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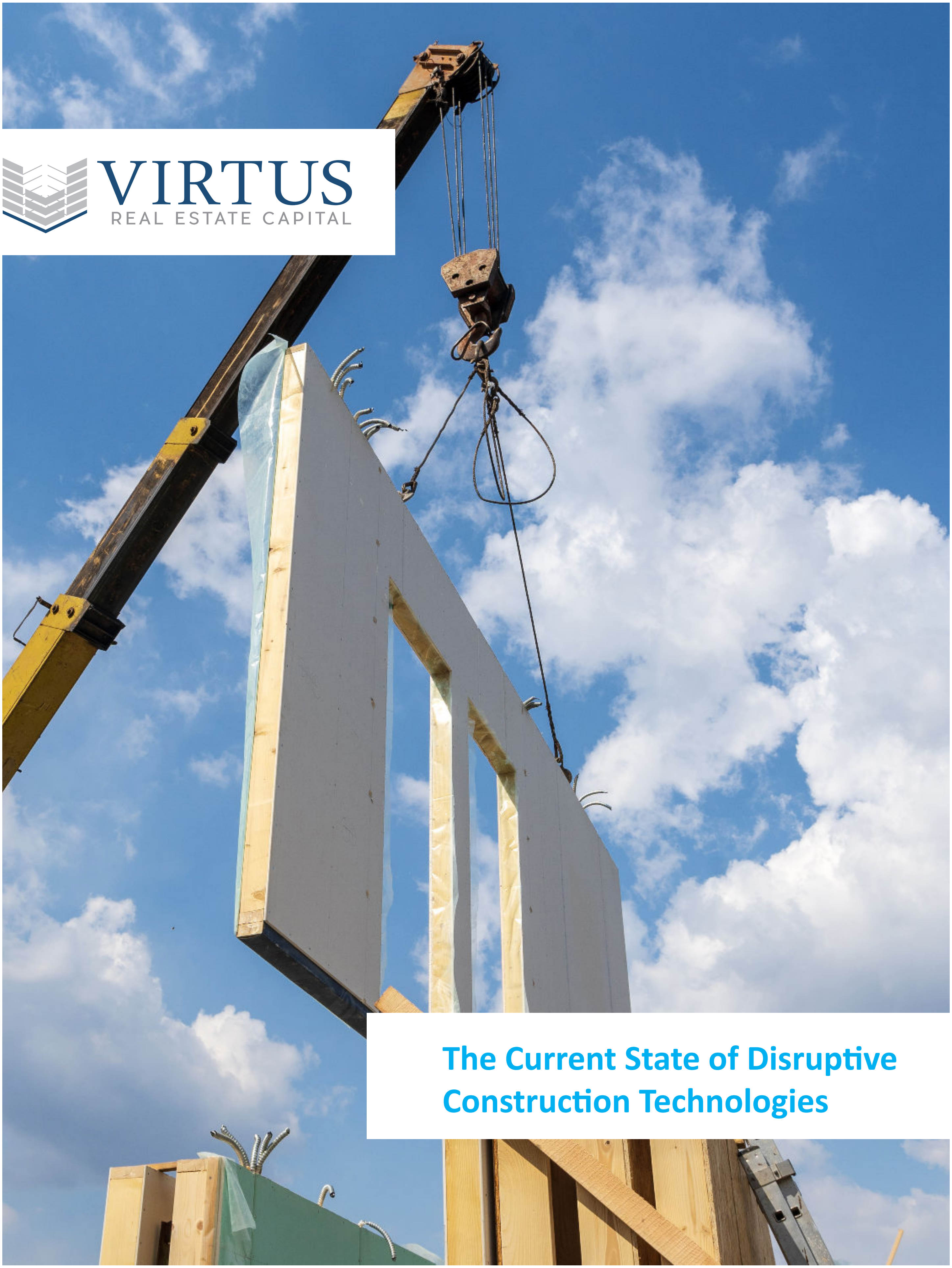

The Current State of Disruptive Construction Technologies

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Construction technology has been relatively stagnant for many decades compared to other, equally crucial sectors. This is true even at the "leading edge" of innovation, where modular technologies have promised to cut both project costs and timelines substantially, but they have yet to reach scale after decades of existence. However, the current moment shows evidence for both progress in existing approaches, as well as increasing diversity of nascent strategies for "industrializing" the production of buildings. These trends are accompanied by a parallel "prop-tech" revolution that promises to make all aspects of commercial real estate more efficient and exacting. Finally, the rising costs and regulations on conventional construction make the risks of innovation increasingly attractive. In this white paper, we make sense of this evolving landscape, tracing the current state of "new best practice" and the most likely trajectory future construction will take as both new technologies and business organizations form. Virtus generally expects that:

Conventional "modular" construction techniques will continue growing and improving, but its fundamental limits remain.

- Conventional, "volumetric" modular refers to projects where entire finished "modules" of space are constructed off-site and trucked to the location.
- This technology performs best in dense areas with extremely high labor costs, but it can still be more expensive compared to existing lower density, mass builder approaches.
- It also suffers from scale and capacity constraints due to the factory nature of construction and hauling finished space on roads. Successful fabricators with good delivery track records often have wait lists exceeding the project timeline savings, plus they may be too far from the site for cost savings.

Other prefabrication strategies will proliferate, but it is unclear which will dominate.

- Other strategies include smaller components of standardization instead of entire modules of finished space—often categorized as "flat pack" prefabricated or "kit of parts" modular.
- It may also include disruptive methods like 3D printing of components instead of conventional construction.
- Such technology performs best with "Internet of Things" type tracking of components, so these approaches will likely grow alongside advances in prop-tech.
- Such methods travel more flexibly and may prove better suited to the inherent need for customization that individual building sites pose—a blend of standardization and site optimization.

The Current State of Disruptive Construction Technologies

Building technology will provide a competitive edge for individual firms, but will not solve housing affordability alone.

- Many of the most promising innovations on the immediate horizon have less to do with construction specifically and more with prop-tech—ways of making project development and management smarter and more visible.
- Such technologies may help realize the potential of new construction methods like modular, but nothing in the immediate horizon promises great enough gains to break the binding constraint caused by zoning and historical underproduction.

