between "prefabrication" and "modular construction." While both are types of offsite construction, modular construction is a factory-based process, producing building components or modules, which are then transported to site. Modules may be volumetric, (like the ones used in citizenM Bowery, Coliseum Connections and Union Flats, profiled in this report) or a kit of panelized, flat-packed parts (for example, the IKEA-sponsored Urban Village Project). While prefabrication can achieve great results, it's modular construction that's generating the talk of disruption.

Second, construction. It isn't the construction industry as a whole that's affected. It's mainly the housing and hospitality sectors that are now ripe for this particular innovation. (Panel-based systems are adaptable to a range of building types, but that's a separate story on its own timeline.) The advent of startups such as Katerra, Entekra, Factory O/S, Stack Modular, Blueprint Robotics, Z Modular, Blokable, Kasita and BONE Structure; the vertical integration of legacy construction firm Skender as it pivots to modular; and the upscaling and/or upskilling of established volumetric builders such as Clayton, Bensonwood (with Unity Homes), and Guerdon—to name a few—are aimed at housing and/or hospitality construction almost exclusively.

So does—or will—the rise of modular construction in the housing and hospitality sectors constitute a disruption? In day-to-day usage, a disruption is a major disturbance in the way things are done. But in business, the word means something more specific. Here's how the originator of the business usage, Clayton Christensen, professor of business administration at Harvard University, encapsulates the idea:

"Disruption" describes a process whereby a smaller company with fewer resources is able to successfully challenge established incumbent businesses… Entrants that prove disruptive begin by successfully targeting overlooked market segments… [and] then move upmarket, delivering the performance that incumbents' mainstream customers require, while preserving the advantages that drove their early success. When mainstream customers start adopting the entrants' offerings in volume, disruption has occurred.

Alternatives to disruptive innovations include sustaining innovations that make incremental improvements on previous practice, and radical innovations that introduce new products or processes that completely replace existing ones.

So in business terms, what's happening now with the rise of modular construction isn't accurately described as a disruption. "We don't yet see any major 'disruptions' in this sector, certainly not in the US," says industry expert Ivan Rupnik, associate professor at Northeastern University's School of Architecture.

He and Ryan Smith, director of Washington State University's School of Design + Construction, see utility in distinguishing between an "industry" and a market or business sector, and they make the case that the absence or minimal presence of qualifying factors—such as a focus on productivity, efficiency and improvement, manufacturing-based and factory-oriented production processes, and a critical mass of companies to foster competitiveness—means that modular construction in the US is not yet an established industry. Before there can be meaningful talk of disruptive, sustaining or radical innovations, the industry needs to develop.

Developing an Industry

Development as an industry will include practices that new and renewing companies are now introducing: vertical integration, supply chain management, standardization, incremental improvement, data, operational management, lean practices and new labor practices, for example. Fabricators will need to understand their ecosystem, and upgrade their capacity and competence. They'll need to cultivate relationships—with regulators, researchers, investors and unions—invest in research and development, embrace technology, make iterative improvements to their products, connect to markets and manage the risks of fixed plant costs in a volatile market sector.

Across the entire supply chain, owners, design teams and general contractors will need to develop the new skills and knowledge that procuring modular systems requires. Design teams will need to optimize their decisions for modular construction: looking for opportunities for standardization to facilitate mass customization, taking account of transportation and assembly, and making decisions much earlier than they're used to. That includes the decision on whether to use modular construction in the first place. It isn't always the best way to go; and, even when it is, research suggests that making a commitment to modular at or later than the design development stage will end up costing the project more than if the team had continued with conventional construction.

Project delivery will depend on earlier access to financing: draws to support the start of superstructure fabrication are needed sooner than in a conventional process. Integration of project design and delivery teams, now still the exception, will need to become the norm. Scope will change: general contractors can expect to see 65% to 70% of a contract executed in a factory, for example. Module and panel setting and assembly require a redesign of the construction process to include near-site staging, or just-in-time delivery.

Permitting and code officials will need to be brought on board. When the manufacturer and the jobsite are located in separate jurisdictions, complexities will compound. Projects may need to hire a third-party inspector to act on behalf of the authority having jurisdiction. To get out in front of this issue, at least one modular manufacturer, Katerra, is seeking to pre-certify its systems with major municipalities across the country.

Even building supplies can be expected to change. All the large building product companies are taking this seriously, says Rupnik. They're looking at their product lines and considering what they'd change if tomorrow, instead of selling products to distributors and installers, they started supplying factories making 60-ft.-long modules, with a robot doing the lifting.

It may be tempting to refer to this widespread change as a "disruption." The word is fittingly dramatic. But it mischaracterizes what, in business terms, is really happening, and it may misdirect businesses that are considering the strategies available to them. As companies develop a map for navigating the housing and hospitality sectors' evolving terrain, they may be better served by what Smith calls "a more judicious and careful way of explaining it." ■

National Institute of Building Sciences Offsite Construction Council: https://www.nibs.org/page/oscc_resources
Modular Building Institute publications: https://www.modular.org/HtmlPage.aspx?name=foundation_resources
ModX publications: https://www.modx.network/media
Ryan E. Smith and John D. Quale, Offsite Architecture: Constructing the Future, Routledge, 2017.

Hares and Tortoises

A Global Perspective on Modular Construction

The findings of this report demonstrate the benefits of modular construction, but it still has not seen wide use in the US. Understanding what has led it to flourish in other markets globally may suggest ways to encourage broader use in the US.

There's little sign of it today, but the US was once a modular construction pioneer. Back in the 1960s, the Department of Housing and Urban Development (HUD), in collaboration with the Department of Defense, initiated Operation Breakthrough, a demonstration project for the commercial potential of modular construction. Despite significant public funding, Operation Breakthrough did not in fact break through; it was discontinued in 1975 due to a lack of private sector uptake. Today modular construction accounts for less than 4% of America's housing market.

In the meantime, other countries have developed modular housing manufacturing into viable industries. In Sweden, panelized construction displaced conventional methods to the point where it now accounts for more than 80% of all housing construction. In Japan, panelized and volumetric modules account for some 20% of the million-odd new single and multifamily homes built annually. In Poland, thriving steel and furniture industries have cross-pollinated to produce modular construction companies exporting to the international hospitality sector. In Singapore, pressure from the government's productivity-focused Building and Construction Authority is speeding the growth of modular (mainly in precast concrete), with an initiative now underway to export the country's rapidly developing expertise to India. The government of Hong Kong is piloting modular in its public works projects, with the most recent budget injecting US$128 million to support innovation in construction technology, including modular. China's growth in this sector is nothing short of astounding.

Why Has Modular Taken Off in Some Countries and Not Others?

Among factors contributing to the viability of modular construction, a 2019 McKinsey report identifies unmet housing demand and the relative scarcity and high cost of construction labor as the most significant indicators. (Additional supply-side factors include supply chain logistics and access to materials, while demand-side factors include site constraints and consumer perceptions of quality, with regulatory context as an over-arching factor.) Mapping the two primary predictors along X and Y axes shows Sweden and Japan in the top right quadrant. Also present in that quadrant are Australia, the United Kingdom,and America's West Coast, suggesting strong potential for growth in those lagging markets.

A six-country analysis in 2016 by Australian researchers Dale Steinhardt and Karen Manley found the uptake of modular construction to be a function of four main determinants: a large housing industry, with a sudden spike in demand; a consumer preference for new rather than renovated housing; state ownership or policies that promote prefabricated dwellings; and a large multiresidential building sector. The report also highlights the need for better data: Despite many years of active academic and industry interest, the authors say available data on prefabrication uptake internationally is still insufficient to support robust conclusions. Even so, it's clear the US is lagging.

The upside of falling behind is the opportunity to learn from the front runners. A focus on the enduring success of modular construction in Japan and Sweden, and the recent growth in Poland, may yield the most productive insights. "What we've seen in China and Singapore is impressive numbers and impressive speed," says Ivan Rupnik, associate professor at Northeastern University's School of Architecture, "but if we're talking about sustainability, and working within a free market, in societies with competition, then Japan, Sweden and Poland continue to be the countries that are doing very, very innovative things in ways that the US can learn from."

Learning From the Leaders

With a modular construction industry nearly as old as America's, Japan is now the most automated market in the world, says Rupnik, "so automated that they haven't changed

their equipment for 20 years, and it's still probably 20 years ahead of even the Europeans." Light gauge steel is the primary material used in the country, although light wood is not uncommon. And while panelized systems predominate, volumetric modular is growing. Arguably the single most significant factor in that growth is a regulatory and inspection system specific to the sector.

In its early days, Japan's modular industry emphasized affordability and speed, but soon shifted to marketing its advantage in quality. Supporting that, proprietary software and an expanded role for architects (including at point of sale) facilitate a high degree of customization and increased client satisfaction without sacrificing standardization in fabrication or predictability in delivery.

Sweden's modular industry is exceptional in its degree of automation, sustainability and market share. It is unique in its double-digit percentage of taller buildings (multifamily and/or hospitality) using modular. Having started in panelized construction, the country's major modular manufacturers began experimenting in the 1990s (in the context of regulatory, market and funding changes) with a value-added process for turning panels into volumetric modules. With Sweden's light-wood volumetric modular housing now surpassing eight stories in height, the method competes with concrete frame construction.

Sweden's vertically integrated companies participate to varying degrees in design and development as well as fabrication. They market modular construction as a green technology, a strategy that has proven successful with consumers and also anticipates stricter environmental regulations coming down the pipe.

Poland is a recent arrival on the modular construction scene. It is notable for translating its unique strengths—the second largest furniture industry in the world (after China) and a major steel industry—into two competing export-based volumetric fabricators almost entirely focused on supplying the hospitality sector. Between them, they have so far shipped units to hotel developments in Holland, France, the United Kingdom, Germany and the US. "Poland continues to be the only country that's delivering to hospitality sector specifications," says Rupnik. "China hasn't. Singapore hasn't. We in the US haven't."

While American manufacturers and other actors in housing and hospitality can learn from many aspects of these countries' experience, one of the most significant aspects pertains to corporate culture: "the way that labor is treated, the way that craft and know-how are valued across the board," says Rupnik. In global front-runners' facilities, instead of unskilled or temporary labour, "it's all people who are very much involved in the entire practice," he says. That's a major factor in public sector support for offsite construction in leading countries. "It's perceived as an industry that produces high-quality, secure jobs," says Rupnik. "That's something politicians like. And something we don't associate with construction in this country."

America's modular manufacturers can learn a great deal from the successes of their international counterparts, and potentially save themselves a lot of effort. But it takes humility to learn from the success of others. "Sweden, Japan and Poland are much more humble in saying, 'America's done some neat things; we need to learn from them.' They've been learning from us since the '70s," says Rupnik. "But we in the US have not done our homework. We are not looking at them enough." ■

That number excludes relocatable buildings. Adding them in would bring it closer to 9 or 10%.
Bertram, Nick et al. (2019) Modular Construction: From Projects to Products.
Japan, Sweden, Germany, Netherlands, United State, United Kingdom.
Steinhardt, Dale A. & Manley, Karen (2016) Adoption of prefabricated housing – the role of country context. Sustainable Cities and Society, 22, pp. 126-135.
Smith, Ryan E. & Rupnik, Ivan (2018) 5 in 5 Modular Growth Initiative: Research Roadmap Recommendations; Modular Building Institute, p. 13.

Use of Specific Types of Modular Construction

Frequency of Using Panelized Modular Construction

The chart at upper right shows the percentage of projects on which respondents, by company-type, say some type of panelized modular construction was used over the past three years and the percentage on which they believe it will be used during the next three years.

- **Design firms report the greatest current use,** and while the overall number predicting future usage does not increase, the percentage of projects using panelized modular construction shows growth.
- **Trade contractors show the most future growth,** although their overall usage is lower than the other groups because not all of them do work where panelized modular construction applies.

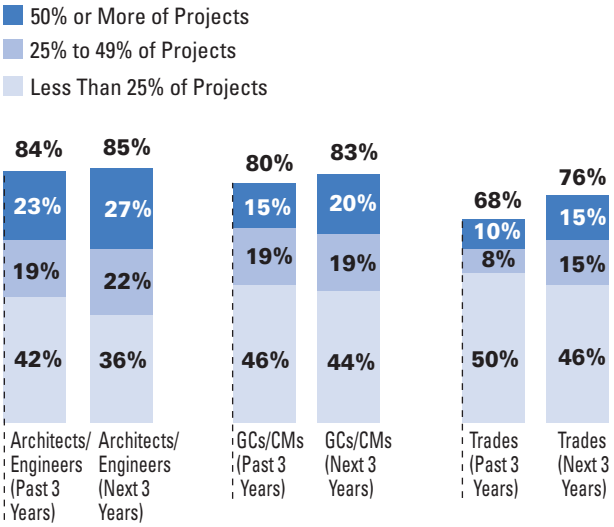
Types of Panelized Modular Construction Being Used

The respondents reporting some level of panelized modular construction usage were asked to identify, from a list of four specific types, which ones they have had experience with on their projects over the past three years. The chart at lower right shows that breakdown.

- **Wall modules are the most frequent among the four types of panelized modular construction,** especially by the architects who participated in this part of the survey (95%), who report higher usage than the engineers.
- **High proportions of both design firms (69%) and GCs/CMs (77%) report using structural insulated panels over the past three years.** It makes sense that fewer trade contractors (45%) report use because many do not work on the building envelope.
- **Nearly half of design firms and GCs/CMs have utilized modular roof panels.**
- **The relatively high percentage (47%) of design firms using modular floor panels may generate a future uptick among contractors** (currently at 32%) because they will ultimately be implementing the design solutions that involve the modular floors.

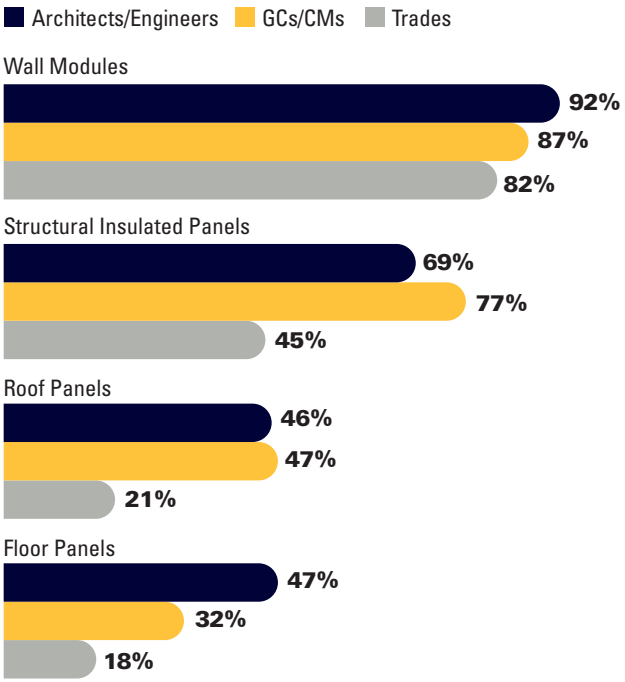
Percentage of Projects Using Panelized Modular Construction
(Past 3 Years and Forecast for Next 3 Years)

Dodge Data & Analytics, 2020



Percentage of Projects Using Types of Panelized Modular Construction (Past 3 Years)

Dodge Data & Analytics, 2020



Frequency of Using Full Volumetric Modular Construction

Today, full volumetric is less frequently used than panelized modular, but future predictions are strong.

