

White Paper

A Preliminary Overview of Emerging Trends for Industrialized Construction in the United States

Tyler Pullen

Teaching Staff, Stanford University
Engineering Consultant, City Systems

Daniel Hall

Assistant Professor, ETH Zurich

Jerker Lessing

Director of Research, BoKlok
Adjunct Professor, Stanford University

February 2019
Version 1

Executive Summary

This paper seeks to capture and analyze the recent growth in industrialized construction in North America from new and existing companies. The concepts and technologies of industrialized construction (IC) - such as prefabrication, preassembly, modular, offsite, and volumetric construction - are relatively well-established. However, the sudden attraction of large-scale investments for entrepreneurial firms adopting these strategies is unprecedented in the AEC sector. The causes of this interest are varied and outside of the scope of this paper. Instead, this paper provides an overview for the current status and potential future of practitioners in this space. To do so, we compare the orientations of industrialized construction firms in the United States across a broad spectrum of categories comprising target markets, business models, and basic strategic details. This white paper reports on high level trends for industrialized construction spreading across the AEC sector in the United States. Specifically, we find nine distinct trends evident in the data across the last two decades:

1. IC companies are growing in number
2. IC is attracting investor funding
3. IC companies emerge from different origins
4. California is leading the United States market
5. The majority of the companies are building volumetric modular
6. Structural system type correlates with building height; mid- and low-rise leads the market
7. IC companies are vertically and horizontally integrated
8. Most IC companies are targeting housing
9. The affordable housing market is active despite a lack of investment

Overall, we find that industrialized construction companies are generating the investment, strategic variety, capacity, and ambition to be worthy of serious attention across the AEC sector. The white paper concludes with future opportunities and strategies yet to be taken that may be important in achieving meaningful differentiation. These include the role of city governments, investment in operations and maintenance, the use of factory automation, and possibilities for more business integration. As old and new firms expand, business models mature, and effective technologies are implemented, more in-depth research can build upon this white paper to yield additional insights and trends for industrialized construction in the United States.

Introduction

Stakeholders in the AEC sector — from property owners and developers to general contractors to architects — have long-searched for new strategies (both organizational and technological) to reduce the resources and time required to construct new buildings. Yet, due to myriad obstacles and continuously rising structural standards, the industry is notorious for its inability to share in the productivity gains afforded to nearly every other major industry (*The Economist*, 2017). These problems have only been exaggerated in recent decades due to increasing urbanization resulting in rising demands from each project in terms of its influence on environmental, financial, and social factors. As such, the motivations for successful implementation of Industrialized Construction (IC) are not new: many of the variables that frequently complicate the infrastructure delivery process can be mitigated by IC's technical advantages. And the concepts are not new either: moving more of the construction process to a controlled, off-site environment can simplify the on-site work required and significantly improve material and labor efficiency. If done correctly, this could drastically reduce the time and cost of new construction projects. The manufacturing industry — especially that of the automotive sector — is the most frequent point of comparison in this respect. Vehicle manufacturers have adopted, committed to, and expanded upon these methodologies for nearly a century, and touted many of the benefits now suggested for applications of IC.

Unsurprisingly, as the ideas have been long-known, many companies have attempted to put IC into practice before. However, only in the last five to ten years have such companies attracted the interest and financial support of vast entrepreneurial investment. The magnitude of these investments are larger than many industries experience as a whole, and are even more unexpected when compared to the historically low rates of investment in innovation, research, and development within the AEC sector. The factors cited for this sudden and overdue change include but are not limited to: rising labor costs, exaggerated productivity lag across AEC projects, increased sophistication of BIM tools, rising demand to minimize the built environment's impact on climate, and firm establishment of global trade routes allowing for more international shipping (*CB Insights*, 2018).

The reasons for IC to emerge now are important, but an equally pressing question is: where is IC headed? What trends are we seeing in the United States today? What does this mean for the future of the AEC sector?

Existing academic research primarily focuses on individual or small-scale aggregates of case studies or theoretical frameworks to think about firms practicing IC (Lessing, 2015). However, few if any papers provide a broad analysis of the IC market in the United States. Especially because of how rapid and recent IC growth has been, in-depth research has not yet had time to react to the change. The purpose of this white paper is to provide a preliminary overview of the emerging market for industrialized construction in the United States. We generate these trends

using a content analysis of IC firms webpages, the creation, analysis and visualization of a comparative database, and personal knowledge and relationships with IC firms built through our organization of the Industrialized Construction Forum¹ at Stanford University. In total, we include data from 67 IC firms in the United States. The full details of the methodology used are described in Appendix 1.

Emerging Trends for Industrialized Construction in the United States

From our analysis, we propose the following nine trends for IC in the United States. Although our insights should be considered preliminary and not necessarily representative of the global IC market, they are nonetheless strongly suggestive of several trends that may characterize the aggregate direction of the sector. These insights will be further verified and validated as more companies are added and analyzed according to the framework proposed.

1. IC companies are growing in number

If it is not clear by now, a large number of companies practicing IC in some form have been founded in the past two decades (see *Figure 1*). The broad list of companies was aggregated using the research team's existing knowledge and connections, literature case studies, recent journalism articles on the topic, and key search terms on public internet databases (the full methodology is described in Appendix 1). Though not comprehensive, these methods served to capture a sufficient amount of the novel activity in this space to be suggestive of the wide-sweeping trends. As such, 1994 was chosen as a useful starting point to show the early inactivity until about 2005, when sudden growth was truncated by the economic recession and very few new companies sprouted for several years. More coverage on this topic is discussed in later portions of this report.