MODULAR CONSTRUCTION - THE NEXT BIG THING...AGAIN?

In June of 2021, the Softbank Vision backed firm Katerra, which had promised to disrupt construction using prefabrication, filed for bankruptcy. Katerra's trajectory mirrors that of the modular subsector at large—first promising major advantages in time and cost, which floundered on the idiosyncrasies of actual projects, until the fiscally distressed company finally broke apart during the upheavals of the development cycle (this time brought on by COVID-19).

Past failures of modular construction, such as the Atlantic Yards development (which suffered from cost and time overruns, plus significant quality issues) could be chalked up to emerging platforms or under-investment. However, Katerra benefited from some of the deepest pockets in venture capital, itself a community that is famously tolerant of achieving success through repeated failure. Therefore, it is an especially stark reminder of how slow construction technology progress has been during a time when so many other sectors have made immense gains.

Back in 1999, Bill Gates boasted of the computing industry's progress along the cost curve, joking that if cars had kept up with their progress, we would have 25 dollar cars getting 1,000 miles per gallon. The comparison is especially amusing in the context of real estate, as both computers and cars have seen gains in performance and cost-savings that make real estate look primitive. In fact, housing has only become more expensive and less productive, taking a greater share of typical budgets than it did even before household computers existed.

Unfortunately, there are a host of reasons for this beyond the direct purview of construction technology (such as zoning and public underinvestment, which Virtus has touched on in past white papers). Nonetheless, the construction sector has been glacial in its productivity gains when one compares it to other verticals of similar scale and importance. However, it is currently a very interesting time for construction technology, because progress finally (or again) seems attainable on multiple fronts—due to continued advances in existing technology, entirely new solutions, as well as a shift in demand brought about by rising costs and regulations. As such, the current environment is one where entrenched strategies (with immense organizational barriers to change) must be balanced against both medium maturity innovations, as well as entirely new technologies.

TYPES OF "INDUSTRIALIZED CONSTRUCTION," FROM VOLUMETRIC MODULAR TO PROP-TECH

For decades, the only candidate promising to change construction substantially was volumetric modular fabrication in which structurally intact, finished spaces are produced off-site and assembled into blocks of space on-site. This approach has significant appeal for certain markets and product types, but also has major limitations. The foremost is that the maximum size of the modules has nothing to do with the end site but is instead limited by the width of the roads the modules will travel along. While vertically designed modular projects are capable of great design diversity that can make the individual modules invisible to the untrained eye, this fundamental constraint still limits the structural and size options of the end space, as well as being unwieldy for transport. Another limitation is that individual modules must have some degree of internal structural integrity that may not be optimized at the full, assembled structural level. Finally, it is a difficult process moving and assembling large pre-built space modules, and errors in the process can cause timelines and costs to balloon.

In addition, there are hybrid modular approaches and other off-site fabrication strategies that are less technologically mature, but which have greater potential for flexibility. These are sometimes referred to simply as "hybrid" modular, or else differentiated into "flat pack" versus "kit of parts" strategies. Flat pack strategies (also referred to as "2D") refer to designs where major components like walls are pre-built off-site, then trucked to the site in densely packed rows and assembled on-site. "Kit of parts" strategies are even less pre-built, instead composed of standardized components assembled on-site. This strategy is so frequently likened to Scandinavian furniture chain, IKEA's flat pack furniture, that it was inevitable IKEA would form a partnership to produce housing. Finally, there are also emerging technologies like 3D printing that take an entirely new approach to fabrication that truly approximates mass production.

Many times, these approaches grow organically from individual product manufacturing, rather than an entire systems-level space design plan. For instance, companies like Baker Triangle have produced prefabricated wall panels that have been incorporated into both volumetric modular and conventional job sites. Meanwhile firms like Porter Co and DPR construction produce standalone mechanical rooms, elevator cores, and even bathrooms that can be plugged into existing job plans. While these solutions are ideal from a product producer standpoint (in satisfying a variety of buyer types), they are still less cohesive than an entire building language that was designed to fit together. As firms like MiTek (a Berkshire Hathaway company) are currently extending this kind of thinking into entire spatial systems, it is likely such "kit of parts" approaches will become increasingly common.

The Current State of Disruptive Construction Technologies

Figure 1: Types of Modular Fabrication

Type of Modular Fabrication	Current Best Application	Near Term Innovations Needed for Growth	Fundamental Limitations
Volumetric	• Multifamily, hospitality, and other uses with regular repetition of unit plans	• More factories for shorter waitlists • Greater industry standardization of components • More advanced robotic component assembly	• Transport limits module size • Modules limit design configurations • Onsite assembly leaves little room for error / revision
Foldable Units	• Single family houses, especially in remote or dense areas with difficult access	• Same as above	• Likely a niche technology that better “kit of parts” and **volumetric** approaches will supplant / absorp
Flat-Pack / “2D” / Kit of Parts	• Larger or more irregular floor plans not ideally served by volumetric modular solutions	• Same as above, plus: • “Internet of things” component tracking from design stage • Greater scale among platforms	• Requires both robust offsite labor force, as well as larger onsite labor than volumetric
3D Printed	• Single family houses and building components	• Maturation of existing platforms • Greater sector capitalization to scale up toward larger projects	• Sector not mature enough to understand fundamental limitations

Figure 2: Volumetric versus Flat Modular

Flat Pack Strategies:
- Travel more efficiently
- Require more onsite labor
- Require greater vertical integration

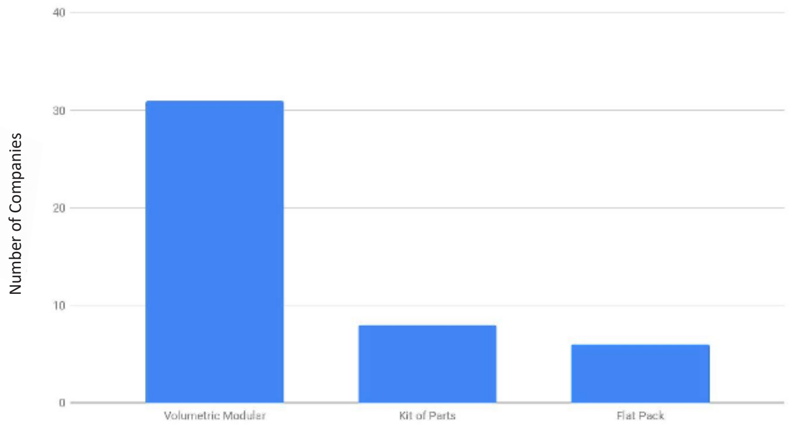
vs.