- **Over one third of design firms (36%) forecast significant involvement (25% or more of their projects) with full volumetric over the next three years,** compared with less than a quarter (24%) of them over the past three years.
- **GCs/CMs forecast the greatest future use,** with one quarter (24%) predicting they will see full volumetric on half or more of their upcoming projects, and only 13% anticipating no involvement.
- **Trades show the biggest projected rise in total users (59% to 75%).**

Types of Full Volumetric Modular Construction Being Used

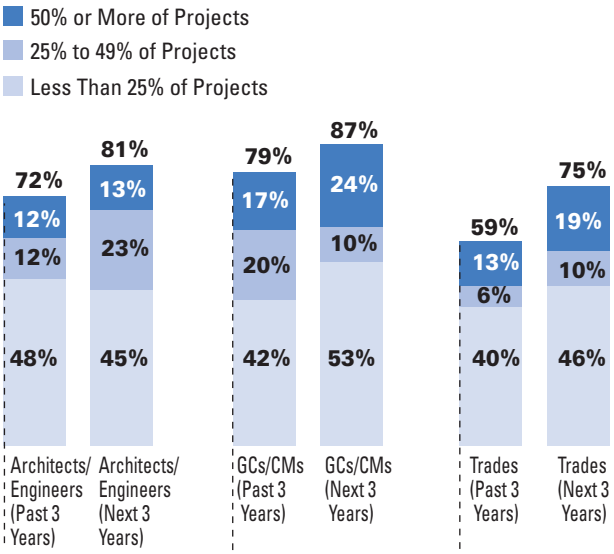
Similar to the frequency evaluation of the specific types of panelized modular, respondents reporting some level of usage of full volumetric modular were asked to identify, from a list of three, which ones they have had experience with on their projects over the past three years. The chart at lower right shows that breakdown

- **3D modules meant to be joined together onsite are the most frequently used among the three types,** with similar percentages reported by design firms, GCs/CMs and trades.
- **Experience with a flat-packed construction system for site assembly is consistent across company-types,** but not as frequent as 3D modules joined onsite.
- **3D modules slotted into a structure that can be transported are most commonly used by trade contractors (46%),** and least frequently cited by both design firms and GCs/CMs.

Percentage of Projects Using 3D Modules/ Full Volumetric Construction

(Past 3 Years and Forecast for Next 3 Years)

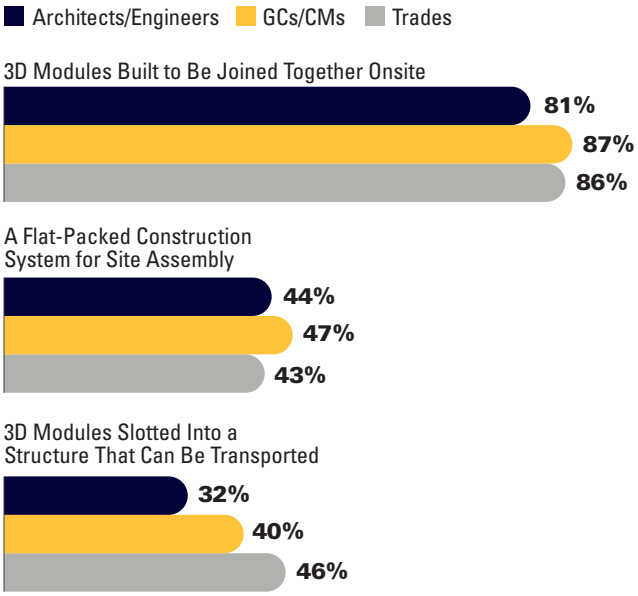
Dodge Data & Analytics, 2020



Percentage of Projects Using Types of 3D Modules/Full Volumetric Construction

(Past 3 Years)

Dodge Data & Analytics, 2020



Frequency of Using Factory-made Turnkey Modular Building Units

About three quarters (ranging between 68% and 83%) of the company-types surveyed report some use of factory-made turnkey building units (e.g., bathroom pods, utility rooms, exam rooms, etc.) over the past three years, although most say that has taken place on less than 25% of their projects.

- **Trade contractors forecast the most growth in usage,** with 31% predicting they will use them on 25% or more of their projects in the next three years, compared with only 10% currently at that level.
- Design firms and GCs/CMs also plan more usage, generating a predicted average that **29% of all company-types will be implementing factory-made turnkey building units on at least a quarter of their projects in the next three years.**

Frequency of Using Relocatable Modular Structures

To distinguish them from permanent modular construction, the Modular Building Institute defines relocatable modular structures as ones that are "designed to be reused or repurposed multiple times and transported to different building sites."

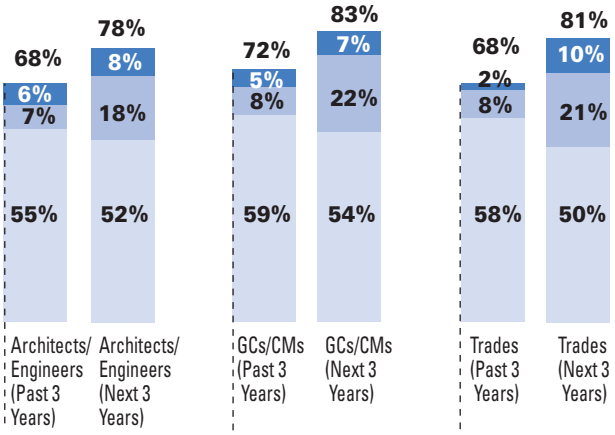
There is notable variety across company types in their reported and predicted use of relocatable modular structures.

- **Two thirds (66%) of design firms report some level of usage,** but predicted growth only increases to 69% in three years.
- **GCs/CMs are the current leaders (71%)** in using relocatable modular, and more (79%) believe they will be doing so in the next three years.
- By contrast, **trade contractors are least active now and show a reduction going forward.** Interestingly, only the companies at the lowest level of implementation (25% of their projects) will decline. The higher implementation levels are expected to remain the same.

Percentage of Projects Using Factory-made Turnkey Building Units

(Past 3 Years and Forecast for Next 3 Years)

Dodge Data & Analytics, 2020



Percentage of Projects Using Relocatable Modular Structures

(Past 3 Years and Forecast for Next 3 Years)

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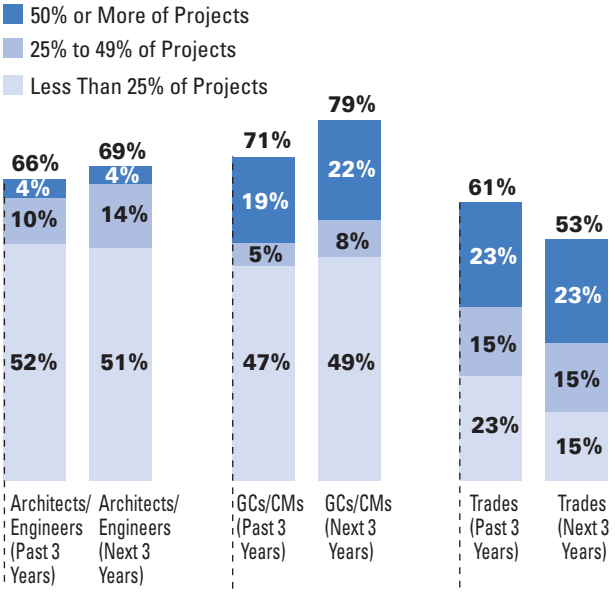


Most Frequent Building Types for Use of

Permanent Modular Construction

Distinct from relocatable modular structures, permanent modular construction refers to the process of creating buildings from premanufactured deliverable modular sections that are meant to remain in place after completion.

Building Types Where Permanent Modular Construction Is Most Frequently Used

Practitioners are finding uses for permanent modular construction on numerous types of buildings. To examine the dynamics of this market, survey respondents in the modular line of inquiry were shown a list of 14 building types and asked to identify those on which modular construction has frequently been applied over the last three years, and also those they believe will see high frequency in the next three years. The charts in this section of the report compare, for each type of company, their top 10 most frequently predicted building types with their historical experience.

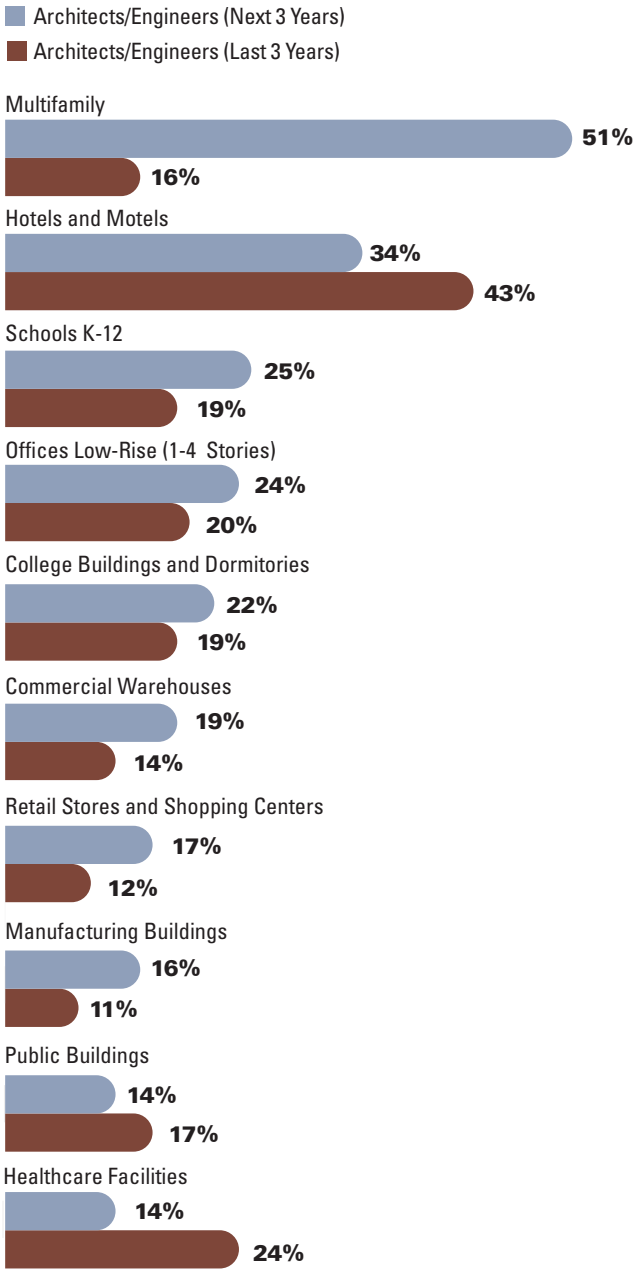
Architects' and Engineers' Perspectives

The chart at right shows the top 10 building types identified by architects and engineers.

- Design firms are extremely positive about the role of modular on multifamily projects going forward. This contrasts sharply with their pessimistic future view for prefabrication (see page 8).
- Fewer, however, predict frequent use of permanent modular on hotels and motels, healthcare facilities and to a smaller degree on public buildings.
- The other six building types each show a solid increase over past levels, although none garner more than 25% predicting high future frequency.

Architects/Engineers' Top 10 Most Frequent Building Types for Using Permanent Modular Construction (Forecast for Next 3 Years Compared With History of Last 3 Years)

Dodge Data & Analytics, 2020



Most Frequent Building Types for Use of Permanent Modular Construction

CONTINUED

General Contractors' and Construction Managers' Perspectives

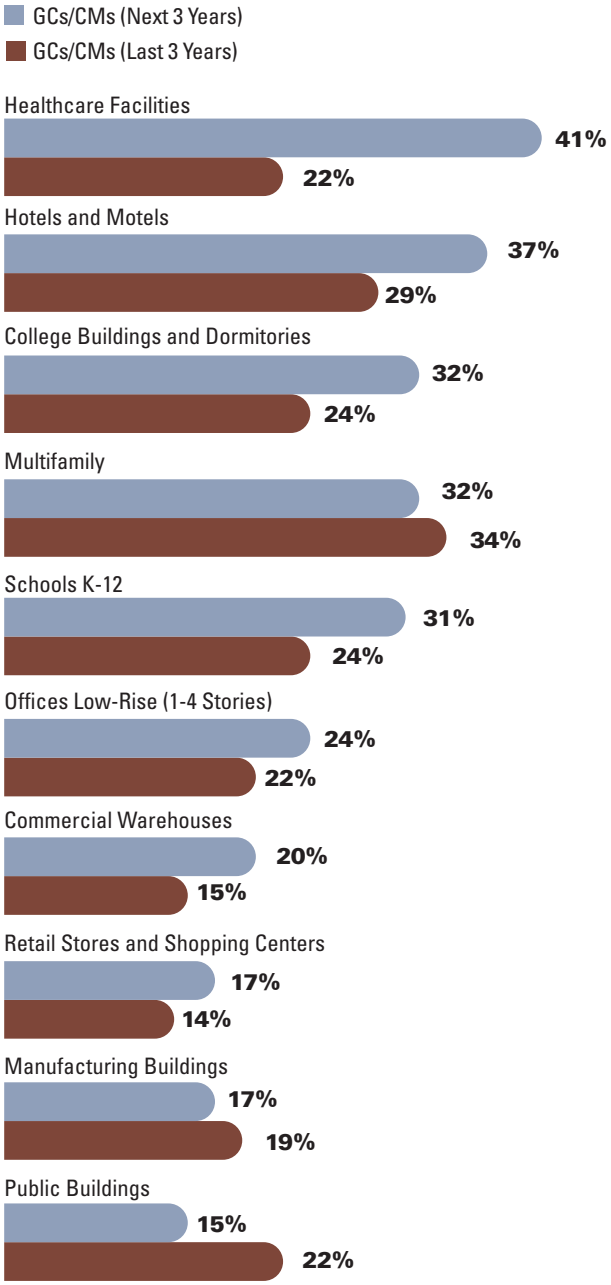
GCs/CMs selected the 10 building types (out of 14) that they believe will have the highest frequency of permanent modular construction in the next three years. The chart at right compares the percentage that chose each with how many say they experienced a high frequency over the last three years.

While GCs/CMs and design firms selected the same 10 buildings from the list of 14, there are interesting differences in their perspectives.

- **Healthcare facilities top the list for GCs/CMs, with 41% predicting high frequency of permanent modular.** This is nearly twice the number who report experiencing high frequency over the last three years (22%) and starkly contrasts with design firms, only 14% of which predict strong future use.
- **The hotel/motel market shows another contrasting dynamic between GCs/CMs, who forecast a strong increase in permanent modular, and design firms who predict less activity.** Interestingly, though, the proportion of each group predicting high future frequency is nearly equal (37% and 34%, respectively).
- **Educational buildings (both higher ed and K-12) are both forecasted for significant upticks.**
- **GCs/CMs agree with the outlook of design firms that public buildings are likely to see less permanent modular activity.** This may be due to general concerns by both groups about available public funding for projects in that market, but it represents a significant part of the US construction industry and should be a focus for the use of innovative approaches.
- **GCs/CMs foresee a slight pullback in permanent modular for multifamily projects (to 32% from 34%),** compared with the high percentage of design firms making a strong growth prediction (51%).