¹ www.indconstructionforum.com

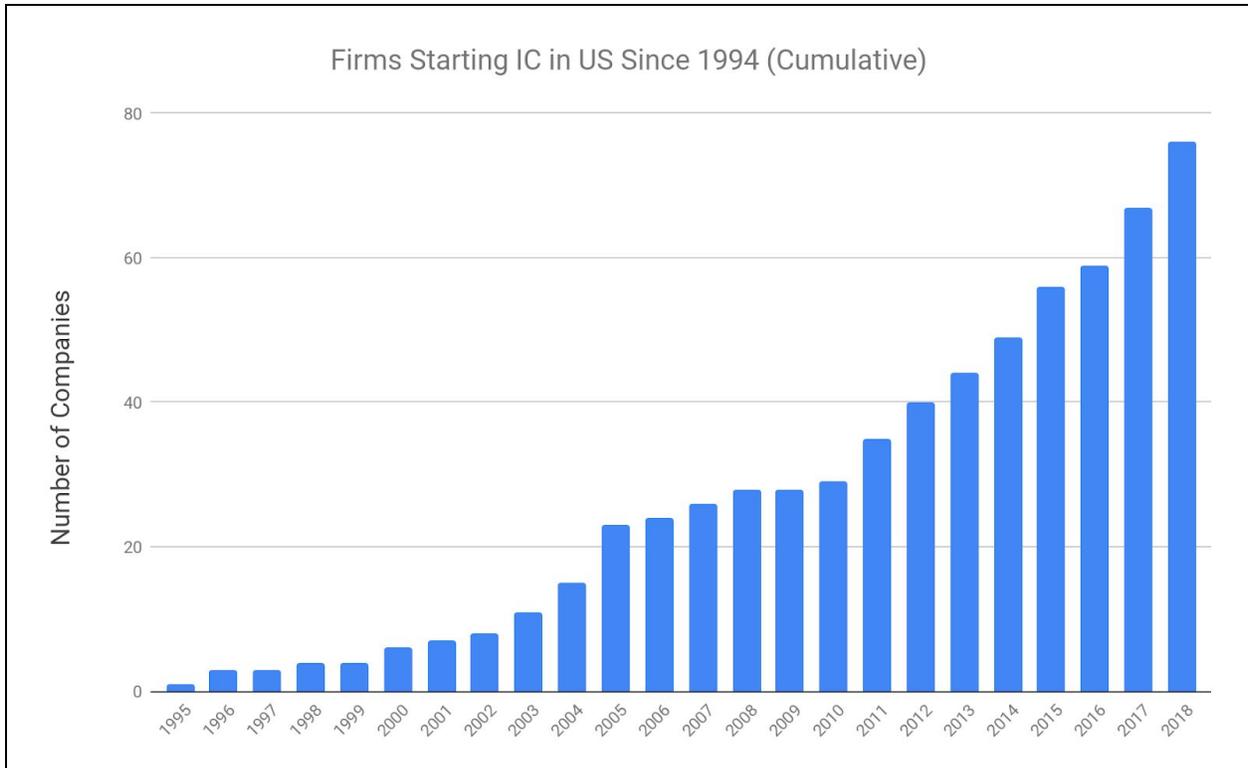


Figure 1: US firms starting IC since 1994

As the graph shows, over 90 US companies have begun adopting some form of IC strategies in the last 23 years. Though they vary greatly, just the raw number of notable companies entering this niche space in such a short span of time (especially for the AEC industry) is a key indicator that this is not an isolated instance. And within this preliminary analysis, 24 of the companies reviewed have completed 20 or more projects. That’s more than just a surface-level start considering the amount of resources required for individual projects and the fact that one of the biggest challenges for new IC firms is achieving scale, especially for the firms that own and operate their own factory facilities (a unique qualifier for firms practicing IC).

2. IC is attracting investor funding

Perhaps the more telling growth statistic is the amount of venture capital (VC) attracted to many of the recent firms highlighted in the first trend, displayed in *Figure 2* below. Most of the data was sourced from the popular online database, Crunchbase, which collects various on companies across all sectors information in near-real-time, including venture capital funding. Where this info was not available or not reported, the research team attempted to fill knowledge gaps via credible journalism articles quoting company representatives and/or the company websites directly. Despite the informality of this method, the team is confident that the most prominent funding across all IC companies has been captured.

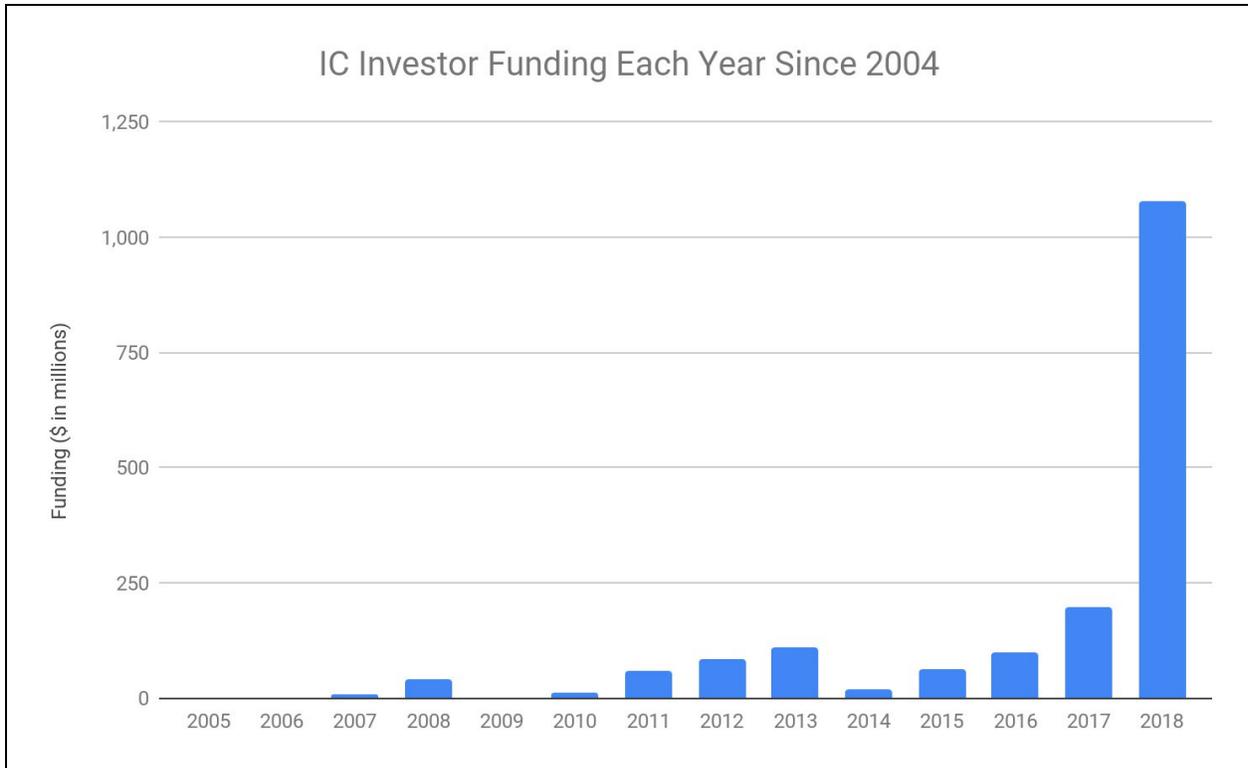


Figure 2: Investor funding into IC firms each year since 2004

Despite a lack of venture capital from 2014-2016 — the reasons for which are unknown — the last two years in particular have seen a momentous increase in investor funding into IC firms. An important note here is that Katerra, a California-based firm, raised over \$980 million in 2018, which represents a very large majority of the funding. However, significant investment in Katerra should not overshadow that many other firms in IC are also attracting meaningful investment. Few other sectors see this much VC investment even *without* a Katerra equivalent, as over \$400 million was raised by IC firms other than Katerra just in the last 6 years. This level of investment in the AEC sector, which is historically averse to startup capital deployed at this scale is unprecedented. And although the exact percentage is not clear at the current stage of research, a number of these entrepreneurial ventures have already proven the business model to the extent that they are stabilized on operational revenue rather than venture capital or debt funding. This is a clear signal that there can be successful and profitable business models using IC technologies and concepts.

3. IC companies emerge from different origins

New startups represent the most active “origin” of new IC firms, referring to whether or not the companies were spontaneously founded or pivoted from existing sectors. However, beyond these startups, many existing companies have transitioned to more IC strategies in some capacity. These firms represent a diverse set of origins from within the broad industry of infrastructure development, spread across architecture, general contractors, traditional

manufacturing, and real estate (See *Figure 3.1*). The designation of “Startup” was independent of the nature of the founders themselves; rather, it was given to any company that sought and earned venture capital or other startup funding (e.g. angel investment), but whose main business strategy revolved around IC techniques. Exception was also made for any company that voluntarily self-identified as a Startup in the relatively ubiquitous “About Us” (or similar) page of their website. An additional distinction of note is that there are a handful of companies that could be identified as “Software” companies; one notable example is Sidewalk Labs, a daughter company of Alphabet, Inc. and sister company of Google. For the purpose of this analysis, the few firms in question were started as independent organizations dedicated exclusively to the pursuit of IC strategies (via software tools), and were categorized as startups as a result.