Volumetric Modular
- Entire modules must travel
- Assembled onsite via cranes
- Still require onsite roof / foundation labor

Source: McKinsey Capital Projects & Infrastructure. “Modular Construction: From Projects To Products.”

However, these strategies are harder to evaluate compared to volumetric modular, because they are far newer and less widely attempted, yet they both depend on a greater degree of cohesive and uniform design language, i.e., a volumetric modular building only needs to fit together at the macro scale, whereas both hybrid approaches require a greater attention to detail from the beginning. This is also why such strategies are best enabled alongside object-intelligent product tracking (following building components from design documents through the contracting process) than has been possible.

Figure 3: Volumetric versus Flat Modular



Source: “A Preliminary Overview of Emerging Trends for Industrialized Construction in the United States.” Pullen, Hall, Lessing. https://www.researchgate.net/publication/335260785

As it happens, such data-aware construction is increasingly possible because there is a burgeoning prop-tech revolution that will enable deeper productivity across all construction approaches by making information more transparent and connective across phases of development that have historically been separate. While this latter trend is only indirectly related to construction itself, it will enable development strategies that were previously infeasible (such as “kit of parts” modular strategies), as well as raising the bar of conventional construction productivity that disruptive trends will need to clear. Covering the universe of prop-tech solutions and their individual appeals would both require an entirely separate white paper and would be premature due to the constantly evolving nature of the space. However, interested readers may find the reports produced by Navitas instructive.

THE ROLE OF PROP-TECH

Prop-tech can refer to niche services like billing software that makes payments drafts or construction liens more efficient and visible, or else specialized job boards tailored to construction labor. It may also refer to “smart” property management platforms that automate maintenance queues or tenant service. More germane to construction, it can be software that translates design documents (which increasingly moving from AutoCAD to object-oriented Building Information Modeling platforms) with contracting bids and ultimately to site crew instructions.

In turn, this will provide the data "infrastructure" necessary for true automation or mass production. Fully realized, this would mean a seamless transition from construction drawings to contractor bids and finally to real, physical building components delivered to either a factory or construction site. **While much of the technology required already exists, its full potential requires pervasive adoption across the massive, infamously slow-moving construction sector. As such, the current moment is one of rapidly proliferating tech solutions across all aspects of the development process—any one of which could prove to be either a dominant industry standard or else defunct within a few years.**

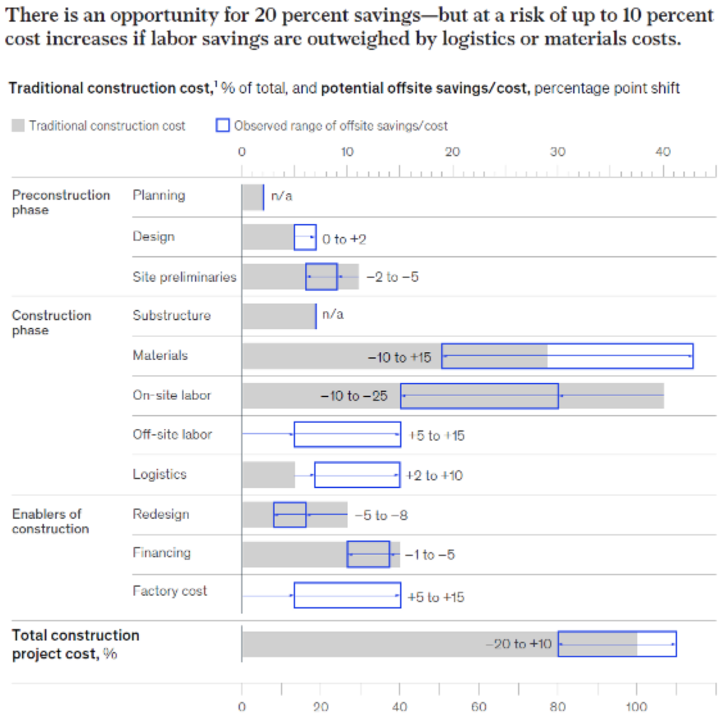
THE CURRENT STATE OF PREFABRICATED CONSTRUCTION

Taking the promise of modular fabrication at face value, it is surprising that such methods are not already standard best practice. After all, the earliest true volumetric modular projects were being completed in the 1960s, so clearly the industry has had entire generations for everyone from developers to laborers to get on-board with such a superior technology. However, over half a century later, it remains a niche approach in the grand scheme of the sector. Growth in project data has still been substantial enough that we can at least benchmark the performance of actual projects against conventional approaches. The McKinsey consulting firm has been producing frequent studies on the sector for several years now, most recently having completed a uniquely comprehensive breakdown of realized projects. They found a range of potential outcomes, from a full opportunity of 20% cost savings on total project, to a risk of 10% cost overages if logistics and materials costs outweighed the labor efficiencies. The extra logistics burden of modular projects is due to needed coordination across both off-site and on-site labor. That said, most modular manufacturers will tout the massive materials savings from efficient factory construction as a given. In reality, the lower economies of scale from small operations, as well as the extra structural redundancy volumetric modular buildings require, mean materials costs can run upwards of 15% higher from off-site construction.

There is more widespread success around project timelines in modular fabrication, with off-site volumetric projects compressing development delivery by 20 - 50%. However, all this comes with the practical caveat that successful modular factories often experience swelled workloads and have wait lists that may exceed the time savings of the project. This also assumes a modular manufacturer is located in close proximity of the project, ideally within 250 miles, so production savings are not usurped by increased transportation costs. In short, modular technology currently offers the potential of a 20% cheaper project delivered in half the time—but the practical implementation carries the risk of a more expensive project delivered longer after initial conception compared to conventional methods.