GCs/CMs' Top 10 Most Frequent Building Types for Using Permanent Modular Construction (Forecast for Next 3 Years Compared With History of Last 3 Years)

Dodge Data & Analytics, 2020



Most Frequent Building Types for Use of Permanent Modular Construction

CONTINUED

Specialty Trade Contractors' Perspective

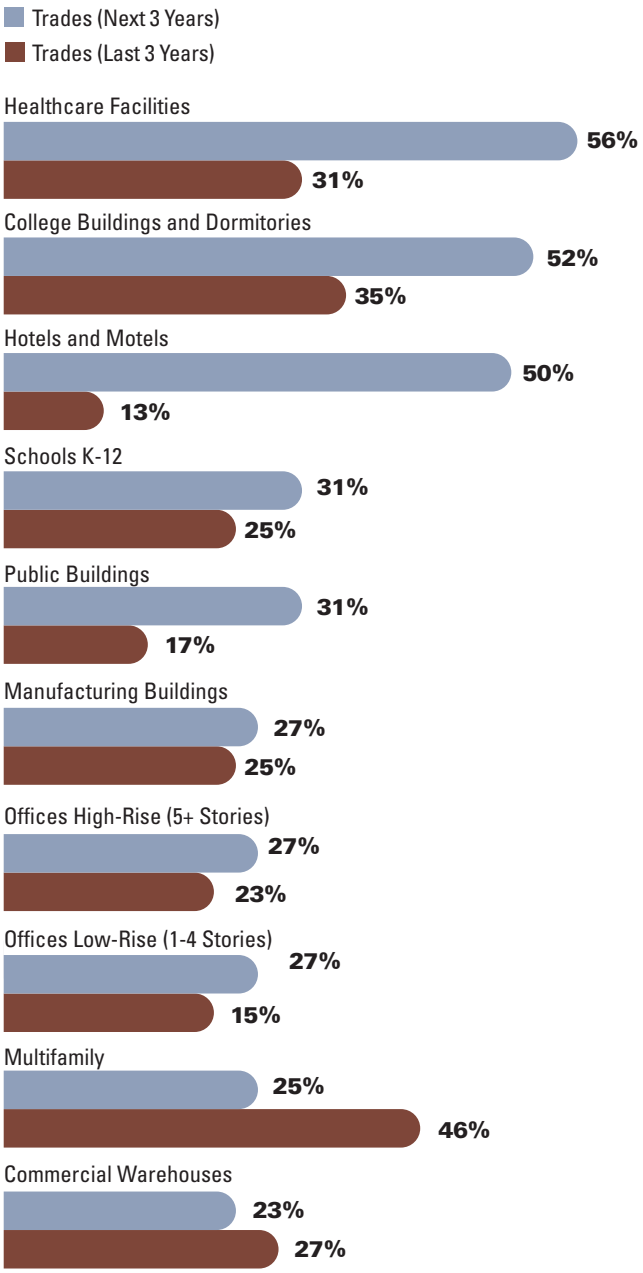
Trade contractors also chose which building types they believe will most frequently feature permanent modular construction over the next three years. The chart at right shows the percentages designating each of their overall top 10 as high future growth markets compared with how many experienced high frequency with them over the last three years.

Trade contractors' forecasts align with those of the other types of companies in several ways but also contrast with them, sometimes quite significantly.

- **Healthcare facilities, higher ed buildings and hotels/motels top the list,** and all earned high frequency growth projections from 50% or more of trade contractors.
- **While trade contractors join the unanimous view that K-12 projects should see more permanent modular in the next three years, they are alone in their positive outlook for public buildings,** almost doubling from those citing a high level of past experience (17% to 31%).
- **Trade contractors are in alignment with the others in forecasting growth in the low-rise office market, but are the only company-type to include high-rise office buildings among their top 10,** with over a quarter (27%) predicting frequent activity.
- **Interestingly, trade contractors agree with design firms on the outlook for permanent modular in multifamily,** with only a quarter feeling optimistic in spite of nearly half (46%) having seen high activity in recent years.

Trade Contractors' Top 10 Most Frequent Building Types (Forecast for Next 3 Years Compared With History of Last 3 Years)

Dodge Data & Analytics, 2020



Impact of Modular Construction on

Schedule and Cost Performance

This page of the report examines the positive impact of modular construction on schedule and cost performance.

Schedule Performance

The chart at upper right shows the percentage of schedule performance improvement that respondents report experiencing over the past three years from modular construction.

- **Almost all (88%) GCs/CMs report positive impact** with 60% citing better than 5% schedule gains.
- **Nearly two thirds (65%) of design firms agree on its positive impact,** with 20% reporting the highest level (over 10% improvement).
- **While over one third (36%) of trade contractors report improvement in schedule performance,** they are less enthusiastic overall than design firms or GCs/CMs.

Cost Performance

The chart at lower right shows the percentage of cost performance improvement that respondents report experiencing over the past three years from modular construction.

- **GCs/CMs are even more enthusiastic about improved cost performance (91%),** with over two thirds (68%) citing better than 5% positive budget impact.
- **Almost half of trade contractors (46%) and design firms (47%) are positive about cost impact** with the similar percentages citing more than 10% gains.

BIM Use Enhances Improvements

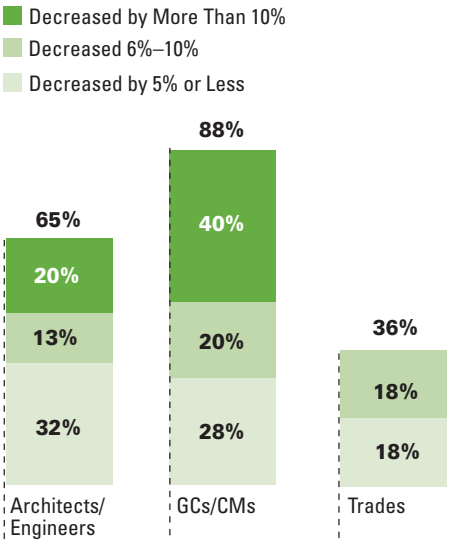
As shown in the matrix below, BIM use correlates strongly to improved cost performance from modular construction and also, to a lesser degree, schedule gains.

Percentages Reporting Improved Schedule and Cost Performance From Modular Construction (by Level of BIM Usage)

	Companies That Do Not Use BIM	Companies That Use BIM on Less Than 50% of Projects	Companies That Use BIM on 50% or More of Projects
Percentage Reporting Improved Schedule Performance	46%	46%	59%
Percentage Reporting Improved Cost Performance	21%	44%	46%

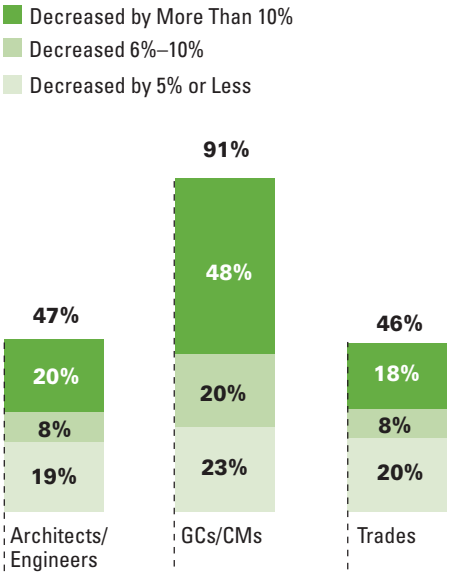
Impact of Modular Construction on Project Schedule Performance (Percentages Reporting Each of Three Levels of Improvement)

Dodge Data & Analytics, 2020



Impact of Modular Construction on Project Budget Performance (Percentages Reporting Each of Three Levels of Improvement)

Dodge Data & Analytics, 2020



Impact of Modular Construction

on Seven Specific Benefits

As shown with prefabrication earlier in this report, the survey also examined the impact of modular construction on seven other specific aspects of project delivery. The chart at upper right shows the percentage of respondents rating each as either making a medium, high or very high level of positive contribution.

- Improvements to productivity, quality and schedule certainty top the list across all company types.
- The other benefits rate strongly as well, with no fewer than 83% of respondents citing the contribution of modular construction to their achievement.

RESPONSES BY COMPANY-TYPE

To examine contrasts and commonalities between their perspectives, the other charts in this section of the report separately show the findings from the three main respondent groups (Architects/Engineers, GCs/CMs, Trades). In each, the order reflects the sum of their medium, high and very high rating levels.

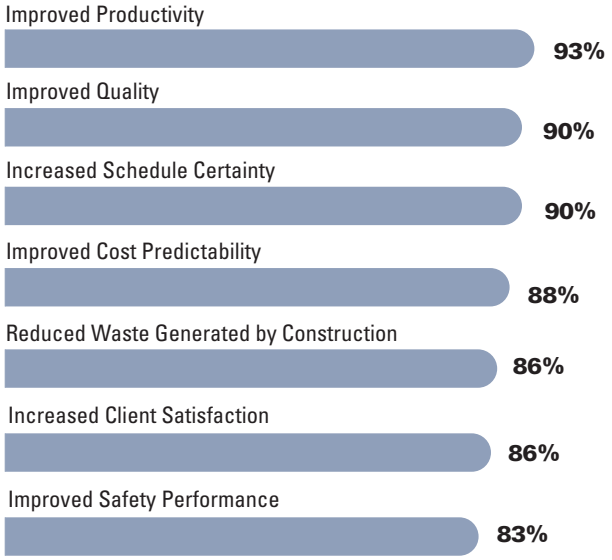
Architects/Engineers

The chart at lower right shows the responses from design firms in the survey.

- **Improved quality, schedule certainty and cost predictability all garner over 90% acknowledgement**.
- **Improved productivity and client satisfaction (both 89%)** follow close behind.
- **Reduced waste earns more very high impact votes (23%) from this group compared with prefabrication (20%),** although the total positive numbers are similar (86% and 85%, respectively).
- **Most (81%) cite improved safety performance,** even though design firms are less directly involved in that aspect. Notably this is a significantly higher percentage than gave a positive safety rating to prefabrication (66%).

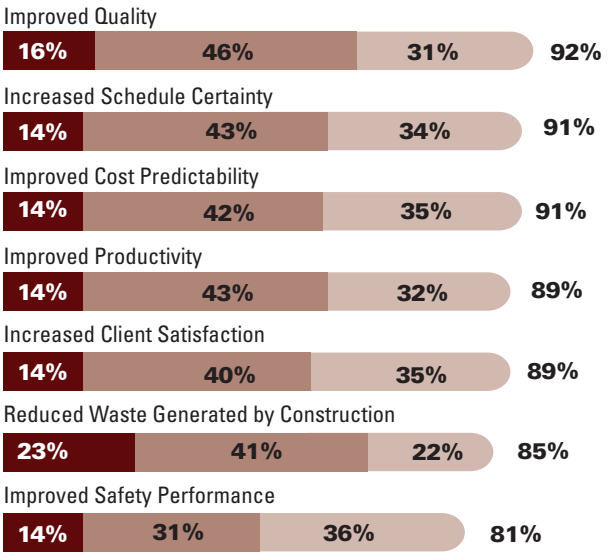
Impact of Modular Construction (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Architects/Engineers: Impact of Modular Construction (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Impact of Modular Construction on Seven Specific Benefits CONTINUED

GCs/CMs

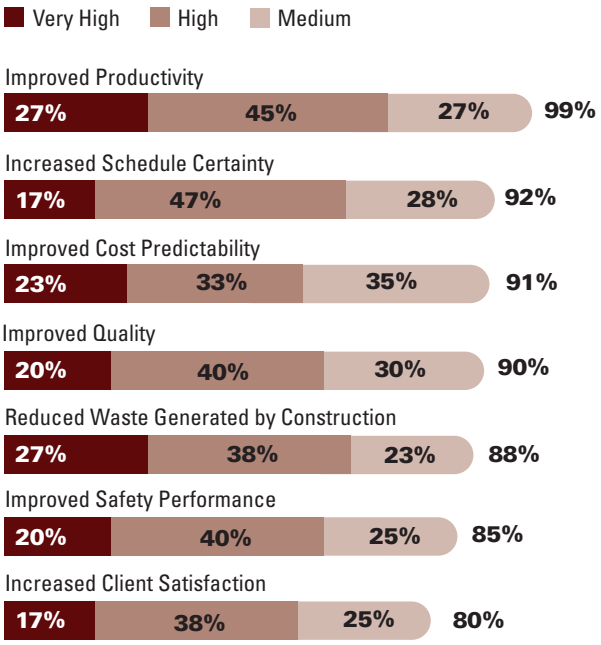
Similar to design firms, the responses from GCs/CMs shown at right are all 80% or higher, showing enormous positive enthusiasm for modular construction.

- **Improved productivity earns nearly unanimous acknowledgement (99%)** firmly establishing it as a reasonable expectation by any user.
- **Schedule certainty (92%) and cost predictability (91%) exceed this group's ratings for prefabrication (90% and 83%, respectively).**
- **The impact on client satisfaction (80%) is strong** even though it places last on the list in relation to the six other outstanding benefits.

GCs/CMs: Impact of Modular Construction on Seven Key Performance Factors

(Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Impact of Modular Construction on Seven Specific Benefits CONTINUED

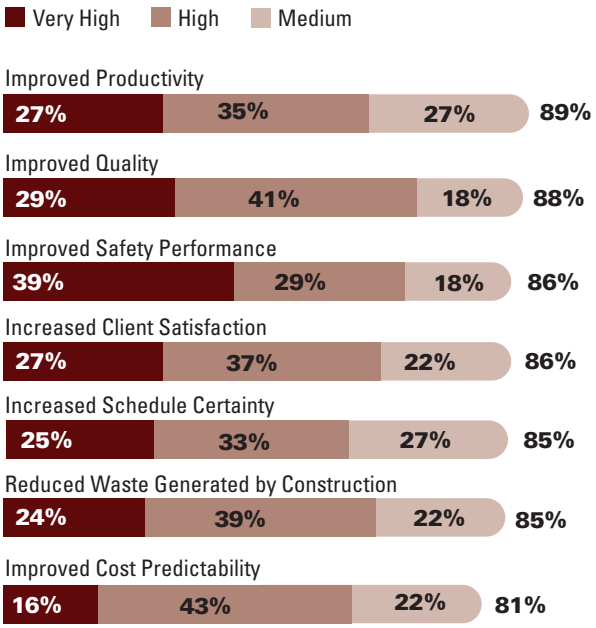
Trade Contractors

Trade contractors align in most cases with the other respondents, and are equally enthusiastic, with more than 80% reporting medium or higher achievement of each performance factor.

- As is the case with their ratings for prefabrication, **the percentages of trades giving very high impact scores is notably larger than that of design firms or GCs/CMs for most of the aspects,** indicating a true appreciation of the benefits provided.
- In second place, **improved quality garners almost twice as many very high impact votes (29%) as were granted by design firms (16%),** even though it ranked it first for designers.
- Even more emphatic than their acknowledgement for prefabrication, their **strong rating for improved safety from modular construction (39% very high and 86% overall)** is again especially meaningful because these are the companies that provide the jobsite laborers most at risk for safety incidents.

Trade Contractors: Impact of Modular Construction on Seven Key Performance Factors (Percentages Reporting Medium, High or Very High Contribution for Each Factor)

Dodge Data & Analytics, 2020



Impact of Project Delivery Models on

Modular Construction

Frequency of Project Delivery Method

Participants were asked how frequently various project delivery methods were in use on their projects that involved modular construction over the past three years. The chart at upper right shows the responses broken out by the percentages of all respondents who cited each method as having been either first, second or third most frequent.

- **Design-build ranks as the most frequent method.** This is different from prefabrication, where it is second to traditional design-bid-build.
- **The second-place ranking of design-bid-build suggests that modular construction can be deployed even in a traditional bid environment.**
- As with the prefabrication results, **CM at Risk and IPD are each included among the three most frequent by about half of respondents.**

Degree to Which Delivery Methods Help Enable Modular Construction

Respondents with modular construction experience with any of the methods shown in the chart at lower right were asked how much they believe that method enabled the use of modular construction.