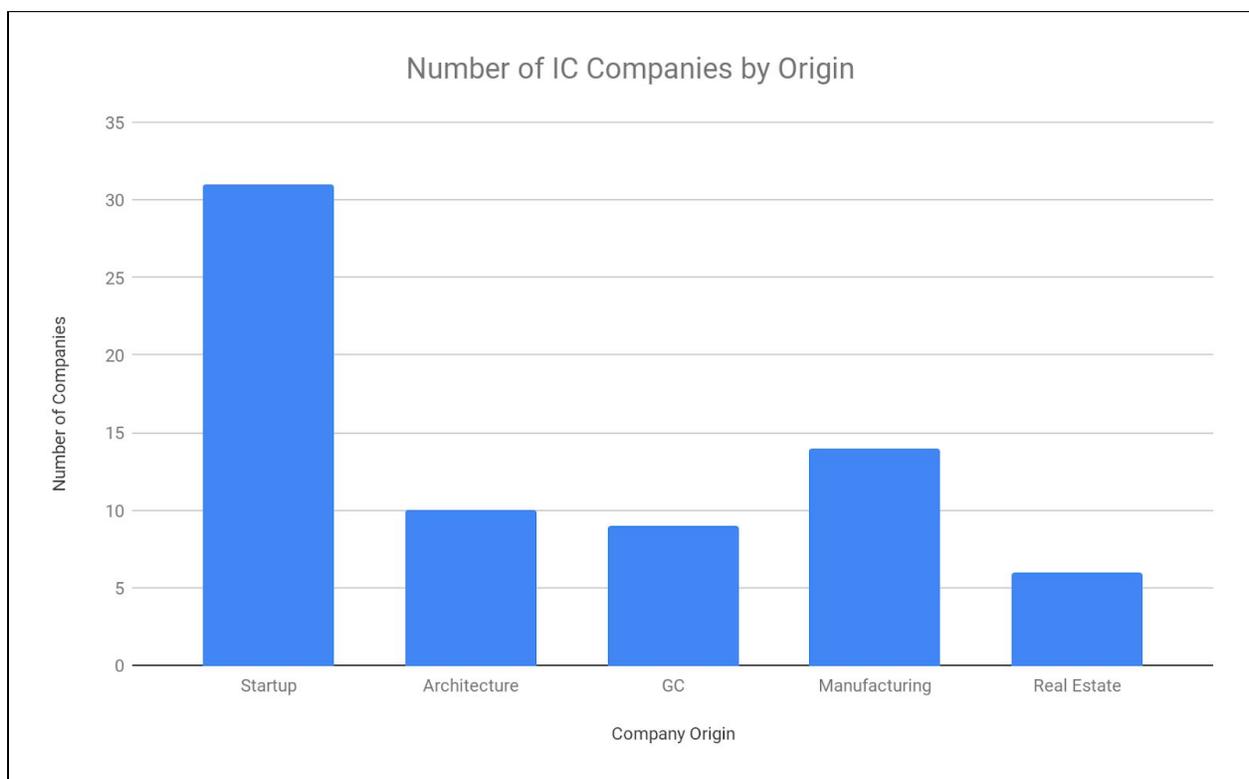


Figure 3.1: Companies adopting IC by origin

Though startups clearly comprise the biggest proportion of companies adopting IC strategies, there are a sizable number of companies from other parts of the AEC industry entering the space as well. The primary takeaway from this is that there are incentives and potential benefits for nearly all of the major stakeholders involved in the development of built environment. There is a myriad of interesting and likely differences in strategy or business model that correlate with the origin of each company as well, but the sheer fact that so many companies are coming from so many different parts of the industry is a promising sign. It also suggests that — because of the value it can provide to most of the existing stakeholders — IC might have the potential to fundamentally change the traditional stakeholder and value chain that dominate the historically

linear phases of infrastructure development. From real estate to design to manufacturing to construction, successful IC development might not suffer from the contractual friction of misaligned incentives that typically discourages other forms of industry-wide technological change. More about this potential can be seen in Trend 7 later on in the paper. *Figure 3.2* below lends slightly more credibility to this potential by showing its adoption by companies of all sizes, not just smaller, more flexible firms.

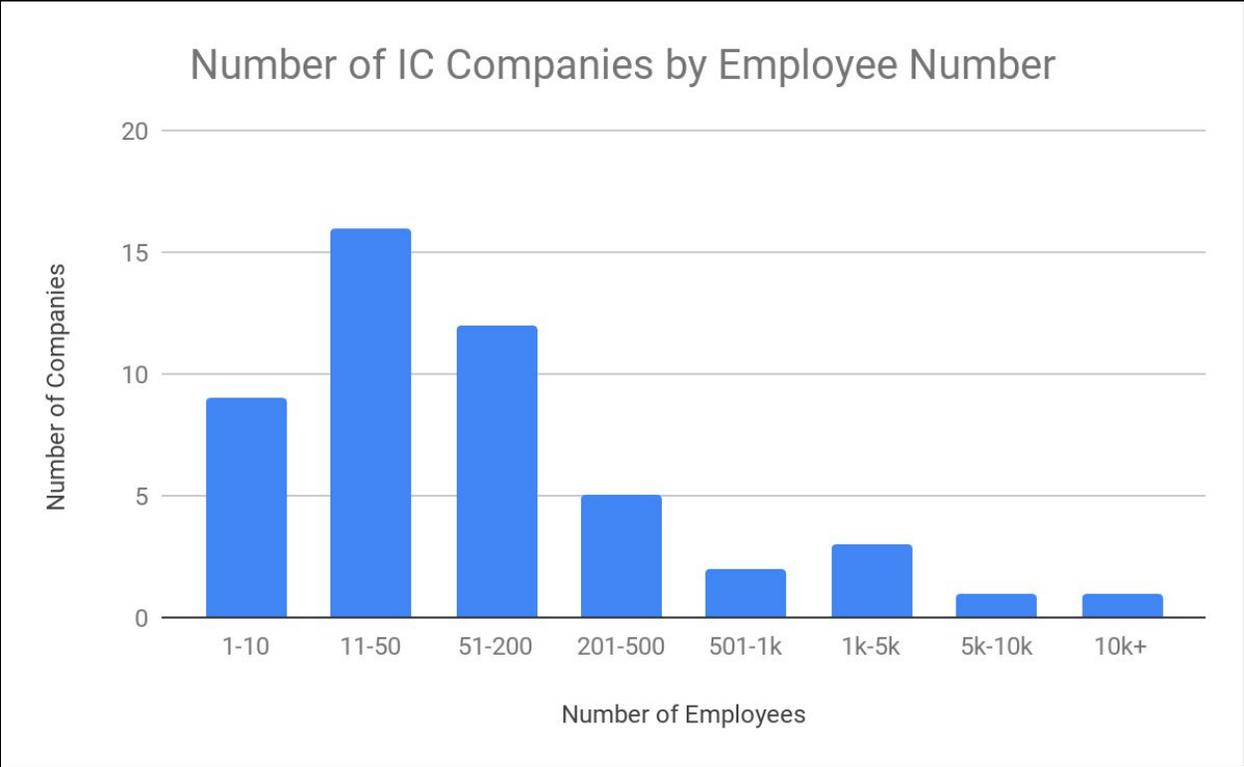


Figure 3.2: IC companies by number of employees

Though the majority of companies are agile, having under 200 (and many under 100) employees, there are still at least 12 companies with 200 or more employees. A caveat is that most of these larger companies are not fully committing to industrialized construction tactics on *all* of their projects, and very few details regarding their changing practices can be found online; most of them are older, well-established, and have more inertia in their business strategy. This is especially true for the general contractors in this category, including Kiewit, Clark Pacific, and DPR. The fact that *any* of these much larger firms are testing out some form of IC strategies on their projects, however, is more evidence of the increasing attention being diverted to the sort of meaningful innovation that has long-awaited the AEC industry. These companies have the advantage of more reliable streams of funding as well as more mature partnerships and project pipeline scaling capacity. What remains to be seen, however, is whether or not this is too drastic a change in mindset and operations of large firms to be able to truly lead — or even participate in — the change that industrialized construction might bring if applied at scale across the industry.