In short, there are very understandable reasons individual projects and firms either stick with "tried and true" processes, sometimes even after having attempted to achieve the gains promised from innovation. Indeed, there are many devils buried in the details of commercial construction that cause this wide range of cost outcomes to persist despite the time modular approaches have been around.

Figure 4: Cost Savings Range Potential and Breakdown



Source: McKinsey Capital Projects & Infrastructure. “Modular Construction: From Projects To Products.”

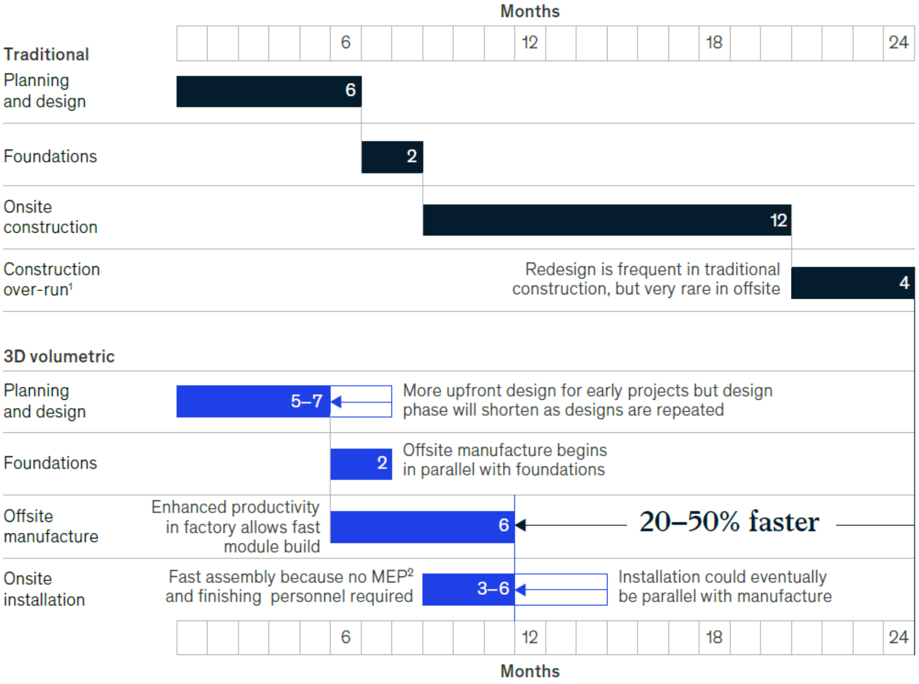
MODULAR CONSTRUCTION CONSIDERATIONS

Construction is Extremely Labor Intensive

Despite the constant references modular fabricators make toward assembly line mass production elsewhere, building construction is innately labor intensive, and off-site fabrication changes only the character (but not the content) of the process. **Factory fabrication teams may be smaller, more task-optimized, or just more experienced, but until modular fabricators can begin using robotic manufacturing more widely, comparisons to car or computer production will always cast construction in poor light.** Currently, the best modular fabricators do use robotic assembly for large pieces like assembled roof trusses and other components.

However, unlike a tiny laptop or even medium sized car, the immense size and task diversity of building components means it is extremely difficult to make robotic mass assembly more cost effective than both unskilled and skilled labor. Unlike the complex minutia that characterizes items like electronics, much of the construction process involves relatively simple individual actions that all cohere toward a much more complex whole. In short, construction poses both higher technological demands, but offers lower cost alternatives than either semiconductors or semitrucks.

Figure 5: Time Savings Range Potential and Breakdown



Source: McKinsey Capital Projects & Infrastructure. "Modular Construction: From Projects To Products."

Site Idiosyncrasies Defy Standardization

Another place the headline potential of "factory" buildings often conflicts with reality relates to the limits of standardization. Building sites have irregular shapes, varying topography, and different setback or programmatic demands for each side. Together, these relatively simple constraints (combined with unique usage needs for each structure) compose a product that defies the kind of true mass assembly that radically shifts cost curves. Returning to our comparisons with other durable goods, cars can give the feeling of customization by allowing multiple cosmetic options on top of a standardized chassis—or at most swapping in different pre-built components. Personal computers follow largely the same process (i.e., assembling a custom PC from parts is relatively easy for an amateur with decent Google skills). Meanwhile, every construction project is closer to designing an entirely new model of car from the chassis up—generally a process taking many months before construction can start. **In short, for all its underlying intricacy, a personal computer is more like a mass-produced off-the-rack clothing item that comes in a few different colors and sizes, whereas large scale commercial buildings are more like bespoke suits—in process and cost, if not quality.**

Off-site Assembly Introduces New On-site Problems

Another area where modular assembly provides an early promise with challenges downstream is in the final site assemblage. Proponents of off-site fabrication characterize it as vastly more precise and accurate to plans compared to the chaos and unseen “make it work” moments of on-site construction. However, even at face value, the alternative side of this argument is that on-site work is more organic and adaptable to error or change. Meanwhile, bringing large, pre-built building blocks to a site can prove disastrous when small tolerance differences (for instance, foundation leveling issues) end up requiring post-factory retrofitting to the “perfect” factory modules. These issues, where tiny inconsistencies get magnified into huge problems, become more prevalent the larger and denser a project gets—which is unfortunately where modular projects have the most potential to excel. The result is a paradoxical situation where smaller projects (already well optimized) attract a larger share of “testing ground” modular attempts, whereas developers of larger projects gravitate toward the familiar risks of “the devil one knows” in conventional on-site construction.

Local Regulators Often Discourage Off-site Work

Local building code and zoning standards can also serve as impediments to modular development as they were standardized before off-site fabrication was a common option. For instance, the off-site rough-in of mechanical and electrical systems has frequently stymied approval from local regulators who view this as less trustworthy or easily verifiable. It is not uncommon for building officials to visit modular factories—at least in cases where they are broad minded to spend the extra effort rather than simply denying necessary permits.