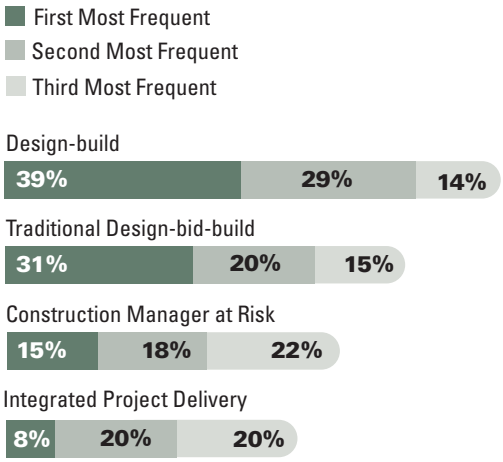
While all three methods garner very positive ratings, integrated project delivery and design-build both score especially well, with 45% and 34%, respectively, earning "significant help" ratings. This is even more positive than the prefabrication findings, where the percentages citing "significant help" are 30% and 26%, respectively.

DESIGN-BID-BUILD HINDERING MODULAR CONSTRUCTION

Participants were also asked if they believe traditional design-bid-build hinders modular construction. Although 37% of the architects responding say they believe design-bid-build hinders the effective use of modular construction, the contractors ranged between 8% and 12%, yielding a total of 20% across all respondents. This suggests that a traditional bid method on a project should not impede the use of modular construction.

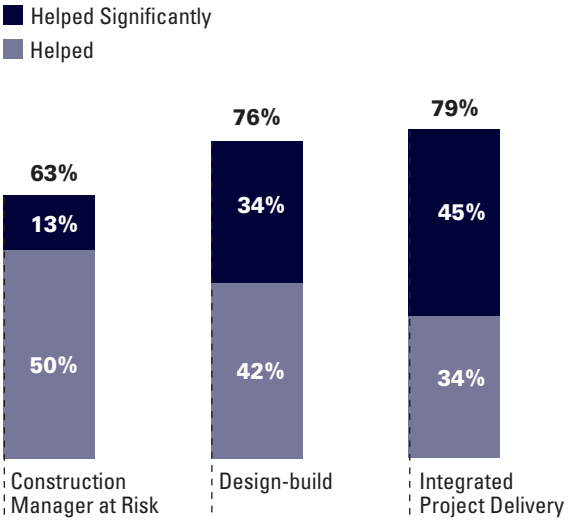
Frequency of Project Delivery Method When Modular Construction Was Used
(Last 3 Years)

Dodge Data & Analytics, 2020



Degree to Which Modular Construction Was Enabled by Project Delivery Method
(By Company Type)

Dodge Data & Analytics, 2020



Selection of Modular Construction Suppliers

Factors Influencing Selection of a Modular Construction Supplier

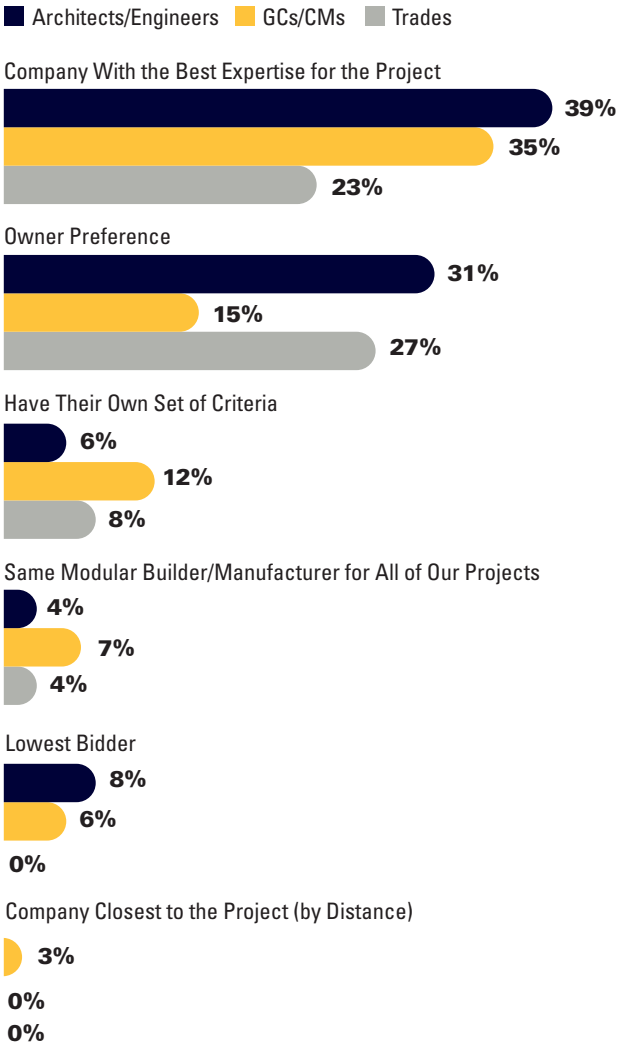
Participants were asked to identify which of six factors is the most influential on their decision-making about selecting a supplier to provide modular construction services on their projects. The chart at right shows the percentages, by company-type, who selected each.

- As with the findings for selecting a prefabrication supplier, **design firms and GCs/CMs most highly value expertise.**
- **Owner input is far greater for modular (average 24%) than for prefabrication (average 12%).** This is especially true for trade contractors (27% compared with 14%). Yet similar to the findings for prefabrication, **design firms (31%) are far more influenced by owners on their modular supplier decisions than GCs/CMs (15%).**
- **Price is not a highly influential factor for selection of a modular construction supplier.** This contrasts with prefabrication where it ranked second overall on this same list of six factors and was cited as the primary influencer by 20% of GCs/CMs. This may reflect the different maturity levels between these two markets, where because there are more suppliers available for prefabrication, price can be more readily used for competitive evaluation. As more providers enter the modular market, price can be expected to become more of a factor.

Top Factor That Influences Selection of a Modular Builder/Manufacturer

(Percentage Identifying Each as the Most Influential Factor)

Dodge Data & Analytics, 2020



BIM-Driven Modular Construction

Most of the companies (89%) that participated in this survey say that BIM is being deployed on at least some percentage of their projects (for more information on BIM engagement, see Methodology, page 64). Within that group, the companies also designated for the modular construction line of inquiry were asked about how BIM is being applied specifically to that activity (i.e., BIM-driven modular construction). This part of the report addresses those findings.

Current and Future Implementation of BIM for Modular Construction

The chart at upper right shows the percentages of the BIM users described above who are currently engaged with BIM-driven modular construction at several levels of implementation, and the percentages who believe they will be at those levels within the next three years.

- **The percentage using BIM for modular construction on at least a quarter of their projects will grow dramatically, from 57% to 77%** in the next three years.
- **Within three years virtually all (99%) BIM users will be leveraging it for modular construction.**

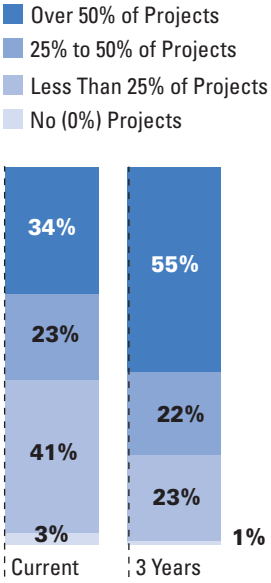
High-Level Implementation by Company-Type

The chart at lower right shows the current and future percentages of BIM users, by company-type, using it for modular construction on 50% or more of their projects. The findings align with those for model-driven prefabrication but with higher percentages forecasting future use (average 54% compared with 40%).

- **Trade contractors are the most deeply engaged,** with nearly six out of 10 (59%) predicting a high level of implementation in the next three years.
- **The number of design firms at a high level of implementation will almost double,** reaching near parity with contractors. This should help to drive an integrated approach to modular construction on project teams.

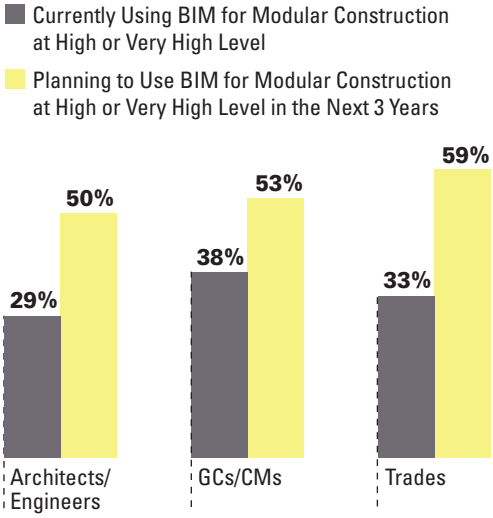
Percentage of BIM Users Engaged With Model-Driven Modular Construction (Comparing Current Implementation Levels With Predicted Levels in 3 Years)

Dodge Data & Analytics, 2020



Percentage of BIM Users Who Are Highly Engaged in Model-Driven Modular Construction (High/Very High Use, Current and Forecasted Over Next 3 Years)

Dodge Data & Analytics, 2020



Reasons to Use BIM for Modular Construction

To understand the drivers for its adoption and the expectations for its impact, current users of BIM for modular construction were asked to select up to three reasons (from a list of 10) why they are engaging with it. The chart at right shows the leading eight reasons broken out by company-type with percentages indicating how many selected each to be among their top three most important. They are listed in order of the average percentage across all who responded.

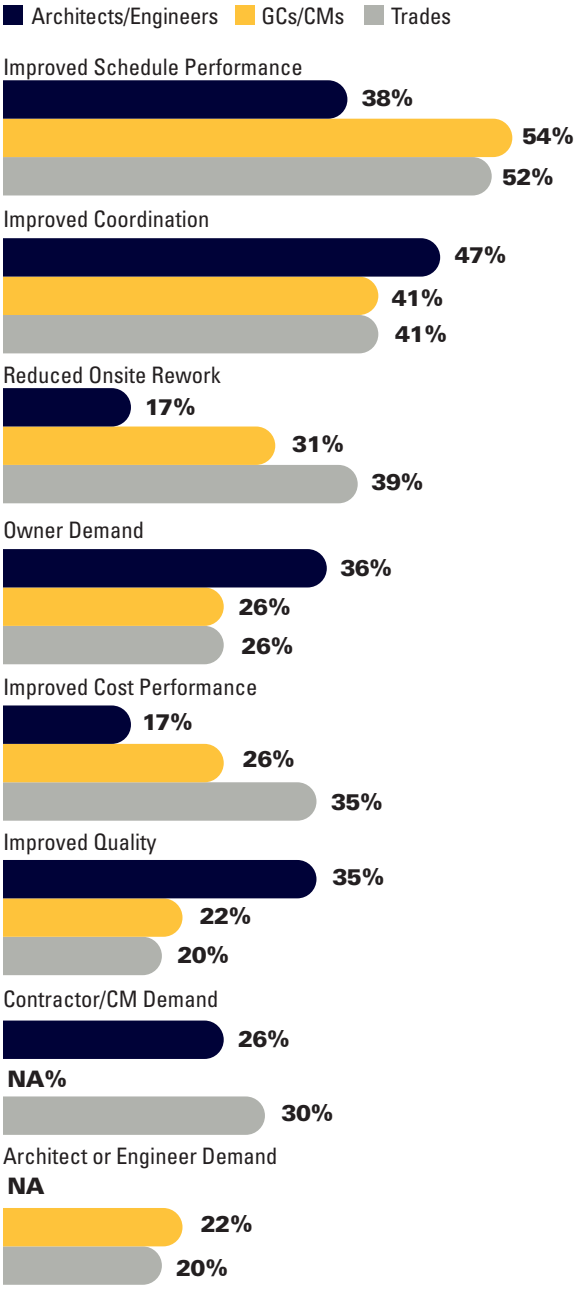
- **Schedule performance is the most widely reported,** reinforcing it as a key benefit of modular construction.
- **Improved coordination ranks second overall and first with design firms.** This is an integral benefit of modular construction because modules are coordinated in production, limiting coordination issues to site alignment and connection.
- **Of nearly equal importance to trade contractors is reducing onsite rework (39%) and improving cost performance (35%).**
- **Similar to the findings for prefabrication, many more design firms (34%) select improved quality compared with trade contractors (20%),** who are more attentive to process-related improvements.

MANDATING THE USE OF BIM FOR MODULAR CONSTRUCTION

Also like the findings for prefabrication, demand by another project team member appears prominently among many companies' top three reasons for becoming engaged in BIM-driven modular construction. For example, 36% of design firms cite demand from owners and 30% of trades identify demand from GCs/CMs.

Most Important Reasons to Use BIM for Modular Construction

Dodge Data & Analytics, 2020



Top Factors That Influenced Use of

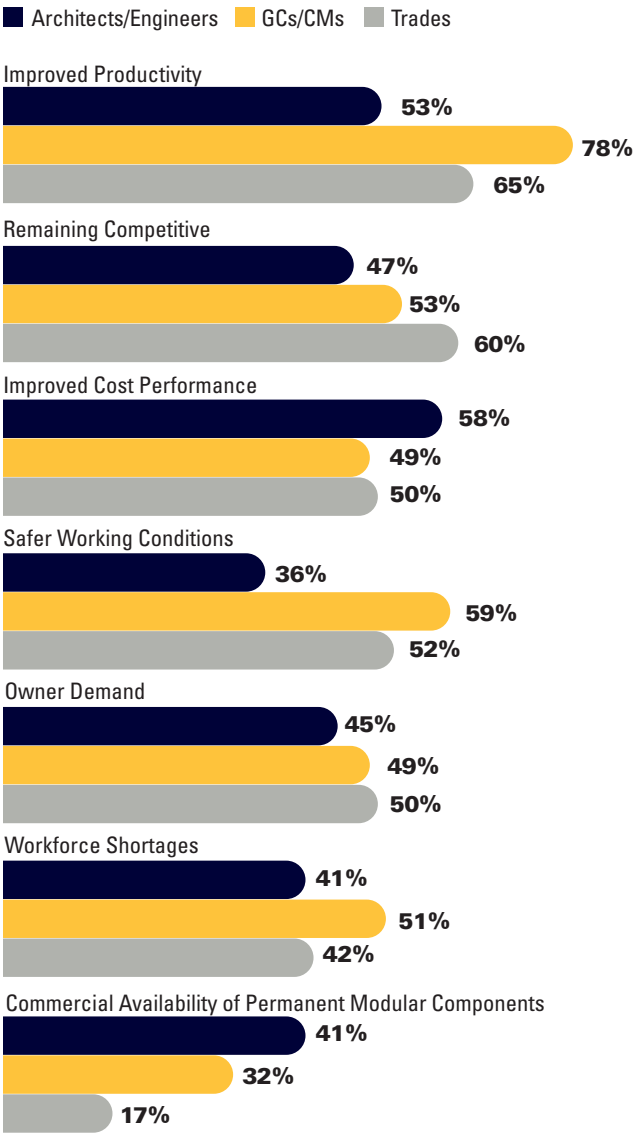
Permanent Modular Construction (Last 3 Years)

Respondents were asked to rate the level of influence that each of seven factors had on their decision to use modular construction over the last three years. The chart at right shows the percentages who cite either high or very high levels of influence, divided by type of company, and in the order of the average of the three company-type ratings.

- **The desire to improve productivity is the most influential factor overall,** reinforcing similar findings for the top drivers of prefabrication (see page 24).
- **Notably larger percentages of GCs/CMs cite the influence of workforce shortages (51%), safety (59%) and productivity (78%)** than do the other types of companies, clearly identifying these as the top drivers for that group.
- **Trades lead in identifying the need to remain competitive (60%),** and being competitive is the second most influential factor overall.
- **Owner demand is a powerful driver for all respondents** and will likely increase as more become aware of the benefits of modular construction.
- Interestingly, **design firms report having been most highly motivated by seeking improved cost performance (58%),** outscoring both GCs/CMs (49%) and trades (50%). This finding aligns with this group's drivers for prefabrication as well, clearly indicating that architects and engineers understand both prefabrication and modular construction can have a positive influence on cost control and should lead to more development of design solutions that consciously enable both.
- **Over one third (36%) of design firms cite safety as a motivator,** and while that is significantly less than either GCs/CMs (59%) or trades (52%), it is an encouraging sign that design professionals are aware of the safety ramifications of using offsite construction and are thinking about everyone involved in the project delivery process.