4. California is leading the market

It is probably unsurprising that sizable attention from startup venture capital has translated into a disproportionate number of new IC firms centralizing around California (see *Figure 4*).

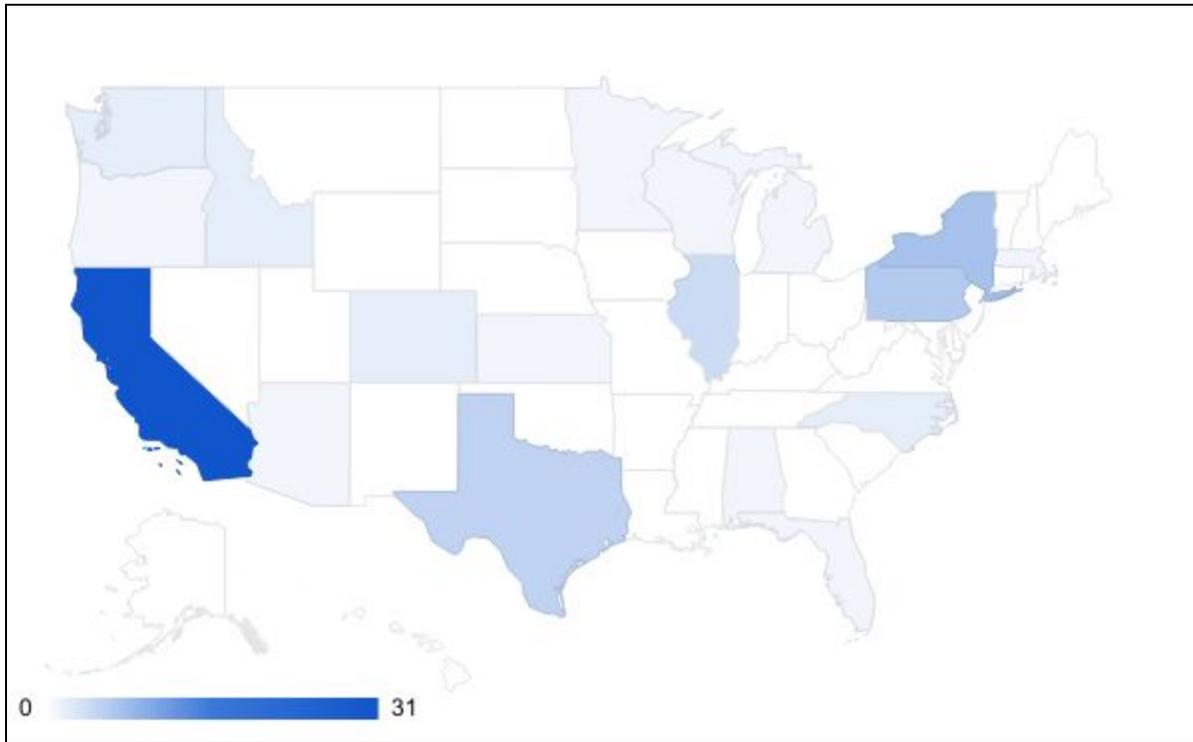


Figure 4: Color map of IC companies by HQ location

At least 31 IC firms have been founded in California in the last couple decades, while the next most numerous state to house new companies in this space is New York, where 7 companies started. Regardless of the state, company locations overwhelmingly favored urban areas and states with rapidly expanding cities, partially explaining why New York, Pennsylvania, Texas, and Illinois followed California as being home to the most new companies. An important thing to note is that, based on the origin of the individuals in the research team (primarily at Stanford University) and resulting partnerships therein, there is an inevitable knowledge bias towards companies in the immediate vicinity of California. However, the enormous difference in sheer number of firms in this state versus others seems significant enough to suggest the trend is still strong. This is corroborated by the fact that the firms in California are also the most heavily-funded. Listed in no particular order, some likely contributing factors include:

- It contains **Silicon Valley**, a world-renowned hub of venture capital and entrepreneurial activity
- The markets and customers in California have adapted to the aforementioned startup activity, and as a result, many individuals prone to be “early adopters” flock to California with a **willingness to trust and test new innovations**

- It offers an **enormous market for small- and large-scale construction** (housing and otherwise) as the most populous state in the US — with almost 40 million people in both urban and rural areas — alongside steadily growing states nearby like Oregon and Washington
- It has a **prolific market for luxury building**, which typically offers higher profit margins than other markets, due to the high earnings of many households in California compared to other states
- There is a desperate need for **rapidly deployable affordable housing** across the urban regions in California
- A state-wide **shortage in skilled labor** has partially contributed to a stark rise in the cost of construction, presenting massive demand for cheaper construction methods
- California has a famously forgiving climate that can simplify building design challenges, especially when compared to areas with harsh summer and winter weather as is the case in much of the rest of the US

One surprising finding is the effect of California's highly demanding energy and seismic codes for buildings. Through personal conversations with several startups in the state, the research team gathered that this is perceived as an opportunity rather than a prohibitive challenge; a construction business proving a successful business and technology model in the most technically demanding market of California could then more easily expand to regions with less stringent requirements.

There are likely other factors that contribute to this clear geographic trend as well, but the conclusion is the same: California is leading the way in the number and size of industrialized construction companies to date.

5. The majority of IC companies are building volumetric modular

The landscape of companies adopting IC techniques almost exclusively fall into one of three strategic categories:

- **Volumetric Modular:** fully prefabricated units with nearly all major components manufactured and assembled off-site; volumes are then shipped to their destination and installation is finished on site
- **Flat-Pack:** Full elements, such as entire walls or floors, are manufactured and assembled off-site, typically with the most complicated elements like MEP systems included; elements are then laid down and stacked on top of each other to be shipped to and connected on the project site
- **Kit of Parts:** Often analogized to IKEA furniture, individual parts are designed and then precisely manufactured off-site, bundled together during shipping and assembled on site; parts are typically designed so as to simplify and improve manufacturing and assembly

Between these three major divisions, most of the recent companies appear to produce volumetric modular, as shown below in *Figure 5*.