Economies of Scale Still Favor Incumbents

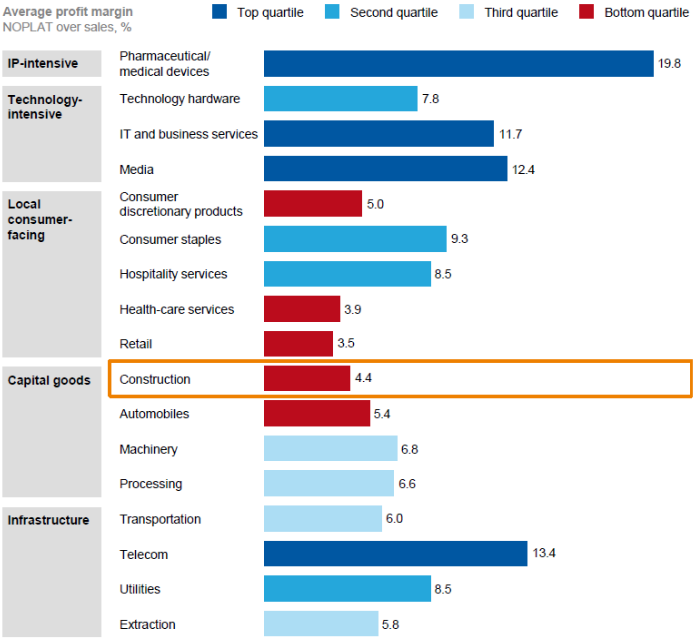
Compounding all the challenges mentioned above, a platform must achieve a certain scale before it can exceed the productive potential of existing methods. According to McKinsey’s most recent report, there is virtually no advantage to modular fabrication from platforms producing less than 1,000 units per year, with the next observable inflection point at 5,000. (We have used these thresholds in categorizing off-site approaches by type and maturity in Figure 5). Producing such a platform entails much greater initial capital requirements to set up a factory, in addition to the formidable organizational challenges and costs associated with forming a conventional development platform. Such platforms are not ideally matched to the “feast or famine” nature of development pipelines. It is much easier to triple productive capacity in a traditional on-site platform simply by contracting more labor during active parts of a cycle, compared to a factory that would need to build out additional space to serve a higher volume once at capacity. However, when the inevitable downward part of the cycle arrives, that excess capacity is a threat to profits, whereas the conventional construction labor pool merely shrinks and transfers to other trades during such times. **It is no wonder that so few modular shops can stay open long enough over cycles to develop truly standardized processes, seasoned teams, or other factors driving deeper productivity. Moreover, the few modular shops that DO rise above this challenge are generally buried in enough work that waitlists frequently exceed the time savings from construction once the project has started.**

The Current State of Disruptive Construction Technologies

Modular Success Requires Commitment from the Start

As if all the above was not challenging enough, off-site fabrication requires full commitment from the start and a high degree of vertical integration from all parties, starting with design professionals. All types of industrial fabrication, from volumetric to “kit of parts” require a design fully optimized for the end system. This means developers can rarely pursue sites using their existing processes, then take the “option” of modular fabrication during the contracting phase—at least not without major changes that will slow down project timelines. As such, industry professionals wanting to access the full potential of these technologies must commit resources, while knowing the current solutions may be rapidly displaced by better or just different industry standards that proliferate. Similarly, the best modular fabricators must parallel track constant optimization and innovation to stay ahead of both their conventional and off-site competitors. Finally, both conventional and industrialized construction need to contend with the low margins and high capital requirements the sector demands. Truly disruptive solutions have the potential to increase these margins, but only after surmounting the input and labor cost challenges that depress margin.

Figure 6: Construction Margins are Bottom Quartile



Source: McKinsey Corporate Performance Analysis Tool; Bureau of Economic Analysis

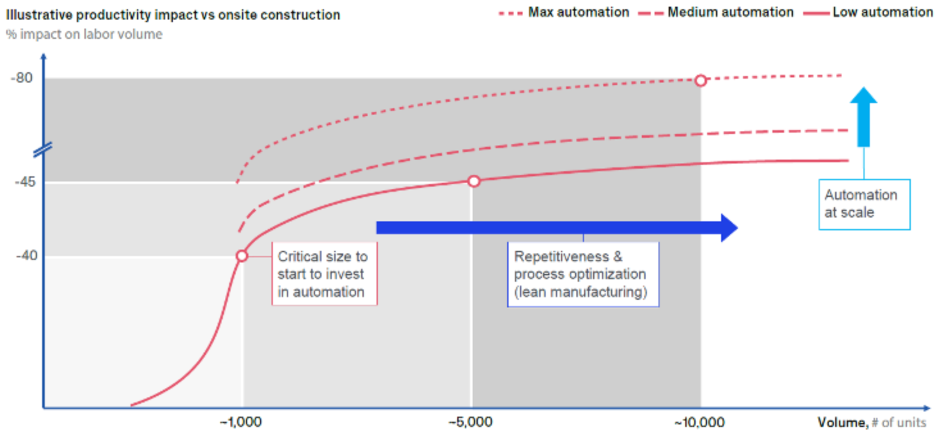
WHAT IT WILL TAKE TO FINALLY BEAT ROADBLOCKS TO INNOVATION

We did not enumerate these challenges to suggest pessimism about the future of construction progress. Instead, they are intended to specify the good reasons why the headline promise of innovative fabrication has so frequently failed to supplant existing methods, as messy and under optimized as they are. Studying the roadblocks that have remained over decades should provide better guides to both how and when more rapid progress may occur. **For instance, rapid advancements in robotics (involving more mobile, spatially aware, and object-intelligent solutions) could finally outcompete human labor by excelling in both production capacity and exactitude, solving two modular roadblocks (labor intensiveness and quality issues) at once**. However, this will depend on multiple parallel breakthroughs in both robotics and artificial intelligence, so it is likely still distant. In addition, the possibility of more technologically intricate buildings could change demand in a way that privileges off-site fabrication. Responsive building envelopes that change opacity or thermal interaction depending on either natural environment or user preferences are currently making their way from prototype to marketability.

If developers of Class-A office or condos begin to see such “smart” building forms as necessary for competitive edge, then the superior production environment of a thermally controlled factory becomes a greater asset.

Finally, both demographic and regulatory trends may benefit the industry as well. For instance, it is increasingly clear that population growth is not evenly distributed, but instead clustered around major job center metros—many of which adopt stringent supply barriers and face labor shortages that boost construction costs. As most construction demand gravitates toward higher cost areas, this favors the risk of innovation compared to business-as-usual.