Top Factors Influencing Use of Permanent Modular Construction in Last 3 Years
(Percentages Citing High or Very High Level of Influence)

Dodge Data & Analytics, 2020



Top Positive Impacts That Will Drive More

Permanent Modular Construction (Next 3 Years)

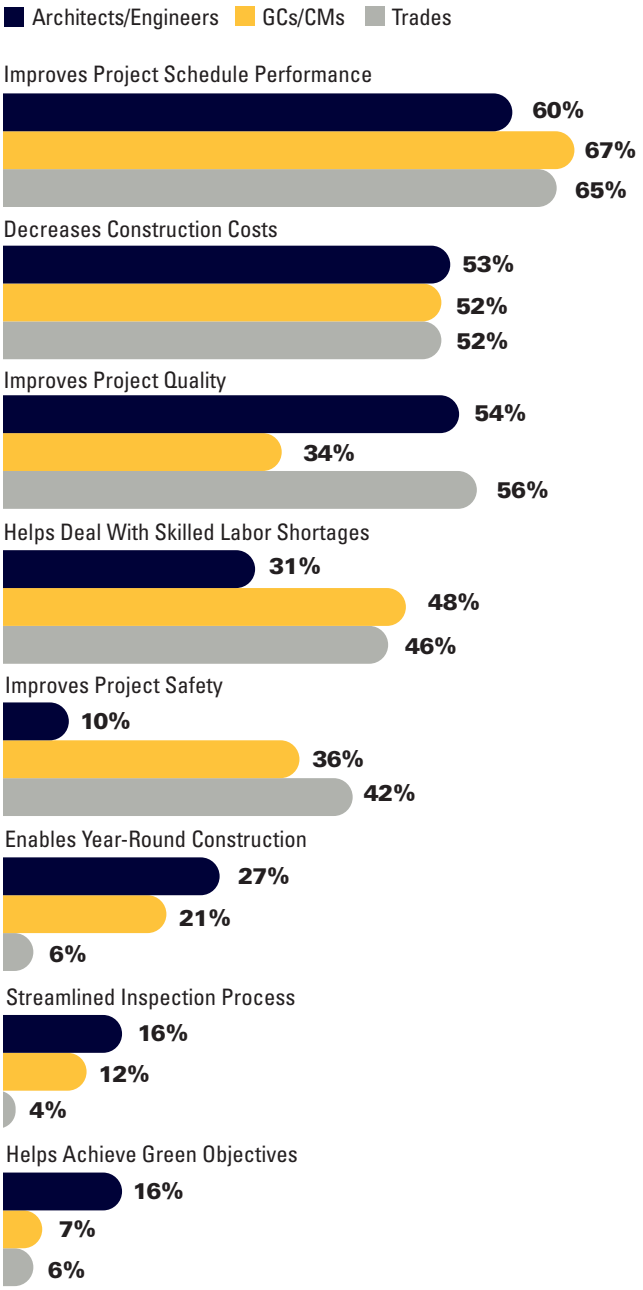
To understand their future expectations, participants were asked to identify which benefits they believe will be the most influential to drive more modular construction over the next three years. The percentages in the chart at right represent how many of each company-type predict a high or very high level of influence. The order reflects the averages of the three company-type scores for each factor.

- As with the findings for prefabrication, all respondents agree that **improving project schedule performance will be the top future driver** for modular construction and **decreasing construction cost is almost as highly rated**.
- Again echoing the prefabrication results, **improving project quality** is third-ranked overall and is a particularly high demand from design firms. But somewhat differently, trade contractors also note it as a strong future motivator (56%) compared with the number acknowledging that for prefabrication (43%).
- And also similar to the findings for prefabrication, **almost half of GCs/CMs and trades indicate they will be very focused on modular construction's positive impact on dealing with workforce shortages** in the coming years, and about one third of design firms (31%) concur.
- **Safety scores strongly with GCs/CMs (36%) and trades (42%),** and even though fewer design firms give it a top rating (10%), that percentage is still significantly higher than those rating it as highly for prefabrication (3%).

The other three drivers (year-round construction, streamlined inspection and achieving green objectives) resonated with design firms more than contractors, although they scored less highly overall. But as more experience with modular construction across the industry generates evidence of its beneficial impact, future studies are likely to show an increased awareness and value related to these and other usage drivers.

Top Factors That Will Influence Use of Permanent Modular Construction in Next Three Years (Percentages Forecasting High or Very High Level of Influence)

Dodge Data & Analytics, 2020



Top Obstacles Inhibiting More Use of

Permanent Modular Construction

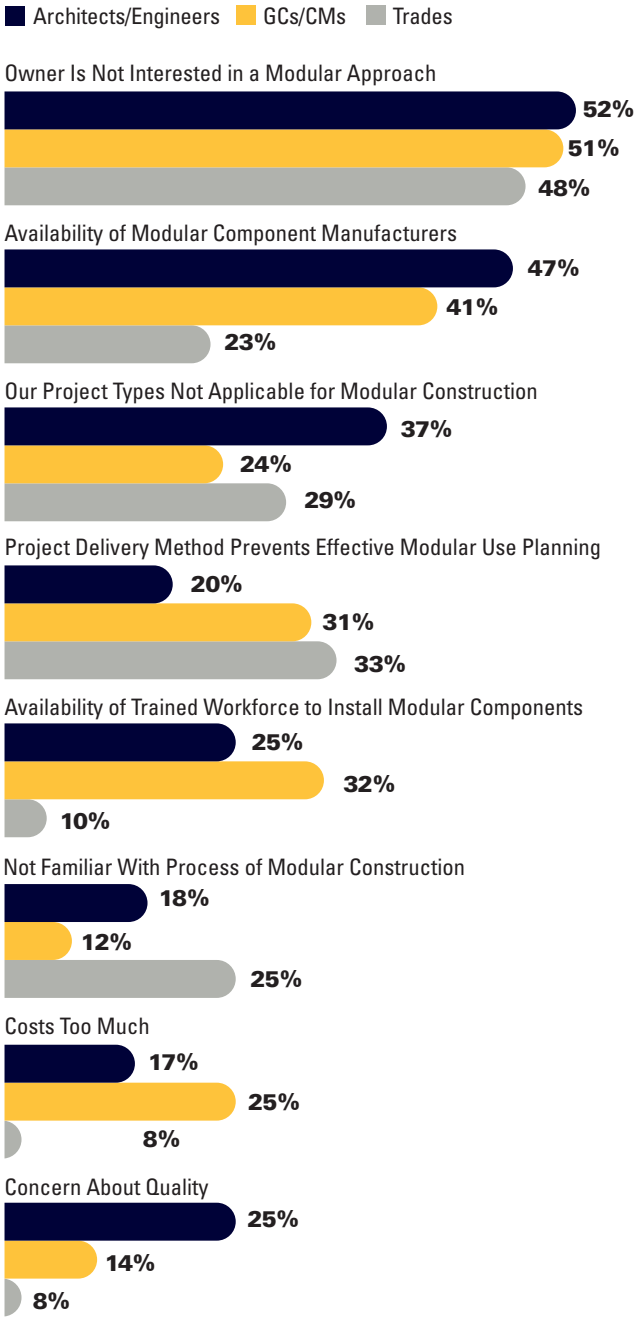
The survey asked respondents to select which three factors (from a list of eight) are the biggest obstacles preventing their companies from doing more modular construction. The percentages in the chart at right represent how many, by company-type, selected each obstacle as among their top three. The order reflects the averages of those scores for each obstacle.

- **Lack of owner interest is the top obstacle for about half of all respondents.** Hopefully this will change as more owners become familiar with the modular process and comfortable with its results. Notably, **unfamiliarity with the modular process is a relatively low obstacle for each company-type,** only ranking sixth among eight, so owner awareness is the factor needing most attention.
- **Availability of modular component manufacturers is the second-most cited obstacle by design firms (47%) and GCs/CMs (41%),** though significantly less so by trades (23%), perhaps because they are not as involved in sourcing suppliers.
- As with the findings for prefabrication, **the type of project and the project delivery method are both meaningful obstacles for all company-types**. These obstacles should lessen as modular becomes applicable to more project types and is included more frequently during design so it can be implemented regardless of delivery method.
- **One third (32%) of GCs/CMs express concern about adequately trained workers,** as do 25% of design firms. Since workforce shortages are an issue across the industry, finding resources specifically trained to assemble and install modular components would be even more challenging. This identifies an important need that can be addressed by associations, trade unions, academic and training institutions, and companies themselves.
- Encouragingly, **relatively low percentages of respondents cite either cost or quality as among their top three obstacles.**

Obstacles to Increasing Number of Projects That Use Permanent Modular Construction

(Percentages That Include Each Factor Among Top Three)

Dodge Data & Analytics, 2020



Interview: Thought Leader

Stacy Scopano, Chief Technology Officer, Skender

Stacy's experience includes a broad spectrum of technologies used by real estate, architecture, engineering and construction industries. Most recently, he was vice president of innovation at Skanska USA. Previously, he was the senior strategist for building construction at Autodesk, Inc. He has served as a past chairman of technology for the AGC BIMForum. He holds a degree in economics from the Georgia Institute of Technology.

What role has the development of BIM played in the rise of prefabrication and modular construction?

SCOPANO: Prefab has always been present in the trades, and it's also telling that BIM had its earliest applications in prefab. Steel and MEP trades in the '90s and early 2000s created models, first and foremost, to maximize their own coordination and production processes—driving detailed shop drawing, bills of material and automated equipment in production.

The majority of designers and contractors followed in the 2000s, generating visualizations, simulations, drawing production and trade coordination, ultimately expanding those early trade applications of BIM.

So as we now see an expansion of prefabrication to integrate more disciplines, trades and material products in the modern offsite process, it's natural that we also see the integration of the entire lifecycle of BIM applications in parallel.

Could you walk us through the use of BIM in a vertically integrated design and fabrication facility?

SCOPANO: BIM is embedded across the lifecycle for us. Very early on, even before we engage the client, we do a lot of modeling to understand what our offering is. It's almost like creating an early product catalog that we begin testing, property by property.

When we then get a project opportunity, we start with this catalog of parts, which we ultimately develop into fully detailed, production-level models. These literally turn into the information flows in our factory that we're cutting steel from, that we're assembling walls from, that drive the production process.

At the end of the project, we look at any modifications that were made to a standard module, wall or detail, and update that source catalog where we start the next project. So it's a virtual feedback loop that makes an iterative learning environment.

What challenges or obstacles would you highlight?

SCOPANO: The architectural and design community is largely standardized around some common sets of platforms. But the closer you get to reality, the more it fractures into a lot of specialty platforms for each discipline and trade. Our approach was to take the design platform, and try to push it as far downstream as possible. That ended up creating a whole host of challenges for us. For the second-generation effort, we're trying to rationalize which of our products and projects can take this single platform all the way down, and where we need to make some hand-offs to complementary platforms.

How are virtual and augmented reality complementing your use of BIM?

SCOPANO: When we develop these models, either upstream for design or downstream to power production, we've looked to extend that effort in a variety of ways, and specifically through virtual or augmented reality. At the early stages of designing the factory, we created virtual and augmented reality experiences for our internal teams to validate the production flow, the design and the ergonomics of the line itself. So at that high-end level, we were internalizing the process as we were developing our production capabilities.

As these visual expressions that inform design are maturing, they're giving us the ability to immerse a broader set of stakeholders. We can put a client in a small, medium or big space. We can put them in spaces with different levels of natural light. And we can quantify the flavors of investment that come with those outcomes. That immersion is sensory. But it's also quantified and informed.

Where do you see modeling technology heading? What's next?

SCOPANO: In the next five-year horizon, these experiences will get richer—with added elegance. But I think there's another axis of productiveness. We're in the early stages of talking about whether this should only be for clients. Why wouldn't we use these same techniques to train our labor force? There's a lot of opportunity to get really intimate with the means of production with some of these platforms and techniques. That's very promising.

Data: Perspectives of Modular Builders/Manufacturers

Differences Between Modular Specialists and Other Respondents

Among the 608 companies that responded to this survey, 15 focus solely on modular construction as their core business.

- **In the last three years, 87% of modular specialists report having used permanent modular construction, and almost all (92%) cited a high level of experience (more than five completed projects).**
- **By comparison, only 37% of all the other respondents have used permanent modular construction in the last three years, and among those, only 29% claim a similarly high level of experience.**
- **They also have about twice the level of experience with relocatable modular construction as other respondents.**

To share their valuable perspective, this section of the report provides highlights of their responses compared with the other participants.

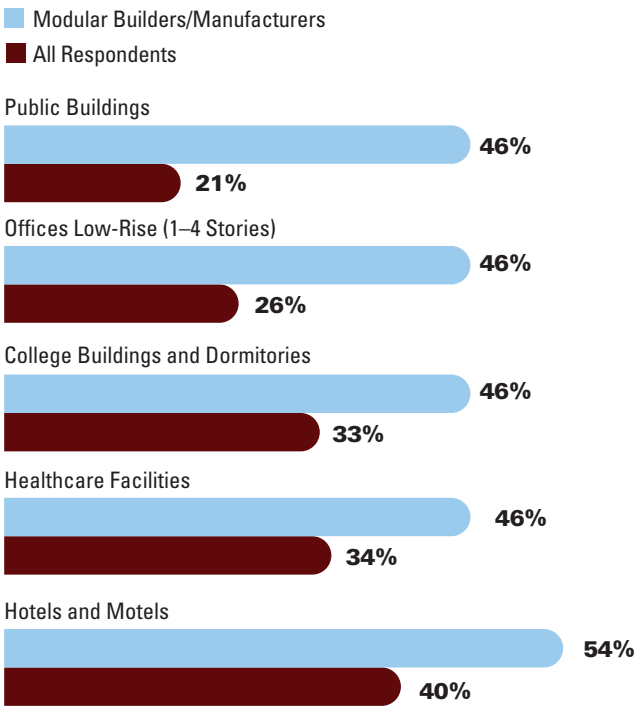
Forecast for Frequent Use of Permanent Modular Construction in the Next Three Years

In general, the modular builders and manufacturers are more optimistic in their view of the future for modular construction than the other participants in the survey. An example can be found in their forecast for which building types will frequently feature modular construction in the next three years. The chart at upper right shows the five building types that feature at least 10 percentage point differences between how many modular specialists foresee high utilization of modular and the number of other types of companies that agree with them. The order reflects the magnitude of the variance.

The modular specialists are more pessimistic than the full study group regarding future modular use for commercial warehouses, manufacturing buildings and retail stores/shopping centers, but these are less targeted markets in general, garnering no more than 20% from either group.

Biggest Variances in Forecast for Frequent Use of Permanent Modular Construction in the Next 3 Years (Comparing Modular Builders and Manufacturers With All Other Respondents)

Dodge Data & Analytics, 2020



Benefits of Modular Construction

Benefits Reported From the Use of Modular Construction

In addition to being more optimistic about forecasting its future use, the modular builders and manufacturers that participated in this research also report significantly higher receipt of the benefits of modular construction.