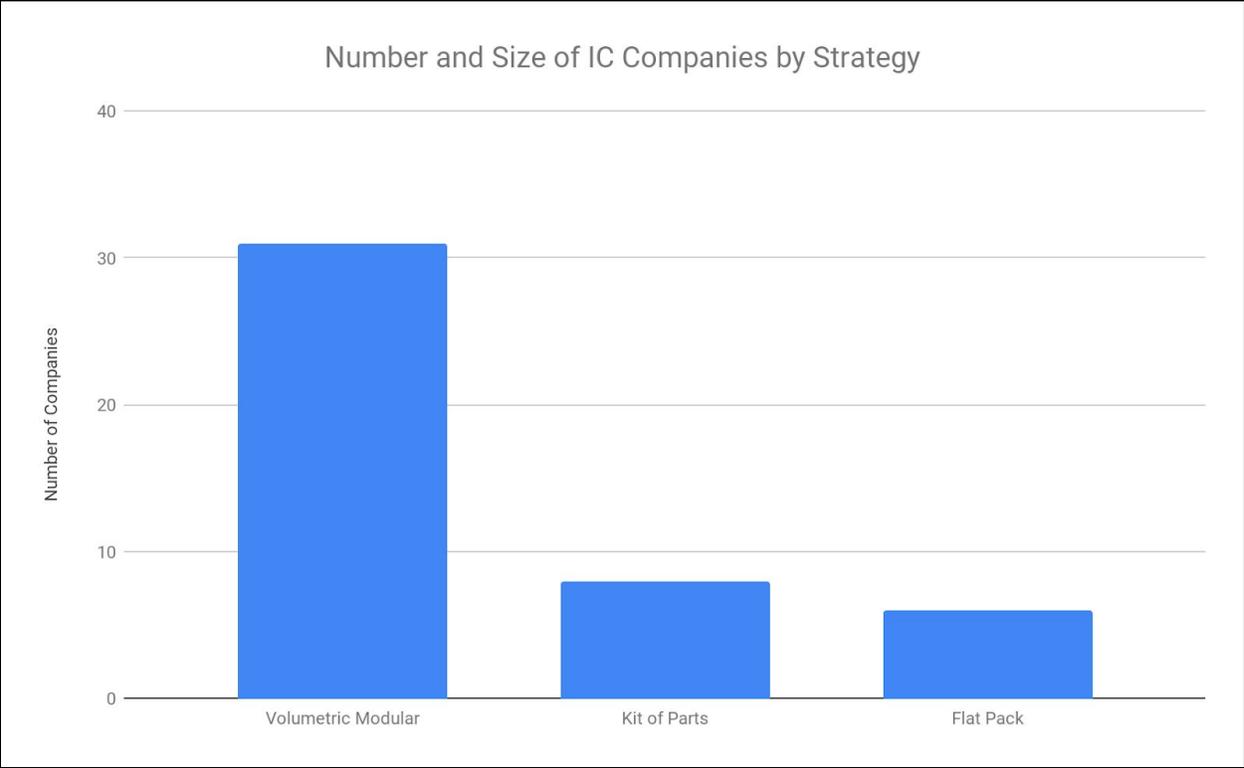


Figure 5: Number of companies adopting each strategy

Almost 75% of the companies observed so far are producing volumetric modular units. This is potentially surprising given that it is the most technically sophisticated and complicated method of the three, likely requiring the largest amount of up-front capital and complementary scaling capacity to be done effectively. However, particularly for the startups represented here, investment is often given to the most unique and innovative offering, which in this case would often be the robust volumetric modules that move the vast majority (sometimes over 90% of total construction value) to an off-site facility. This technique also gives the firm inherently more control over their own process and business because they require some degree of horizontal integration in their offering. Flat pack or kit of parts solutions, on the other hand, are still somewhat beholden to many of the existing stakeholder paradigms (and friction) that are partially responsible for the innovation-starved industry in the first place. These factors might serve to eliminate perceived risk to investors and encourage the early capital to flow into companies oriented towards volumetric modular production as a result.

Based on the methodology which favored the most robust, well-funded, or at least most novel entries into the IC space, there is potential that the above graphic is not reflective of the IC industry as a whole. Additionally, the division between these three strategies — especially between the two underrepresented categories that reflect more nuanced approaches to IC — may underreport firms that have not been explicitly branded as practicing “industrialized

construction” or any of the other key phrases used during the research. Though the project team does believe the above graphic to be reasonably representative, these reservations should be kept in mind.

One additional note worth acknowledging is the rise of a small number of firms promising 3D printed structures. Though their influence on the observed trends is minimal, the research team chose to classify them as volumetric modular strategies even if the “construction” is performed on-site. As academics and practitioners become more familiar with these innovative approaches — and as more companies potentially adopt such techniques — a different categorization may be deemed more appropriate.

6. Structural system type correlates with building height; mid- and low-rise lead the market

Companies building larger structures are generally using more stable or rigid materials for their construction. Between timber, steel, and other (either concrete or unique lightweight plastics) material types, timber dominates the low-rise market, while steel has the advantage for high-rises, as shown in *Figure 6* below.

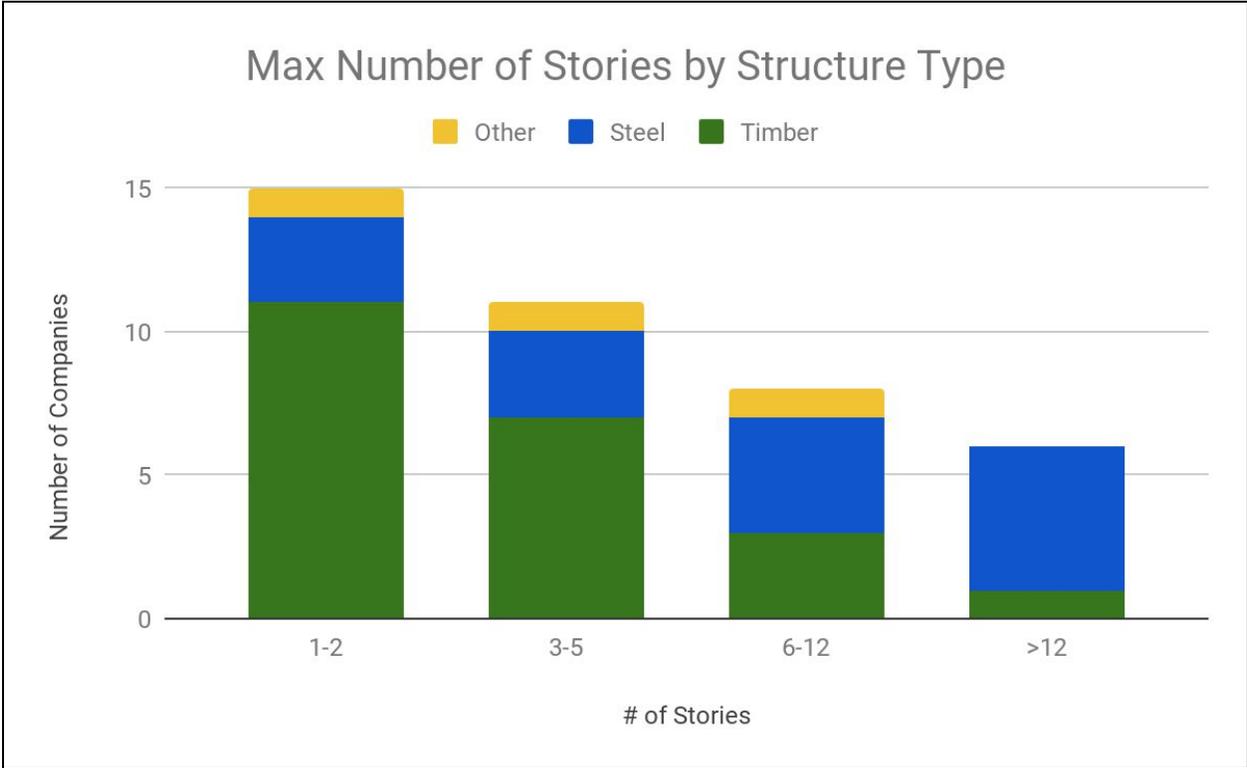


Figure 6: Max number of stories by structure type

With the exception of recent Cross-Laminated Timber (CLT) construction techniques, wood structures are most often used for low- and mid-rises and not typically for taller and more

complex structures. It is also cheaper than most other materials, making it far more appropriate for smaller construction, particularly in the single family home market. Steel, meanwhile, is more expensive but better-performing and thinner than most wood-frame construction, making it more suitable for adaptable unit design as well as higher seismic standards of taller buildings. The expansion of research and proven case studies (both domestically and internationally) with taller CLT-based structures may change this trend.