Figure 7: The Role of Scale and Automation in Cost Savings



Source: McKinsey Capital Projects & Infrastructure. “Modular Construction: From Projects To Products.”

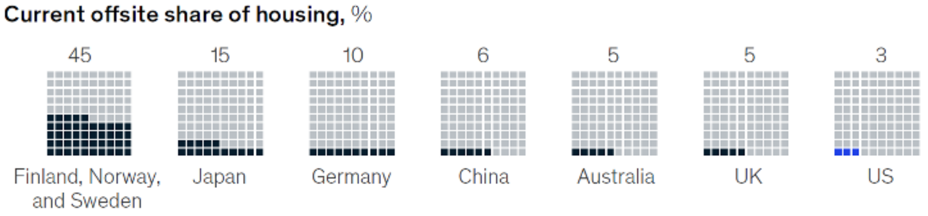
The Current State of Disruptive Construction Technologies

The current questions are which projects, sites, or markets tip the balance in favor of existing innovations—and which innovations on the horizon will grow most rapidly. While it is likely that "sub-modular" approaches will gain traction, the most mature and scalable construction innovations operating today still fall into the "full modular" category. This is simply because there are more such firms at a mature platform stage, and commercial construction requires economies of scale to even match, let alone exceed, the performance of existing solutions. As such, most of the progress seen in large-scale commercial developments is likely to be from mature stage modular platforms such as Guerdon, Finfrock, and Z Modular that specialize in well aligned product types and high labor cost markets.

Modular construction types will likely also grow most rapidly in markets whose cost and operational challenges make it more attractive. Some global context may prove helpful: off-site fabrication is most pervasive in Nordic countries, accounting for nearly half of all residential buildings currently constructed. It is notable that these countries are all cold much of the year (making on-site development difficult or impossible), have expensive labor, and finally their settings tend to be either distinctly urban or more rural/small town-like. Both high urban density and low rural density increase labor and materials costs, so places like Sweden (whose housing authority is currently working on a modular collaboration with IKEA) are very intuitive places for the technology to flourish.

In this sense, the opposite of a setting conducive to modular expansion would be Sunbelt suburban America—with its plentiful land, comparatively low labor costs, and temperate climate. Ironically, those metros have taken such an outsize share of national population growth that they have gradually grown into the problems of coastal gateway metros: high and rising housing costs due to a supply-demand imbalance. **As such, places like Denver and Dallas pose some of the most interesting environments to see construction innovations play out. Historically, their development scenes have been too busy, too profitable, and too entrenched for the risk of innovation. However, with available land becoming more scarce, local regulators demanding more of developers (in both product and tenants served), and development margins generally thinning, this complacency seems ripe for change.**

Figure 8: The Role of Scale and Automation in Cost Savings



[1] Construction wage divided by national median wage.
[2] 2017–20 average housing projection as a % of national housing stock
Source: 5 in 5 Modular Growth Initiative (Ryan Smith); ABS.Stat; CMCH; curbed.com; Euroconstruct; HIA Australia; ILOSTAT; interviews; Ministry of International Trade and Industry (Japan); Mitsui Fudosan; Natural Resources Canada; OECD; Prefab Housing (Matthew Aitchison); Roland Berger; UK Ministry of Housing; Urban Redevelopment Authority; US Census Bureau; McKinsey Capital Projects & Infrastructure

Source: McKinsey Capital Projects & Infrastructure. "Modular Construction: From Projects To Products."

These markets will serve a much more effective threshold test for the viability of off-site fabrication than markets like San Francisco or New York—both of which have regulatory and governance issues making development difficult on a level beyond what only density or local materials costs would suggest. And again, the continued rise in both firm formation and venture funding suggests that this trend is indeed taking place.

THE ROLE OF PROP-TECH: COMPONENTS VS. RAW MATERIALS

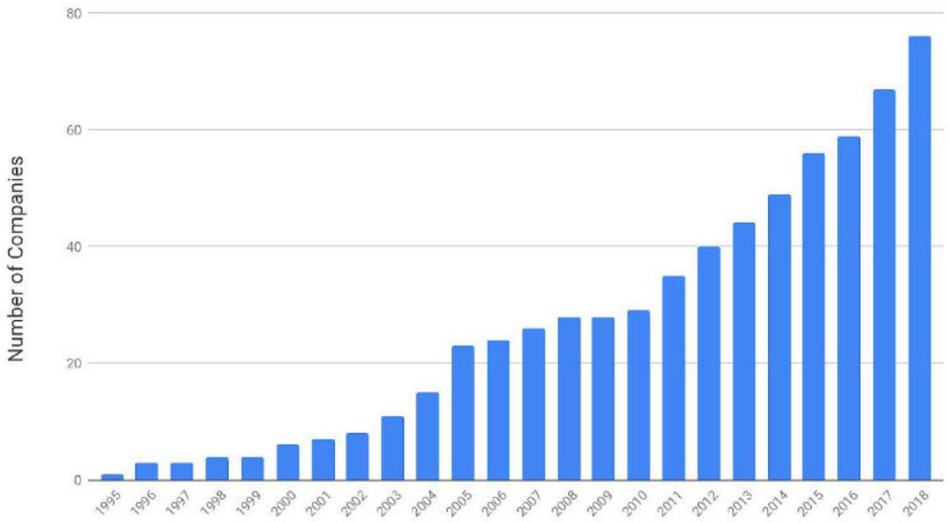
Finally, many prop-tech advances—even those only tangentially related to construction—will not only make all existing forms of construction more efficient, but also enable nascent strategies that are currently infeasible. There are various sub-strategies within the current prop-tech landscape that lend themselves especially well toward modular fabrication, but they generally converge on driving a view where buildings are composed of various components vs. raw materials.

The most obvious example is in Building Information Modeling ("BIM") design solutions that effectively create 3D "digital mirrors" of actual buildings before construction—models in which a cabinet is not a collection of lines, but rather an object with an assigned category and embedded data on materials and quantity. Virtus has already adopted this technology in demanding projects for life sciences and healthcare uses, where complex code and use standards require heavy construction oversight. The most advanced modular fabricators already have customized build-outs of these software packages tailored to their specific plan books and component libraries. Any building produced this way will have much better visibility over quantities and thus costs—especially as changes occur and estimates are updated instantly from a building model. Further, these approaches will dovetail with other prop-tech solutions downstream.