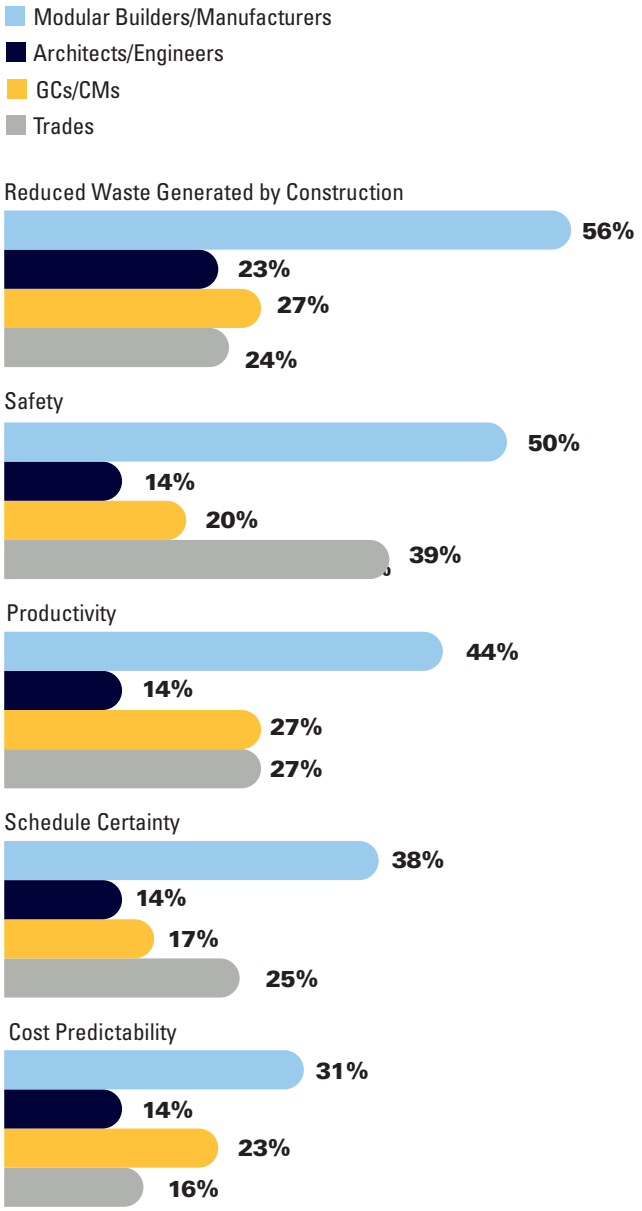
The chart at right shows five benefits with the greatest difference between how many of the modular specialists report receiving a high or very high level of that benefit from the use of modular construction and the number of other participants that report similar results, by company-type.

Although the variances are extreme, they provide an encouraging target for all practitioners, pointing the way toward a far more efficient future of the industry by embracing modular construction.

Biggest Variances in Benefits Reported From the Use of Modular Construction

(Comparing Modular Builders and Manufacturers With All Other Respondents Rating High/Very Positive Impact)

Dodge Data & Analytics, 2020



case study

Using Prefabrication to Mitigate Skilled Labor Shortage Risks

University of Delaware's Science Technology and Advanced Research Campus

NEWARK, DELAWARE

When contractor IMC Construction was first brought on to the $150 million University of Delaware's Science Technology and Advanced Research (STAR) Campus project, it quickly became clear that the project faced a significant challenge—lack of available skilled labor. The project owner, global chemical company Chemours, wanted the 312,000-sq.-ft. laboratory and office facility in Newark, Del., to be delivered in two years. But the project was scheduled to start in 2017, just as the local construction market was heating up. According to Dodge Data & Analytics statistics, construction starts by value in the Philadelphia/Camden, N.J./Wilmington, Del., area rose 58% from 2016 to 2017. Manufacturing sector starts, specifically, rose 257% during that same period.

"We had projects (under construction) in the area, and we had been bidding projects," says Bob Liberato, project executive at IMC Construction. "We knew the other projects that were ongoing in the market, and we had a difficult time getting bids (from subcontractors). We saw that we couldn't get enough people to do the work."

Certain trades, such as mechanical, electrical and plumbing, were especially scarce. "This particular work is very high end," he says. "You can't just call the plumber down the street. We had people tell us they'd like to do the job, but on the schedule that we were laying out, they couldn't find 30 guys to put on the job when we needed them. It was evident we were going to have a problem."

Utilizing Labor Resources Across the US Through Using Prefabrication

To help meet labor demands, IMC employed a prefabrication strategy that would allow the team to manufacture building elements in areas with more available labor. "We decided, 'The Philly area and Wilmington are stretched right now—let's take the resources and spread them around the country,'" Liberato adds.

The STAR building was designed by architect L2 Partridge in a U-shape, which created two long corridors that provide access to offices on one side and labs on the other. IMC saw an opportunity to create long MEP racks down the 10-ft.-wide corridors.

IMC contracted H.T. Lyons, a subsidiary of ENGIE North America, to help design and manufacture the racks at its Allentown, Pa., facility, which is located roughly 100 miles north of the project site.

"By outsourcing that portion of the work and going two hours north of the jobsite, they were able to tap a pool of skilled craftsmen, who could work in a controlled environment with all of the added benefits of working in a shop," says Chris Bernecker, vice president at H.T. Lyons.

Designing and Building MEP Racks Offsite

With much of the project still in schematic design, Bernecker says his team was able to provide both design and schedule input. Racks consisted of supply duct, exhaust duct, lab services (including RODI, breathable air, elemental gases and vacuum), high-pressure steam, chilled water and hot water. In total, the racks consisted of 153,650 pounds of welded stainless steel duct and galvanized duct with approximately 32,463 linear feet of HVAC, potable plumbing and laboratory gas system piping.

"We took two-dimensional drawings, and, in a virtual model, we conceived a way to build and sub-assemble these racks and ship them in 25 foot-long, 3,000 pound assemblies," he says.

Completed racks were shrink-wrapped and shipped to the site, where they could be installed with the protective wrap still on. This would prevent the racks from being exposed to the elements until the building was closed in.

MEP racks were preassembled in a shop about 100 miles away and shipped to the site in 25ft-long 3,000-lb assemblies.

Image courtesy of IMC Construction

CONTINUED

University of Delaware's Science Technology and Advanced Research Campus

NEWARK, DELAWARE

H.T. Lyons, which is a union contractor, was able to build all of the racks using its existing shop employees. However, Bernecker says the company has the option to bring in additional union workers as needed on large projects. The multi-trade crew first built the frame, then the duct work, followed by the piping. Most of the work was completed by 30 employees during a standard day shift, but at peak production a second shift of 12 workers was added.

Because the racks were designed at LOD 400 modeling, they could be manufactured while steel erection was under way on the STAR building. Once the building was ready, it took IMC crews roughly four months to install the racks. By comparison, Bernecker estimates that if the systems had been "stick built" onsite rather than preassembled, it would have taken crews roughly nine months.

Prefabricated Central Utility Plant

Another major element of the building that the team was able to manufacture offsite was the central utility plant. The CUP was initially envisioned inside the building with an outside utility yard for equipment such as cooling towers. Liberato says that by moving the CUP outside and stacking it, the team was able to move the entire CUP outside the building and onto the planned utility yard site. This freed up roughly 5,000 sq . ft. of space inside the building to be used for other purposes.

The team contracted Ohio-based modular building systems manufacturer Systecon, which is also a subsidiary of ENGIE, to design, manufacture and deliver the CUP. "It was basically a mini design-build project," Liberato says. "We gave them the basis of design and the footprint. We had working sessions to nail down the final design and get things tweaked."

Liberato says Chemours facility mangers participated in several of the working sessions to make sure they would approve the access points and spaces between units.

"It also eliminated that process where the engineer designs then comes back, gets feedback from contractors and goes back and designs more," Liberato says "It was all designed simultaneously."

In order to enable the CUP to be delivered from Ohio to Delaware, it was designed as 16 segments that could be reassembled onsite.

Because the CUP was manufactured in Systecon's shop, Liberato says work on the CUP was able to begin three months earlier than if it had been built entirely onsite. Overall, he estimates that the CUP would have taken roughly nine months to build, if it had been constructed conventionally. By using the modular option, the CUP project only required 5.5 months.

Most important, IMC estimates that the strategy transferred about 1,500 man-days offsite. "That's a significant amount of labor that we just didn't have [onsite]," he added.

The modular CUP solution cost roughly 3.3% more than was estimated to stick-build the CUP onsite. However, Liberato says that cost increase was likely offset when accounting for the shorter schedule. "When you build onsite, you're going to run into things like coordination issues that will set you back," he says. "In the end, I believe [the modular strategy] was cost neutral."

Although labor was a driving force in the decision to use prefab and modular, Liberato notes that the team also benefited from other advantages. For example, quality control of the CUP was assured before it was shipped to the site. "We did all of the pre-commissioning [at the Systecon shop] and then they take it apart and ship it," he says. "You know that you have a running, working and tuned-up CUP before it's delivered to the site."

Liberato also notes that the strategy helped remove some potential safety risks by moving production to a controlled shop environment.

Thanks in part to the prefabrication and modular strategy, the project was completed on time in December 2019—roughly two years after it broke ground. "Without the use of prefab, I don't see how we could have met that schedule," he says. ■

Project Stats (stats)

University of Delaware's Science Technology and Advanced Research (STAR) Campus
Newark, Del.

Ground breaking: December 2017

Completion: December 2019

MEP Racks consisted of 140,000 lbs. of ductwork and 24,900 linear feet of piping.

MEP Racks consisted of:
- Supply duct
- Exhaust duct
- Lab services, including RODI, breathable air, elemental gases, vacuum
- High-pressure steam
- Chilled water
- Hot water

MEP Rack Schedule
- Prefabrication required four months of field installation
- If conventional stick-built, schedule estimated at 9 months

case study

Modular Construction and Sustainability's Triple Bottom Line

The Union Flats Housing Development

UNION CITY, CALIFORNIA

The Union Flats, a 2.4-acre, 243-unit, mid-rise housing development 30 miles southeast of San Francisco, pioneered large-scale modular construction in the region while achieving exemplary environmental performance. Completed in 2018 by developers CityView and Windflower Properties as northern California's largest modular multifamily development, the Union Flats epitomizes the advantages of offsite construction in a tight market. The question for practitioners of green design and development is the degree to which modular construction also enabled the project's LEED Platinum certification.

The vertiginous cost of housing in the Bay Area makes it impossible to forget here that sustainability has economic and social dimensions, as well as environmental ones. "It's quite a struggle right now for those of us in the Bay Area trying to do housing development that is affordable to even middle-income earners," says Windflower CEO Fei Tsen. She cites such contributing factors as the shortage of skilled labor that has resulted from migration out of the trades and/or the region during the recession of 2008, and the inability of housing development, with its lower profit margins, to compete with nearby big tech projects for the remaining workers now commuting two or three hours a day to work in the area. "So it's imperative that we look at prefab and modular," she says.

Modular to the Rescue

The Union Flats shows what is possible. Its location—only a block from an intermodal transit station—made the development eligible for millions in funding from the Infrastructure Infill Grant Program of the California Department of Housing and Community Development. But that funding mandated a completion date that conventional construction couldn't meet. Modular—with its simultaneous construction of sitework and superstructure—could.

The development consists of 388 wood-framed modules, shipped from Idaho and craned into place—either onto a foundation, atop a Type I podium, or wrapping a Type I concrete parking garage—at a rate of 12 per day. The resulting schedule compression allowed the project to meet its funding deadline, and in that sense made the rest of its achievements possible.

Designed by San Francisco-based David Baker Architects (DBA), the building fronts onto a new civic plaza, edges a landscaped promenade along one side, presents ground-floor front doors to a sidewalk along the other and backs onto an embedded parking garage. Cladding materials include wood, stucco and strips of fiber-cement panels in board-and-batten configuration. The massing is self-shading: At the southwest façade, balconies are recessed; at the northwest and southeast, bays are articulated to provide shade while opening up to daylight and views of the nearby hills. Helping to foster the casual interactions among neighbors that can build social connectivity, a central courtyard provides a swimming pool and green-roofed pavilions with spaces for leasing, co-working, fitness, events and a dog spa.

Sustainability Independent of Modular

But beyond that initial enabling schedule compression, how much did modular construction contribute to the project's LEED Platinum achievements? As it turns out, surprisingly little. Reduced construction waste was the main

The Union Flats features 388 wood-framed modules, craned into place at a rate of 12 per day.

Image: OxBlue

CONTINUED

The Union Flats Housing Development

UNION CITY, CALIFORNIA

factor, says Daniel Simons, a principal at DBA. And the manufacturer was also able to obtain linoleum flooring at a price that allowed the project to substitute it for the VOC-emitting vinyl more commonly used in multifamily housing, which improved the project's indoor air quality. But, in general, says Simons, "most of the things that we did that made the project more sustainable were independent of it being modular."

The Union Flats was DBA's first modular project. The firm now has another almost complete, and four or five more in design or about to start construction. "We've learned a lot since the first one," says Simons. "It was definitely a bit of a proving ground." Even so, he says that the environmental opportunities that were missed on this project—and that continue to be missed in modular construction more generally—"mostly come from sustainability not yet being on the radar of the factories as a benefit." Modular manufacturers know that it is the method's time and cost savings that are selling their products, he says, so their research and development efforts are aimed at improving those outcomes even further. Now, however, he sees some manufacturers beginning to realize that prioritizing sustainability can open up more opportunities.

Room for Improvement

Top of Simons' wish list is healthier materials. DBA's efforts to improve the quality of materials in their multifamily projects are often stymied by a lack of product ingredient transparency, a lack of choice, prohibitive costs or a combination of all three. Unlike the office sector, where money-backed research and advocacy has been able to improve materials transparency and health, "that hasn't really happened with multifamily housing," says Simons.

But while individual housing developments may lack access to the economies of scale that have allowed corporations building millions of square feet to advance materials health in the office sector, modular factories may have an opportunity. "They've started getting purchasing agreements with manufacturers because they know they're going to need a lot of this stuff, and so they know they can get good pricing," says Simons. "But they haven't taken that next step to say, 'not only can we get good pricing, but we should also push for PVC-free flooring and other materials health priorities that could be on our radar.'"

Another sustainability advantage fabricators could offer lies in their tighter control of quality standards. "The quality of multifamily construction is variable, to put it generously, in terms of quality of insulation installation, thinking through thermal breaks and even down to mechanical systems," says Simons. He sees these as areas where modular fabricators could leverage their factory-based methods and growing market position to improve the sustainability options available to the multifamily sector. "If it becomes a factory standard, we could bring in more advanced technologies to help with energy efficiency and ventilation at prices that are accessible," he says. "There's a bunch of areas like that where multifamily housing isn't very sophisticated, and modular could help."

Such improvements will come too late for the Union Flats. Nevertheless, the project's parallel achievements—in pioneering large-scale modular development and attaining LEED Platinum certification—stand as a milestone for the multifamily sector. They demonstrate how modular construction's schedule and labor market advantages can help get an environmentally and socially progressive project built and contribute to sustainability's triple bottom line. ■

stats

Project Data

Location: Union City, California
Completed: August 2018
Number of Units: 243
Project Sq. Ft.: 289,987
Site Sq. Ft.: 107,522
Units/Acre: 99
Open Space Sq Ft.: +/-20,000
Parking: 244
Certification: LEED for Homes Multifamily Mid-Rise—Platinum
- **Innovation & Design Process:** 6.5/11
- **Location & Linkages:** 9/10
- **Sustainable Sites:** 16/22
- **Water Efficiency:** 9/15
- **Energy & Atmosphere:** 23.5/38
- **Materials & Resources:** 8/16
- **Indoor Environmental Quality:** 9/21
- **Awareness & Education:** 2/3

Lead Developer: CityView
Co-Developer: Windflower Properties
Architect: David Baker Architects
Landscape Architect: April Philips Design Works
General Contractor: Cannon Constructors North, Inc.
Modular Fabricator: Guerdon Modular Buildings

case study

Doing It Right the First Time

Coliseum Connections

OAKLAND, CALIFORNIA

There's a first time for everything. With design for manufacture and assembly (DfMA) on the upswing across North America, a growing number of developers, design teams and contractors are embarking on their first experience of modular construction. Fresh from their first foray into DfMA is the project team behind the recently completed Coliseum Connections, a $43 million, 110-unit housing development located adjacent to a rapid transit station in Oakland, Calif.