Another trend documented here is that a far higher number of companies observed are targeting the low and mid-rise markets than the high-rise market. There are a few likely reasons contributing to this:

1. The market for single family homes in the US is far more numerous and diverse than that for high rises (which are confined almost exclusively to urban areas), which makes it easier for newer and smaller companies to infiltrate the market in most cases
2. The technical requirements for high-rises is markedly more rigid and demanding due to seismic hazards. This can complicate the design of individual modules that must meet such stringent standards when they are assembled into a single superstructure, and the risk can be infeasible for smaller companies when trying to attract venture capital
3. Scaling up annual capacity is already a primary obstacle for new companies attempting industrialized construction, and working exclusively on larger, more involved projects can be very risky. Effectively, this requires a perfectly aligned project pipeline between large, individual projects; one failure — regardless of whether or not it is the fault of the IC firm — can completely and permanently disrupt a newer company's revenue stream.
4. Small-scale projects offer the promise of less complex stakeholder dynamics that are infamous for time and cost overruns on large infrastructure projects, historically. Though IC strategies may encourage integration of some of these dynamics into one unified business model (see the next Trend discussed), the barriers are harder to overcome early on, when new IC companies do not have a foot in the door with bigger landowners, developers, and municipal stakeholders

All this being said, the fact that there are still six companies that have already completed or are in the process of completing structures with more than 12 stories is a promising sign that some of the IC companies are overcoming the above challenges. As demand for vertical growth rises with the infill development potential of growing cities, the right side of this graph may rise as well.

7. IC companies are vertically and horizontally integrated

Adopting sophisticated IC techniques requires a certain degree of business integration. Vertically, this implies a firm will participate directly across formerly divided stakeholder groups *outside* of the building structure itself, in order to serve across multiple phases of infrastructure development. For the purpose of this research, five phases were defined and included: real estate, design, construction, manufacturing, and operations and maintenance. Companies with explicit or implicit references (on their website or press materials) to substantial involvement in

any of these five phases received a check mark for the respective category. Horizontal integration comprised of the combination of services and goods typically separated *within* the building structure. This was divided into 6 sub-topics: foundations, structural components, Mechanical/Electrical/Plumbing (MEP) work, facades, interiors, and fixtures (kitchen appliances, faucets, etc.). If a company was specifically responsible for physically manufacturing and assembling any of these categories, the respective box was checked. The data was then aggregated by taking the sum of the categories that had a check mark. This was a number between 1 and 5 for vertical integration and between 1 and 6 for horizontal integration, with the resulting pair of numbers serving as the X and Y coordinates, respectively. The reflection of this data is presented in *Figure 7* below.

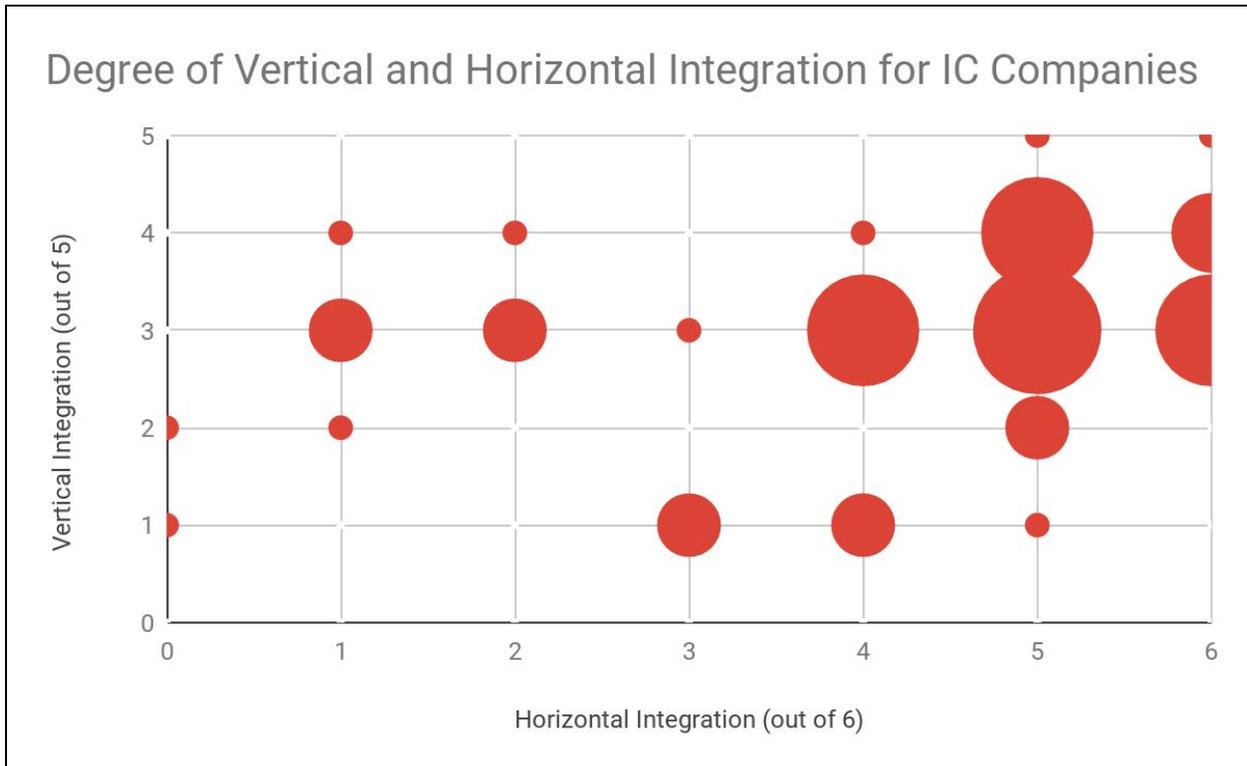


Figure 7: Degree of horizontal and vertical integration

The visual clearly shows that a large majority of the companies analyzed combine many different vertical and horizontal categories. While mapping in this aggregate form, the data regarding *which* factors an individual company combined in their unique business model are obviously lost. But the degree of integration is still strong. When the entire infrastructure development and delivery process is housed and built quite literally under the same roof, a firm can achieve a more cohesive vision of what they are creating and selling. Through this, individual companies can exert a greater degree of control over their business strategy and direction. Such control allows and encourages the development of complete *product* offerings rather than the traditional service-based methods of the siloed AEC sector stakeholders. This point cannot be understated: a strong trend within companies applying industrialized

construction methods is the consolidation of the fractured stakeholder groups that historically define the industry.

This is fundamentally different from how most other innovations in AEC operate. Building Information Modeling (BIM), for example, can integrate information flow between traditional stakeholders and eliminate disputes throughout a project's delivery and life cycle. But it still relies on the complex network of participants — who must *opt-in* to this unfamiliar information exchange strategy and software — for it to be effective. Similarly, even novel contractual approaches such as Integrated Project Delivery (IPD) depend on the owner or developer to choose to implement upfront. They must set up the conditions for this organizational format early on, and it is difficult for stakeholders (such as architects or general contractors) who are not yet involved to communicate the benefits of IPD upstream to project sponsors. Highly-integrated industrialized construction firms can bypass all of these conventional bottlenecks for innovation by aligning incentives across all phases of infrastructure development before a project even starts. Moreso, this alignment is consistent from project to project because all of these existing services are offered by a singular business entity. Especially as some of the firms analyzed and presented here include real estate development, they can negate the need to convince an owner to adopt a particular technology or contract type because they *are* the owner. Though it is still early on, the implications for how companies like this could fundamentally change the AEC industry — and its acronym — are enormous.