For instance, there is a growing market for three dimensional camera / laser telemetric models of actual buildings under development—generally used to ensure quality, exactitude, and timeliness of construction. These solutions will become widely adopted across all types of jobsites, but they will be especially useful in jobs with a pre-existing digital BIM model that the camera imaging can compare against. In a conventional jobsite, the camera imaging still needs constant manual checks against drawn plans. However, full integration between a BIM model and a digitally mapped jobsite would enable an entirely different level of quality assurance: on-site telemetry could be compared against every aspect of the BIM model, and installation of components could be updated automatically provided both tech platforms had them logged.

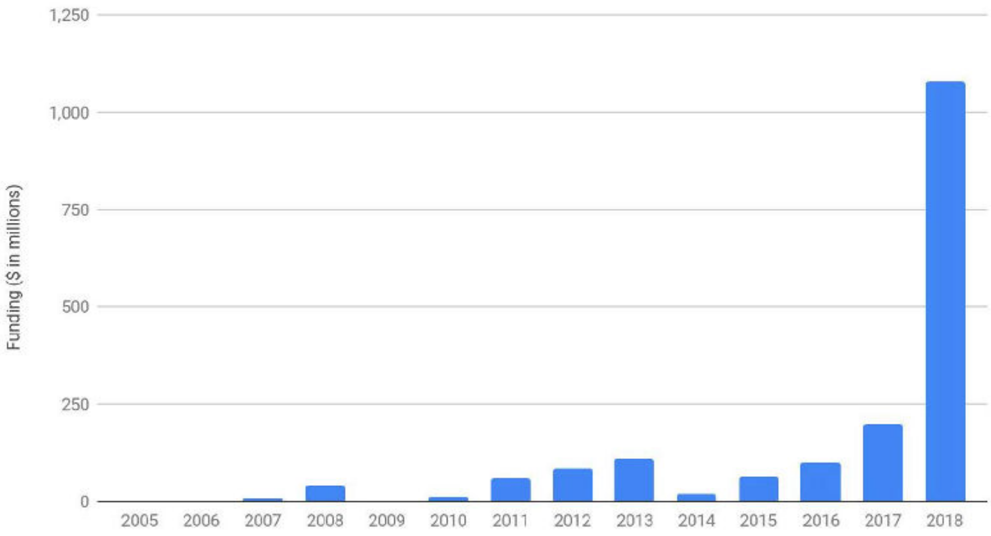
As these technologies mature, they will incentivize upstream producers to better tailor their product catalog toward industrialized fabrication methods. For instance, it is already common for window and cabinet manufacturers to produce BIM models of their catalog so that designers can drop the actual unit into a model at perfect scale. However, as factory fabricators grow, they can reverse the direction of industry influence, with component makers taking directive from modular factories.

Figure 9: Number of Industrialized Construction Firms in USA



Source: “A Preliminary Overview of Emerging Trends for Industrialized Construction in the United States.” Pullen, Hall, Lessing. https://www.researchgate.net/publication/335260785

Figure 10: Growth in Investment Volume



Source: “A Preliminary Overview of Emerging Trends for Industrialized Construction in the United States.” Pullen, Hall, Lessing. https://www.researchgate.net/publication/335260785

The growth of modular networks like the Modular Mobilization Coalition, which often cooperate in helping each other assemble or transport factories, also helps consolidate building standards and hopes to standardize component dimensions from various sources. **In sum, disparate technologies working together can help to shift the influence centers in the construction sector away from massive incumbents and toward growth nodes in off-site fabrication.**

DIFFERENT SCALES OF INNOVATION

Assuming these factors add momentum to progress, the next question is whether volumetric modular will remain the most dominant form of off-site fabrication, or whether other methods will overtake it. For the foreseeable future, the answer is likely to be "it depends," but in arenas where existing modular solutions have already been plentiful, they will likely continue to grow. Examples of such are large hotels, student housing, or other mass projects where a few totally standardized (and small) units comprise most rentable space.

By contrast, larger open plan developments, projects offering tenant improvements on shell space, or complex projects with large, varying units will likely continue to defy full development by volumetric modular means. Instead, these projects may require hybrid approaches, where complex components are fabricated off-site, then trucked to the end location (much more efficiently than in entire modules of built space) and assembled on-site. They may even involve processes currently foreign to construction but widespread elsewhere—an example of which could be "3D printed homes" such as those pioneered by Austin-based ICON housing or else "foldable" modules that pack into blocks and unfold at the jobsite. Currently, these technologies are most effective in smaller scale projects like single family homes. While 3D printed homes may seem outlandish, such truly disruptive methods will be necessary to exceed the performance of the fairly optimized homebuilding sector, which has achieved the closest existing approximation to true "mass production." Smaller scale projects will likely see increased experimentation with hybrid and alternate approaches, but they will need to be scalable to achieve the larger potential of gains compared to less efficient commercial construction.

In doing so, these approaches must contend with the larger challenges that more complex commercial projects entail. Again, single family homes are already better optimized and offer the closest approximation to mass production processes, especially when including manufactured housing.