As one of the first truly mixed-income developments in the Bay area, half of Coliseum Connections' units are rented at rates accessible to households earning 50% to 60% of the area median income (AMI), and the other half, to households earning 80% to 120% of AMI, with no segregation or differentiation of units by income. "We knew from the start that it would be cost sensitive," says Peter Waller, principal in charge of the project at Pyatok Architects, "so it had to be as efficient a construction approach as we could manage."

The wood-framed volumetric modular project's straight-forward layout consists of four buildings of two types: a five-story block of 66 elevator-served flats along the west side of the site, facing the transit lines, and three rows of two-story townhouses meeting the low-rise neighborhood to the east. All units of both building types were prefabricated at Guerdon Enterprises, a manufacturing facility in Boise, Idaho.

Planning for Success

Except for the factory itself, no one on the project team had prior experience with DfMA. So the team adopted a strategy of overplanning everything in order to execute well, says Purnima Villanueva, project manager at Cahill Contractors, the project's general contractor. "It was a taxing approach, but we all left thinking this was a fantastic, successful project," she says.

From a design perspective, "overplanning" required the team to consider, coordinate and finalize decisions much earlier in the process than conventional construction requires, and those decisions had to be right. "The advantages of prefabrication are lost the moment you have to start opening up walls and changing things," says Waller. "Working with modular instills a discipline in the process—for the design team and also the owner." The result, he says, was both a more efficient process and a more efficient design.

To give a boost to the team as it ramped up the learning curve, a prefabrication consultant helped to develop an effective set of drawings for the modular system and to guide the permitting of them. A pleasant

stats

Location: 801 71st Avenue, Oakland, Calif.
Construction Type: I-A, III-A, V-B
Completion: 2019
Construction Cost: $43 million
Site: 1.36 acres
Building Sq. Ft.: 134,584 sq. ft.
DUA: 81
110 Units: 1 BR Flats (48), 2 BR Flats (18), 1 BR townhomes (17), 2 BR townhomes (27)
Car Parking: 86
Bike Parking: 98
Certification: GreenPoint Rating Platinum (149)
Owners: UrbanCore LLC, Oakland Economic Development Corp
Architect: PYATOK architecture + urban design
General Contractor: Cahill Contractors
Modular Building Manufacturer: Guerdon Enterprises LLC
Modular Consultant: Prefab Logic LLC
Civil Consultant: Luk and Associates
Structural Consultant: DCI Engineers
MEP Consultant: Emerald City Engineers, Inc.
Energy Consultant: Davis Energy Group, Inc.
Waterproofing Consultant: SCH Simpson Gumpertz & Heger Inc.
Utility Consultant: Millennium Design and Consulting, Inc.
Interior Design Consultant: DE + Dilworth Elio Studio, Inc.
Acoustics Consultant: RGD Acoustics, Inc.
Color: Colour Studio, Inc.
Lighting: Minuscule Lighting Design
Landscape Architect: Golden Associates Landscape Architects, Gates + Associates
Specifications: Pawprint Specs, LLC

CONTINUED

Doing It Right the First Time

OAKLAND, CALIFORNIA

surprise was how smoothly the complex permitting process ran, says Waller. In California, prefabricated volumetric modules are permitted at the state level, while site work, onsite connections and building envelopes are permitted locally. In keeping with their overplanning strategy, the architect met with the city's plan checker early and often to maintain communication lines throughout the complex approvals process. Far from setting up objections to the innovative construction method, the building department was keen to engage. "Everyone's talking about modular, and we need to learn how to permit these projects," is how Waller describes the attitude. And although the inspectors naturally wanted to consider the safety of the project as a whole, they were able to limit their review to the municipality's jurisdiction.

Another key aspect of planning was the staging of the delivered modules prior to installation. Leasing a nearby parking lot enabled units to be delivered at all hours and placed in exactly the right order to be transported just a few blocks to the site as they were needed. Because the crane and crew that set the modules are in high demand—and expensive—having everything in place to increase efficiency is a big deal, says Waller. At peak flow, the crew was setting 14 to 16 units a day, taking only five weeks to set them all.

Challenges

But even with exemplary planning, challenges arose. Chief among them from Cahill's perspective was quality control. It is the nature of prefabrication that modular units are being built in the factory and below-grade structure is being built onsite at the same time, and both require supervision. For the modular units, quality control is not just a matter of making sure the finishes are to spec; it is also validating critical tolerances: alignments for the anchor tiedown system that runs continuously through the stacked units from the foundations, for example, and points of connection that have been coordinated with MEP contractors in the field. "All of that at once is a challenge people may not think about when they think modular," says Villanueva.

The project had its own quality control representative monitoring production at the factory full-time, but with over 20 workstations at the facility, "you're not going to catch everything," says Villanueva. (She plans to beef up factory monitoring on modular projects Cahill has lined up for next year.) Atypical units, such as corner suites, seemed to give the most trouble, with egregious glitches like missing plumbing or electrical wiring necessitating remedial work onsite. Villanueva estimates that finding and correcting such deficiencies post-delivery amounted to about 4% or 5% of the factory contract value. "The challenge is trying to account for these unknowns in a schedule," she says. "How much out of tolerance units will be, how many deficiencies you'll find—you just don't know."

Even with those deficiencies, however, using DfMA still enabled the project to shave about $4 million dollars off the construction cost compared with conventional stick-built methods, and to reduce the entire construction schedule to 17 months, about 4 months less than estimated for a similar site-built project. Because the cost of the modules themselves wasn't significantly less than conventional construction, much of the savings accrued from reduced staffing overhead on the shorter construction period. A shorter construction schedule also meant the owner was able to begin collecting rent sooner, which for an affordable housing project in the Bay Area's notoriously unaffordable real estate market, makes a difference. "Schedule is money," says Waller.

Intensive planning helped achieve goals like a shorter construction schedule for Coliseum Connections.

Underlying these hard metrics, the major achievement of this first venture into DfMA was teamwork. "The city, the developers, the contractor and the design team: People were motivated to make this project a success," says Waller. Villanueva agrees: "The fact that we worked together, figured it out, over-planned it, saw it succeed and now know what to expect so that future projects will be even more successful, that's a huge accomplishment," she says. As other project teams embark on DfMA for the first time, they may find that encouraging. ■

Image Courtesy of Pyatok Architects

case study

A High-Rise Stylish Modular Hotel Rises in NYC

citizenM Bowery

NEW YORK, NEW YORK

As adoption of modular construction picks up in the US, the high level of repetition in hotel buildings makes the hospitality sector well positioned to capitalize on the method. Standardization maximizes the efficiencies of modular, while the consistency of hotel chains' specifications from project to project can unlock even greater economies of scale. Pioneering the way, with the world's tallest modular hotel, is citizenM Bowery, a 19-story, 300-key building completed in 2018 on Manhattan's Lower East Side.

"For hospitality, for some healthcare, even for some residential, modular makes total sense," says Isaac-Daniel Astrachan, a principal with Stephen B. Jacobs Group Architects and Planners, architect for the project with Amsterdam-based Concrete Architectural Associates. "Because there's so much repetition, and because it's increasingly difficult to find skilled labor, the more we can do in the factory, the better."

citizenM Bowery, a 19-story modular building constructed in Manhattan, demonstrates that modular hotels can be stylish high-rises.

Image courtesy of citizenM

Piece by Piece

Developed by Dutch hotel brand citizenM, which earned its modular construction chops on eight European properties, the Bowery building consists of 210 modules, stacked in 15 stories on a three-story (plus cellar), site-cast concrete podium. Modules were shipped complete with windows and thermal enclosure, fire-proofing, finishes, lighting, fixed furnishings and fittings, and a frosted-glass-enclosed shower and toilet pod. Added onsite were a wall-mounted TV (pre-wired), art, movable furniture and the room's iPad—which controls lighting, blinds, andTV.

Each module typically comprises a section of corridor with a 165-sq.-ft. guest room on either side. Dimensions of 48 feet by 8 feet by 9 feet allow the steel-framed modules to ride on a flatbed truck through the streets of New York—with only the units designed for ADA compliance requiring a Department of Transportation permit and special convoy.

Transportation required careful planning to protect the modules en route. As each one was completed in the climate-controlled manufacturing facility, it was individually wrapped in a waterproofing membrane to prevent moisture ingress during transport. Delivered modules were staged on a neighboring lot, then unwrapped as required and craned and bolted into place.

Pros and Cons

Although citizenM markets itself as offering affordable luxury, modular construction doesn't necessarily contribute to affordability. "From what I hear," says Astrachan, "the cost of construction is not that much different between conventional and modular." What chiefly makes citizenM affordable is its small unit size. The Bowery property fits in about a third more guest rooms than what a typical hotel with the same square footage would achieve.

With construction costs coming in about even, schedule is often one of the main reasons to go modular. (Units are under construction simultaneously with site work, which typically shaves weeks or months off construction.) But for this project, a number of complicating factors meant that advantage did not pan out. For example, the decision to use a manufacturing facility in Poland (which had built the modules for the client's hotels in Europe) added shipping and customs to the schedule. Then wind speeds during

CONTINUED

A Stylish High-Rise Modular Hotel Rises in NYC

NEW YORK, NEW YORK

construction exceeded the crane's capacity, resulting in lost time. And there was a several-months-long break in construction due to an extraneous circumstance. "Little things add up," says Astrachan.

Modifying for Modular

And contrary to the usual recommendation to design with offsite in mind from the outset, citizenM Bowery didn't start out as modular. The project was originally intended to be site-cast concrete, and the design had already been approved by New York City's Department of Buildings (DOB) when a change in ownership structure resulted in the shift to the new method. The design team filed a post-approval amendment to modify the building to facilitate modular. Changes included relocating the mechanical room from the 18th floor to the third floor to reduce the weight the modules would need to support and to allow work to begin on it while the modules were being placed. A structural redesign was also needed.

The structural solution entails three distinct layers. The lowest layer, up to the third floor, comprises large-volume amenity spaces—such as a lounge with a cafe and bar, a ground floor cafe, and a double-height lobby—that were not well-suited to modular construction; rather than force things, this section remained in site-cast concrete. A massive, three-foot-deep transfer slab, with spans reaching 34 feet, was introduced at the fourth floor to provide a base for the 15 stories of guest-room modules. And above them, the top floor—which accommodates a rooftop bar with outdoor seating and views—is framed with structural steel. A concrete core and a blade shear wall support the building's lateral loads, with modules fastened to these elements and one another via steel connections.

"Marrying up the tight tolerances of a module with a cast-in-place concrete core was a challenge," says Michael Schwartz, a senior associate at DeSimone Consulting Engineers, structural engineers for the project. Connections for the modules had to withstand the large forces a tall building generates, while also providing sufficient field tolerances, avoiding interference with adjacent modules and allowing room to assemble the modules. Wherever the two structural systems met, the engineers maximized the connections' tolerances, and stood ready to respond in the field with a sketch or site instruction to keep the modules stacking at a rate of eight to 10 a day. Astrachan describes the potential for problems where conventional and modular systems meet as the project's "No. 1 lesson learned."

Quality control may be the primary advantage of modular construction that this project was able to realize. With work being conducted out of the weather, at workbench height, and with assembly-line production methods, "modular construction takes the pressure off the back end of the construction schedule," says Schwartz. "There was none of the usual check-listing—cracked tile, loose wallpaper—when the hotel was trying to open."

The Bowery location is citizenM's second shot at building modular in New York. The first initiative (which became the brand's conventionally constructed Times Square property, completed in 2014) switched to conventional when the DOB refused to permit the incorporation of a sprinkler system that could not be locally inspected. Since then, the city has become more supportive of modular construction, and DOB inspectors travelled to Poland to inspect sprinklers in Bowery modules. With citizenM's first North American modular development now complete, "they're over the hump," says Schwartz, and the company has modular hotels for other American cities in the works. ■

stats

Project Data

Location:
New York, NY

Project Size:
100,000 square feet

Construction Start:
2012

Construction Complete:
2018

Owner:
citizenM

Architect:
Stephen B. Jacobs Group Architects and Planners

Interior Design:
Concrete Architectural Associates

Structural Engineer:
DeSimone Consulting Engineers

General Contractor:
The Rinaldi Group

Modular Builder:
Polcom Group

case study

Systematic Modularization

Advocate Aurora Health

ILLINOIS AND WISCONSIN

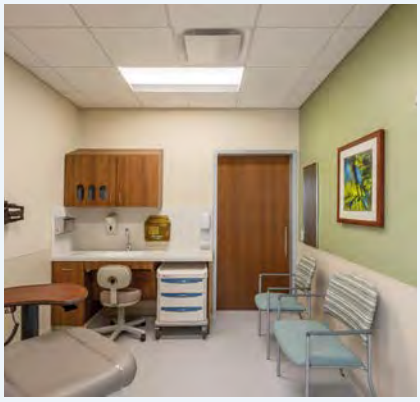
With costs for medical office buildings trending upwards at 12% annually, Advocate Aurora Health (AAH), an Illinois- and Wisconsin-based healthcare system comprising some 500 care centers and 27 hospitals, is exploring the potential of modular construction. AAH has embarked on a program of standardization and modularization—not just on a single project, but across its billion-dollar capital improvement program.

"By shifting to modular design and construction approaches, healthcare organizations can create competitive advantage by accelerating speed-to-market, improving cost certainty and delivering consistent results across their system," says CannonDesign, architects for AAH's modular program, in a written overview of the initiative.

Working in collaboration with Cannon, AAH has developed a set of consistent design standards for its frequently repeating spaces, such as patient exam rooms, emergency care stations, bathroom pods, inpatient care rooms, and reception and intake spaces. Applying these standards, AAH has now begun modularizing construction of one of ambulatory care's most common spaces: patient exam rooms. To date AAH and its integrated project delivery team has installed 137 exam room modules across three different sites of care, including a tenant improvement of an existing building.

Iterative Improvements

The program began with a beta test—a hypothetical modularization of a medical office building then under construction—and has progressed across three sites of care, including a 55,000-sq.-ft. outpatient center completed in 2017 in Chicago, a 8,630-sq.-ft. tenant improvement in Lombard, Ill., and a 62,300-sq.-ft. new-build completed in 2019 in Oak Lawn, Ill. With each iteration, the number of variations that were needed to achieve the design dropped: from an initial five for the beta test (to meet the requirements of a building that had not been designed with modular in mind) to just two once the project-integrated modular fabricator suggested a tweak to the Oak Lawn building's structural grid.



AAH has begun to use modular construction for patient exam rooms.

Image Courtesy of CannonDesign

Indicators of quality improvement include no defects in delivered pods, no need for onsite rework (typically 30% of construction cost is rework, says CannonDesign), no punch list items for modules across all three sites of care and construction tolerances of 1/8 of an inch per 10 feet. In a set of notes generated for this case study, project representatives from owner, design, construction and fabrication perspectives identify the following as the most significant contributing factors:

- **Mockups to confirm design decisions and their execution prior to starting production**
- **Consistency of design across the pods**
- **Teams consisting of properly trained union labor, and consistent teams from project to project**
- **A quality review checklist for each pod**
- **Productive and ergonomic setups, such as table-height work and production jigs**
- **Nested prefabrication wherever possible, including preassembled plumbing, pre-bent electrical pipe and pre-piped boxes, precut steel studs, and CNC-cut gypsum board**
- **Higher quality materials to withstand transportation logistics**
- **Kaizen learning (a process of continuous improvement)**

Because manufacturing teams are able to work eight hours a day (a 25% improvement over the six-hour day that's typical for construction field work), productivity gains improve the projects' speed-to-market. Overall schedule savings attributable in whole or part to modularization range from two weeks on the initial 55,000-sq.-ft. care center to twice that on the most recent 62,300-sq.-ft. care center. A typical reduction in delivery time from use of modular is about 28%, according to CannonDesign.