Similar to the comparison in Trend 5, the research thus far may be biased towards companies with the most exciting and novel offerings. Thus, when more companies are analyzed, it may be the case that there are more modestly integrated companies that populate the bottom left of *Figure 7*. However, the research team feels confident that hypothetical companies with such low levels of integration, but still attempting to practice IC techniques, would face severe challenges in achieving market differentiation within the complicated existing horizontal and vertical stakeholder groups of the AEC sector.

8. Most IC companies are targeting housing

Graphing the number of companies targeting each major market (shown in *Figure 8*) revealed that the residential space is attracting the most activity from IC firms thus far. The characterization for each company was determined either by their self-labelled biggest market (on their website or other primary source materials) or by whichever market in which they had completed the most projects. Thus, only their most prolific market was taken into account so as to avoid over-counting companies with only one-off projects in other sectors. It should be noted that many companies in the multifamily space were also active in the hospitality sector, though most of these still displayed project preference for purely residential projects. Mixed-use developments were categorized by whichever use case — retail or residential — held the majority of the floor area for a project. In nearly all cases, this distinguished them as residential projects. Even given these methodological caveats, the trends are striking.

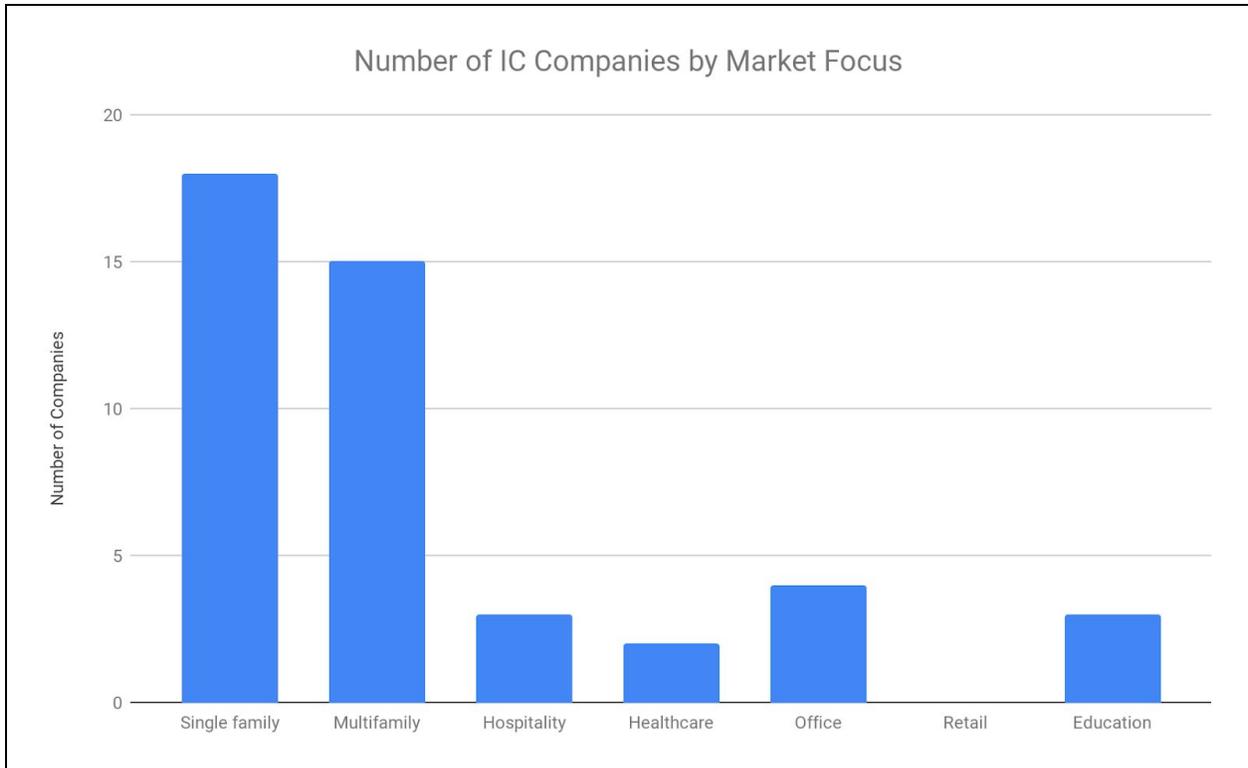


Figure 8: Number of companies focusing in each major market

As referenced earlier, the high number of companies targeting single family homes is somewhat unsurprising given the superior size of the market and the lower technical and project standards implied by standalone low-rise structures. However, a weakness of this market is that it depends on the ever-decreasing availability of open land for new homebuyers, and that makes scaling up particularly difficult for these firms. At least one exception is in the California market, where recent damage from massive wildfires have driven a sudden and enormous demand for high quality single family housing across much of the state. Several IC firms have already explicitly targeted this as a pressing demographic to serve with their time-saving offering.

The similar number of companies targeting the multifamily sector, on the other hand, are particularly well-suited to cross over into the hospitality space as well. This could insulate them from the fragility of the housing market (which is already less volatile than single family development trends), allowing for a more diverse portfolio to maintain consistent production. Especially given the rising urbanization and resulting vertical growth of cities domestically and internationally, the high existing demand for companies able to rapidly and cheaply deploy high-rise apartment structures is likely to grow in the near- and long-term. This serves as a clear advantage for IC companies that are able to optimize at scale for this market, which appears to be reflected by the large number of companies targeting this area despite the higher technical challenge presented by larger structures. However, this trend might also partially reflect that multifamily dwellings such as apartments and student dormitories offer a higher degree of standardization without compromising on the attractiveness of the offering. By contrast, single

family homes are more likely to have a demand for individual unit customization that negates some of the primary advantages of producing structures en masse via IC technologies and methods. Regardless of the reason, it is clear that IC companies are attempting to make an indelible mark in a variety of building markets.

9. The affordable housing market is active despite a lack of investment

Part of the motivation for IC and the resulting lowered cost of construction is born out of the rising demand for affordable housing across the world. So it seems relatively intuitive that the majority of IC companies in the residential space are primarily targeting the affordable market, as shown in *Figure 9.1* below. Though the number of companies shown here include non-startups (without a “funding” value), the cumulative amount of venture capital relegated to each of the three target markets is shown in red as well, corresponding to the dollar values on the vertical axis on the right. Regarding methodology, a similar strategy was used as in the analysis for Trend 8: a company was categorized based on any self-applied labels on their website or based on the market in which they completed the most projects.