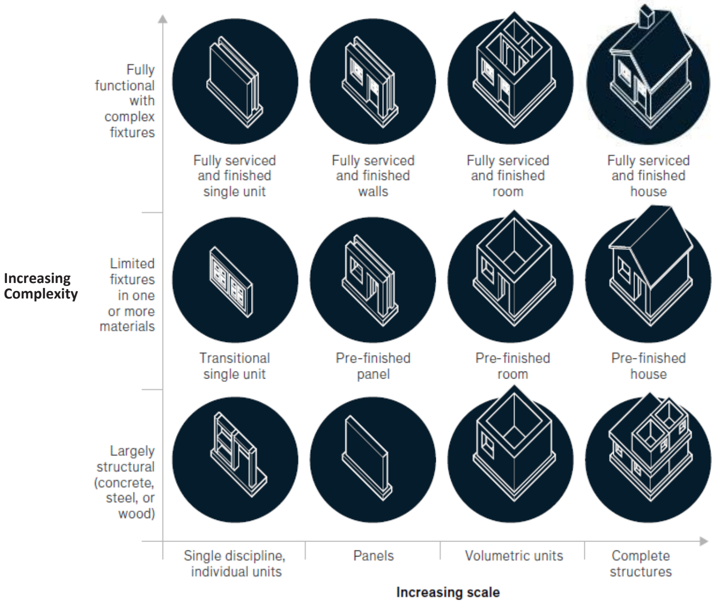
However, larger commercial projects are more niche, more specialized, and less common than mass market residential building—meaning firms will need significant scale while chasing a smaller number of individual deals. Ironically, governments like those of Sweden or Singapore have been instrumental in achieving this sector scale in their home countries, whereas the private sector in America has proved a more fitful and volatile supporter thus far. However, the tide finally seems to be turning toward a massive upswing in venture investment, which will spur innovation across the entire landscape of housing.

THE LIKELIEST TRAJECTORY FOR FUTURE CONSTRUCTION

In summary, the greatest immediate progress in larger commercial projects is likely to be in mature volumetric platforms and prop-tech sectors that are less capital intensive and benefit from less entrenched incumbents. This means that while individual firms will benefit from being "Goldilocks" adopters of new tech—ideally waiting for a dominant solution but incorporating it before the competition—there is less likelihood of solutions that would reliably break the upper bound of 20% cost reductions. In turn, this means a slower technological resolution to the affordability problems in multifamily housing. However, parallel innovations at smaller scale in single family or townhome scale projects will produce a wider evidence for the effectiveness of technologies like 3D printing than these emerging solutions can currently provide. Figure 12 on the next page shows McKinsey estimations of total potential cost reductions by sector, and all forms of housing currently offer the largest potential due to the sector size and relative ease of repeated units.

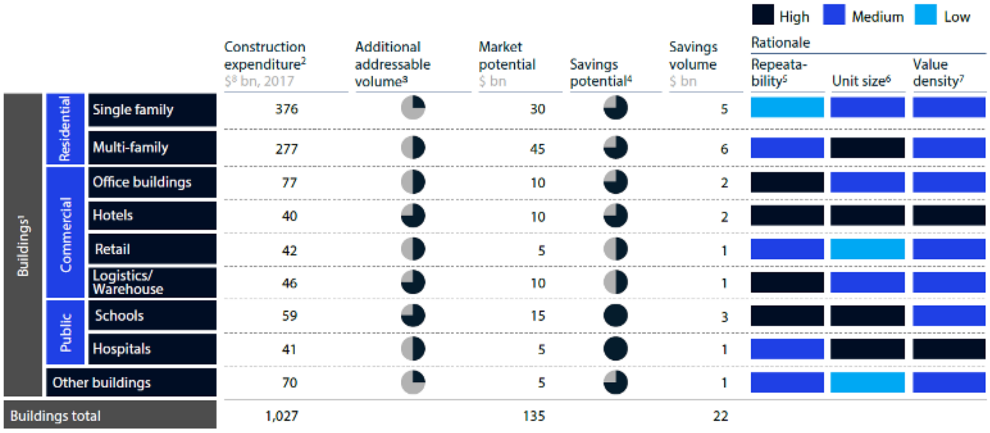
Prop-tech will ultimately provide the necessary data infrastructure that would allow more direct building innovation to both make good on existing potential as well as find new goals for productivity gains. The most obvious example of this is object-intelligent solutions making smaller hybridized approaches to pre-fabrication easier than they are currently. This will likely be the next major disruptor for actual construction, though it will likely be another development cycle or two before those approaches are mainstream. While it is still a distant aim, the adoption of true automation in construction (involving factory processes seen currently in computing or other high tech sectors) is likely inevitable and may even be faster than the distance from early modular to the current state—especially given the increasingly global array of attempts to innovate. As such, anyone involved in commercial real estate—from contractors to fund managers—would do well to follow this space much more closely than in the past.

Figure 11: The Role of Scale and Automation in Cost Savings



Source: McKinsey Capital Projects & Infrastructure. "Modular Construction: From Projects To Products."

Figure 12: Cost Savings Potential by Sector



⬛ High 🟦 Medium 🟦 Low

			Construction expenditure[2] $[8] bn, 2017	Additional addressable volume[3]	Market potential $ bn	Savings potential[4]	Savings volume $ bn	Rationale Repeata-bility[5]	Unit size[6]	Value density[7]
Buildings[1]	Residential	Single family	376	◔	30	◕	5	Low	Medium	Medium
		Multi-family	277	◑	45	◕	6	Medium	High	Medium
	Commercial	Office buildings	77	◑	10	◕	2	High	Medium	Medium
		Hotels	40	◕	10	◕	2	High	High	High
		Retail	42	◑	5	◑	1	Medium	Low	Medium
		Logistics/ Warehouse	46	◕	10	◑	1	High	Medium	Medium
	Public	Schools	59	◕	15	●	3	High	High	Medium
		Hospitals	41	◑	5	●	1	Medium	High	High
	Other buildings		70	◔	5	◕	1	Medium	Low	Medium
Buildings total			1,027		135		22			

Source: McKinsey Capital Projects & Infrastructure. "Modular Construction: From Projects To Products."

CONTRIBUTORS

Terrell Gates	Zach Mallow
Founder & CEO	Director of Research

ABOUT VIRTUS

Virtus Real Estate Capital, founded in 2003, is a hands-on, data-driven, curious investor that delivers compelling outcomes from cycle-resilient investments for all stakeholders. Through thoughtful evolution and resilience in challenging times, Virtus has purposefully worked to foster thriving communities that empower people to live better lives. Over the last 18 years, it has acquired 255 properties for a combined acquisition value of over $4.7 billion, and has fully realized 181 property investments. With a strong and established track record, Virtus has proven to be successful in all phases of the market cycle. For more information, please visit virtusre.com.

VIRTUS
REAL ESTATE CAPITAL

836 W. 6th Street, Suite 1500 / Austin, TX 78703

virtusre.com / (512) 891-1200