As an incident of the quality and productivity measures, project waste has plummeted. When precutting of drywall is possible, waste consists almost exclusively of packing boxes for the modules' accessories and fixtures: an average of only one or two dumpsters of waste for the modular scope.

CONTINUED

Advocate Aurora Health

ILLINOIS AND WISCONSIN

Many of the factors contributing to improved quality and efficiency also foster worker safety—both in the factory and, through reduced congestion, onsite. In 10,485 hours worked across the three projects, there were only two safety incidents, and neither was OSHA recordable.

A Collaborative Effort

Underlying the achievements and iterative improvement of AAH's modular program is an Integrated Project Delivery structure. "It took true team collaboration and effort to get this all to work," says Greg Heiser, a principal in CannonDesign's Chicago office. "We can't stress that enough." In particular, IPD's characteristic cost transparency incentivizes wholehearted collaboration. According to a joint statement from owner, design, construction and fabrication representatives, "without IPD commercial structure, the true cost advantages of the exam pod integration with traditional construction would be difficult to bring to fruition."

The owner's role as proponent is essential, as is the early onboarding of the CM, the design team and the modular fabricator. "It is a different process," says Heiser, "a different way of thinking." The team also highlights the role of technology in the projects' successes: "You're taking a completed element and dropping it into something that's already partially constructed," says Heiser. "That wouldn't have been possible without BIM to help us understand the tolerances involved and the coordination all this would take."

Prime examples of that coordination include:

- **Early communication with the construction manager/build partner to bring all trade partners on board prior to finalizing the pod layout**
- **Resolution of MEP and fire protection routing before prefabrication starts (coordination and routing that optimize the pods might not optimize MEP design efficiency and productivity)**
- **Reduction of onsite through-floor penetration tolerances**
- **Planning of site logistics for unloading and hoisting the pods, with implications for the window of entrance, the rest of the building production schedule and the enclosure schedule: (a minimum path of 12-ft.-wide-by-10-ft.-6-in.-high is typically needed to transverse the pods through the building, and must be coordinated with all overhead work)**
- **Procurement of the pods**
- **Early engagement of the Authority Having Jurisdiction to facilitate an efficient, systematic and collaborative approach to inspections in-shop and onsite**

Based on the success of its modular initiative so far, AAH and its project delivery team are now exploring opportunities for expanding the use of modular construction to other frequently repeated spaces. As the modular program takes its place in the organization's suite of offsite construction strategies—including building envelope panels, multi-trade racks and interior wall panels complete with rough-ins—additional advantages are expected to open up. "The things AAH wants to see next, and the volume of their capital demand, will drive some of these," says Ryan Yoho, director of construction management at the Boldt Company, CM for the projects. "If you have the right capacity, you can be more bold with what's next." ■

Project Data

Owner: Advocate Aurora Health
User: AMG
Construction Manager: The Boldt Company
Modular Standardization and Design: CannonDesign
Modular Fabrication: Integrated Modular Design
Examination Room Pod Area: 120 sq. ft.
Total Examination Room Pods (Three Projects): 137
Total Pod Area: 16,440 sq. ft.
Total Project Area: 125,922 sq. ft.

Medical Office Building (AMG Sykes):
Type: New build
Completed: 2017
Project Area: 55,000 sq. ft.
Exam Pods: 53
Exam Pod area: 6,360 sq. ft.
Schedule Compression: 2-3 weeks

Medical Office Building (AMG Lombard):
Type: Tenant improvement
Completed: 2018
Project Area: 8,630 sq. ft.
Exam Pods: 12
Exam Pod Area: 1,440 sq. ft.
Schedule Compression: None

Medical office building (AMG Oak Lawn):
Type: New build
Completed 2019
Project Area: 62,292 sq. ft.
Exam Pods: 72
Exam Pod Area: 8,640 sq. ft.
Schedule Compression: One month

stats

Owner Perspectives

On Using Prefabrication and Modular Construction

Owners who are engaged with prefabrication and modular construction sing its praises, but they also recognize that they have to be the driving force to see wider use of it in the industry.

The Research

To gain the perspective of owners who are engaged with prefabrication and modular construction, interviews were conducted with five individuals with projects using these approaches in four sectors: healthcare, education, hospitality and residential. Interviews were kept confidential in order to encourage a frank and open discussion of the benefits and challenges of using prefabrication and modular construction.

- All participants are senior executives in their companies and responsible for the decision to use these approaches, from a managing partner, to assistant and senior vice presidents, to an executive director and acquisition and development manager.
- The five participants have different levels of experience with modular. One has been building the majority of projects using prefabrication for a while. Two have completed one or two modular buildings, and two are in the midst of planning their first modular projects.
- All are planning to increase their engagement with these approaches in the future.

Benefits Driving Use of Prefabrication and Modular Construction

Many of the owners cited similar benefits driving their use of prefabrication and modular construction.

- **Nearly all of the owners who participated mentioned the ability to compress schedule as a major factor in their decision to use these approaches.**
  - Healthcare owner: "You can do it in parallel with other activities like permitting or getting the sitework done or the steel put up."
  - Education owner: "We originally looked at modular because it was a solution that could be completed relatively quickly."
  - Residential owner: "We want sustainable buildings, and we also want to build them faster and cheaper, and modular provides all of that."
  - Hospitality owners: Both owners mention schedule as an important driver, and one explains its exact appeal: "You gain a lot more operating history in your overall hold period [for the property]. If you have an overall hold period of 60 months, and 18 months of that is spent building traditional, then you only have 42 months of operations. But if you only spend 12 months building, you have six additional months of operations. That really attracted us to this concept."
- **Two owners mentioned quality as a significant factor in their decision.**
  - Healthcare owner: "We think [modular construction] is better quality because a lot of it can be tested or it can be inspected in an easier environment than out in the field.
  - Hospitality owner: "More consistent quality of finishes in the guest rooms" was an important driver.
- **Two owners mention dealing with labor issues as a major factor driving the use of these approaches.**
  - Healthcare owner: "Trained, skilled labor is becoming more scarce ... it's generally a different labor pool that is doing the prefabricated work."
  - Residential owner: Since the homes they are building are in New York, he mentions that they are using an offsite facility in Pennsylvania with "much lower labor rates," which are only partially offset by transportation costs."
- **Improved site logistics are important drivers for two owners.**
  - Healthcare owner: Many of their projects take place in functioning medical facilities, and he notes a key driver is reducing the impact on the operating hospital because "you don't have as many people out there trying to park somewhere, [who] need bathrooms and break areas."
  - Education owner: She notes that they are constructing their multi-phase program on a two-and-a-half-acre urban site. "We had limited space, and we did not have interim housing, so we were moving people around a Rubik's Cube on a small piece of land. The fact that a lot of major construction elements happen offsite shrunk

the space needs as we went from phase to phase."

- **Three of the five owners mention the desire to be innovative as a key driver.**
  - Hospitality owner: "Taking part in an innovative approach to this industry is something that is important to us because we believe that if you are not changing, then you are falling behind."
  - Residential owner: "We are a new firm, and we like to think of ourselves as agile and moving with technology."
  - Education owner: Mentions that they selected their modular vendor because they "had the style and the environmental aspects that we were attracted to."
- **Sustainability was an important factor for the education and residential owner.**
- **While only the residential owner mentioned cost savings as driver (they have the expectation that it will be at least 10% cheaper than traditional stick-build for them due to their labor market), a few did mention that being cost neutral was important in the decision.**

Decision-Makers for Taking This Approach

One clear finding from the five interviews is that owners drive the use of these approaches. The only owner who wasn't the direct driver of its use was one from the hospitality sector, and he credits the leadership of the brand with which he is affiliated as being the major driver.

The healthcare owner notes that after they initially drive prefabrication, their construction partners have embraced it: "We are getting to the point where, instead of saying 'I want you to prefabricate,' we are starting to say, 'We want you to optimize the amount of prefabrication on this project.' In some cases we even set up a percentage goal of offsite hours versus onsite hours." He reports that their general contractors and trade partners are seeing their own advantages. "They are trying to find a workforce to get work done, and [using prefabrication] is a force multiplier when they can build something in a shop with one superintendent managing multiple builds in one place instead of a superintendent required at every project." He has seen them shift from prefabricating components to prefabricating whole rooms.

Challenges With Using Prefabrication/Modular

While the owners agree on the benefits, each brought up unique challenges they have faced in implementing these approaches.

- **The healthcare and one of the hospitality owners find that the supply chain of prefabrication and modular companies is still limited. Both expect more activity to help address this issue.**
- **On a related issue, the healthcare owner also notes that these companies are also still very manual, and he sees an opportunity for industry improvement with greater automation.**
- **Accurate cost estimation is another challenge noted by the healthcare owner.**
  - "Cost systems are not based on modular and prefab. We are not at the point where we are really comparing apples to apples. As an example, if I am building half of the building offsite, I have half the amount of people onsite and all the overhead associated with those folks. That cost is not accounted for in the prefab model."
- **The residential builder notes that the financing sector still needs to better understand this mode of construction, and he is part of a group in this industry who are working on providing big financial lenders with basic guidelines on what to expect from these projects.**
  - "Lenders are not used to lending for modular. They don't understand the parameters and the draw schedules."
- **The education owner finds that there is a trade-off in terms of the limitations of the modular model. You have to work within its parameters.**
- **Getting designers to change their processes to design for prefabrication has also been a challenge for the healthcare owner.**

It is important to note that the owners who raise most of these challenges expect them to be far less of a factor as the industry matures. All agree that, for their types of buildings, the construction industry will embrace these approaches. In fact, the healthcare owner states, "The industry is moving in this direction for survival ... I see major construction companies starting to buy their own prefabrication shops and modular building plants. The industry is moving in this direction naturally due to the workforce [shortage issues] and the need for speed." ■

Methodology:

Prefabrication and Modular Construction Study Research

Dodge Data & Analytics conducted the 2019 Prefabrication and Modularization Study using an online survey of construction industry professionals in October and November of 2019. The data was collected from the following sources:

- **Dodge Data & Analytics Architect and Contractor Panels:** The Dodge Data & Analytics Architect and Contractor Panels contain representative samples of construction architects and contractors across the US. The panelists are identified by many categories, including size, region, types of projects undertaken and specialty.
- **Dodge Database of construction professionals**
- **Participation from the memberships of association partners, including both research and funding partners.**
  - Associated Builders and Contractors (ABC)
  - American Institute of Steel Construction (AISC)
  - Modular Building Institute (MBI)
  - Mechanical Contractors Association of America (MCAA)
  - National Electrical Contractors Association (NECA)
  - The Association of Union Constructors (TAUC)

Respondents

A total of 608 qualified responses were received to the survey.

FIRM TYPE

Only respondents who worked for the types of companies listed below were allowed to participate in the study.

- **Architecture (excluding landscape architecture)—165 responses**
- **Engineering—33 responses**
- **GCs/CMs (category includes general contractor, construction manager, design-builder, civil/site/geotech contractor)—176 responses**
- **Specialty/trade subcontractors (category includes steel fabricator/erector, concrete fabricator/erector, building enclosure fabricator/installer)—219 responses**
- **Modular builders/manufacturers—15 responses**

ADDITIONAL REQUIREMENTS FOR PARTICIPATION

To participate in the study, respondents had to have worked on a multifamily or non-residential building project in 2018, and a prefabrication or permanent modular construction project in the last three years. In addition, no more than 50% of their projects could be one or two-family homes.

PREFABRICATION AND MODULAR RESPONDENTS

The survey used in this project had two lines of inquiry, one for prefabrication and the other for modular construction. For consistency, some survey questions used similar response options for both lines of inquiry, but other questions were tailored specifically to the unique nature of each approach.

Based on rules built into the initial screening questions in the survey instrument, 34% of the 608 total respondents were determined to have had enough experience with modular construction to serve as the group representing those users and respond to the modular construction line of inquiry for the remainder of the survey. The other 66% responded to the prefabrication line of inquiry. Below is the breakdown by discipline, which meets statistical significance thresholds for all groups involved.

The table below shows the percentages of overall survey respondents by type of company.

BIM USE

Level of BIM use is used as an analytic variable in the analysis.

- **Do Not Use BIM:**
  - Prefabrication Respondents: 11%
  - Modular Respondents: 12%
- **Use BIM on Less Than 50% of Projects**
  - Prefabrication Respondents: 46%
  - Modular Respondents: 33%
- **Use BIM on 50% or More of Projects**
  - Prefabrication Respondents: 43%
  - Modular Respondents: 55% ■

Prefabrication and Modular Respondents

	Prefabrication Line of Inquiry	Modular Construction Line of Inquiry
Architects	62%	38%
Engineers	40%	60%
GCs/CMs	66%	34%
Trade Contractors	77%	23%
Modular Builders/ Manufacturers	11%	89%
TOTAL	66%	34%

Resources

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

DODGE DATA & ANALYTICS

Dodge Data & Analytics
Main Website: **www.construction.com**
Dodge Construction Central: **www.construction.com/products**
Market & Competitive Intelligence: **www.construction.com/products/construction-market-data**
Sweets: **www.construction.com/products/sweets**
SmartMarket Reports: **www.construction.com/toolkit/reports**

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American Institute of Steel Construction: **www.aisc.org**
National Electrical Contractors Association: **www.necanet.org**
The Association for Union Contractors: **www.tauc.org**

Other Resources

BIMForum: **https://bimforum.org**
Lean Construction Institute: **www.leanconstruction.org**
National Institute of Building Sciences main website: **www.nibs.org**
National Institute of Building Sciences Off-site Construction Council: **www.nibs.org/page/oscc**

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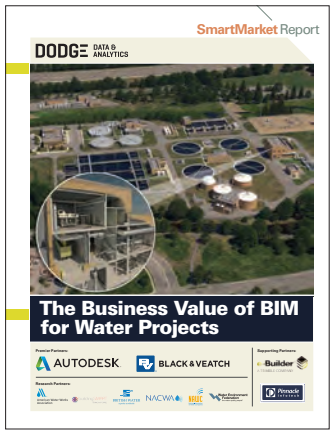

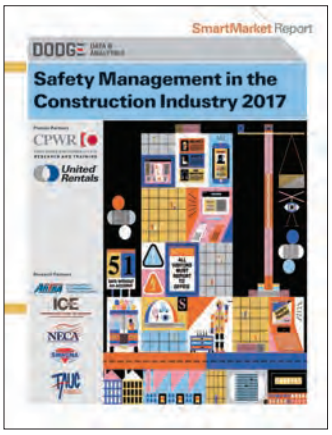

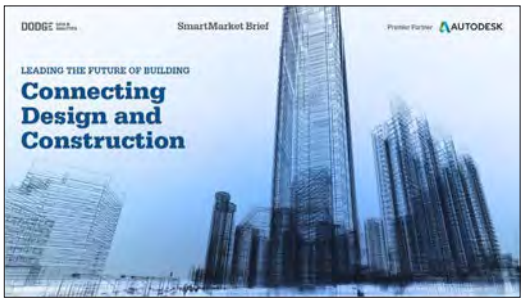

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