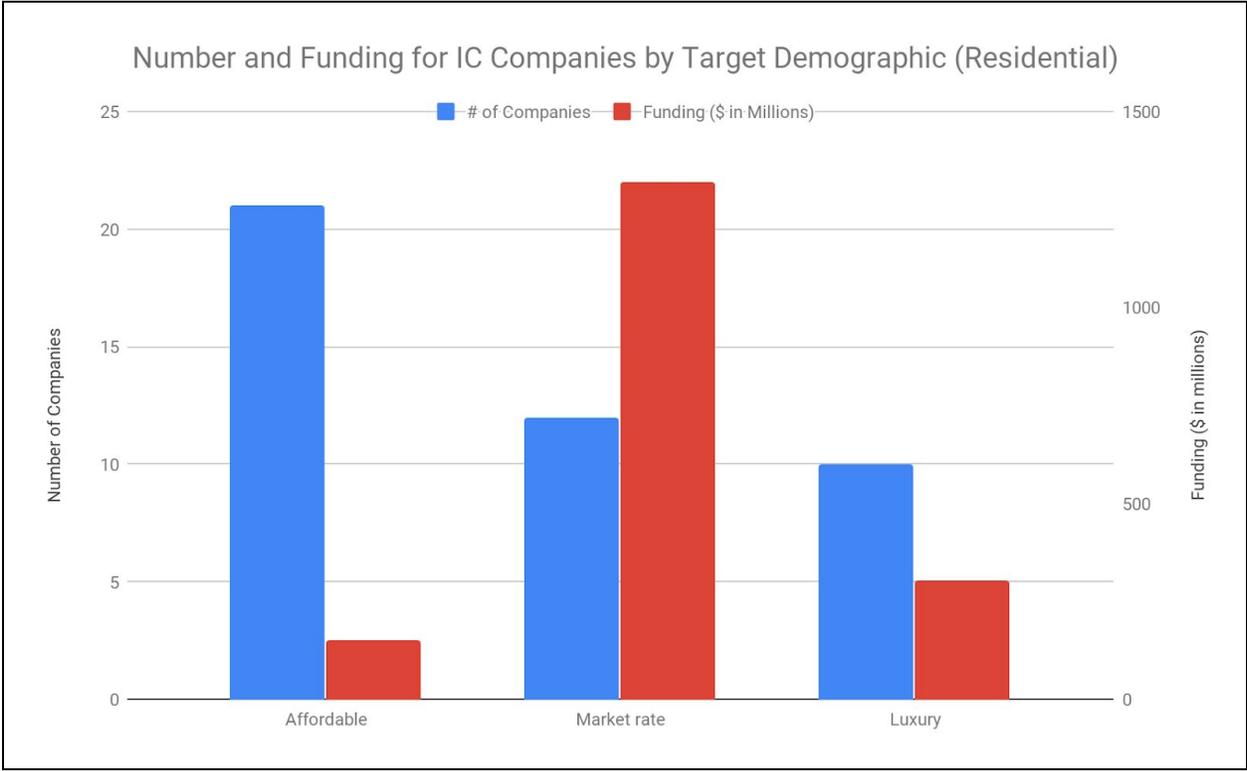


Figure 9.1: Number and funding amount by residential market

Clearly, a high number of companies are specifically targeting the affordable housing market. This aligns with the theory that the growth of IC is driven by the need for cheaper construction,

which is especially true for affordable housing. Regarding the funding: an important reminder that Kattera singularly offsets these numbers by a large amount, as it is responsible for \$1.2 billion of the funding displayed for the companies dedicated to market-rate housing. Even when ignoring this influence, however, the luxury-oriented IC companies still received more than twice the venture capital than the affordable market, despite having less than half the companies operating in that space. There are a few potential causes for this. On one hand, the luxury housing market offers higher profit margins than affordable housing projects, which would lead financially-motivated investors to channel their funds to luxury-based companies rather than affordable ones. These profit margins also allow for a certain degree of forgiveness in terms of technical performance, where as the extremely money-sensitive affordable housing projects are riskier if a company is still unsure of its delivery on capacity and cost savings (as is the case for any new firm practicing new project delivery methods). Additionally, the higher number of companies targeting affordable housing suggests that none of the companies have established a dominant business model or technical strategy. The more diverse and unproven landscape of companies might discourage would-be venture capitalists to fund any individual firm. However, as shown in *Figures 9.2 and 9.3* below, the theory suggesting that demand fuels growth is given weight by showing that the rise in affordable-housing-focused companies appears to directly mirror the housing prices in some of the most expensive cities in the US.

It should be noted that based on the categorization methodology for the graphic, it overlooks companies that target each of the markets in differing proportions. More detailed analysis might reveal more nuanced meta-trends within this category. Furthermore, some of the startups known to the research team are merely *starting* in the luxury market, but ultimately intend to pivot towards more affordable markets once they can verify their technical performance. They are effectively using luxury projects as proofs of concept to stabilize their technical strategy and delivery on production time and costs.

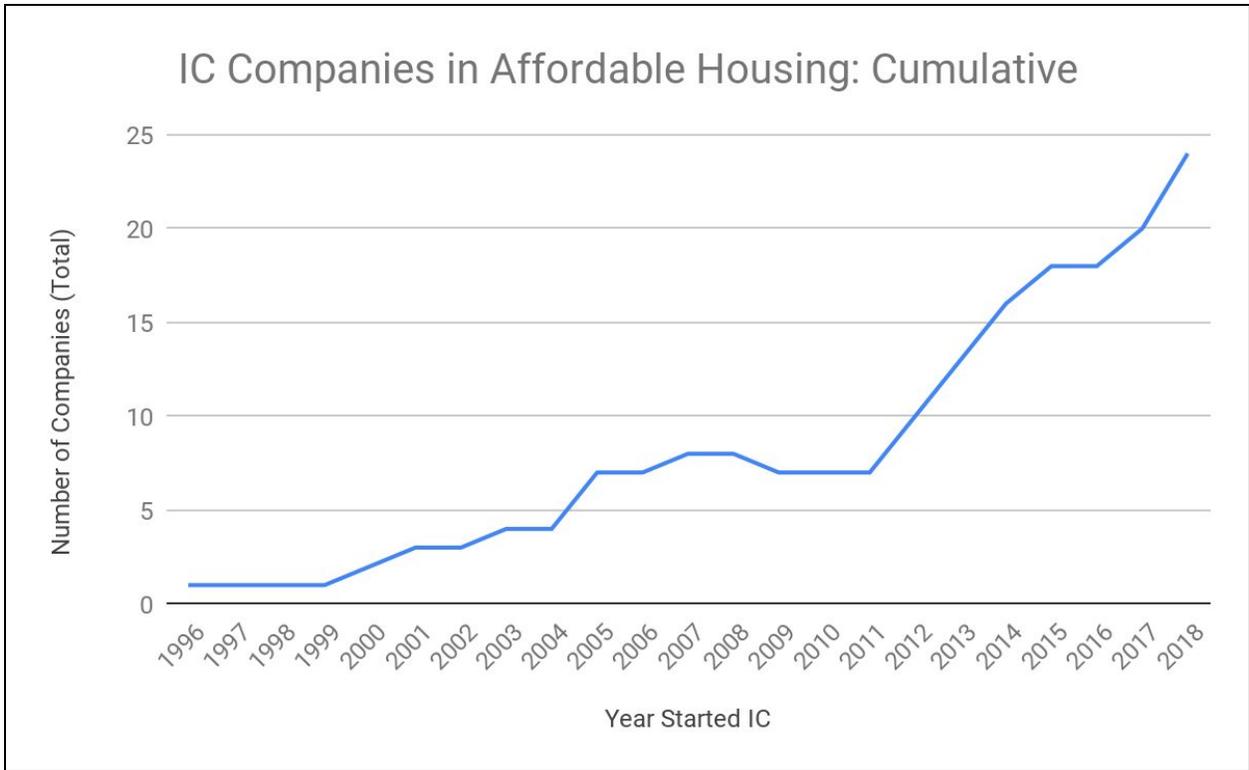


Figure 9.2: Cumulative growth of IC companies targeting affordable housing

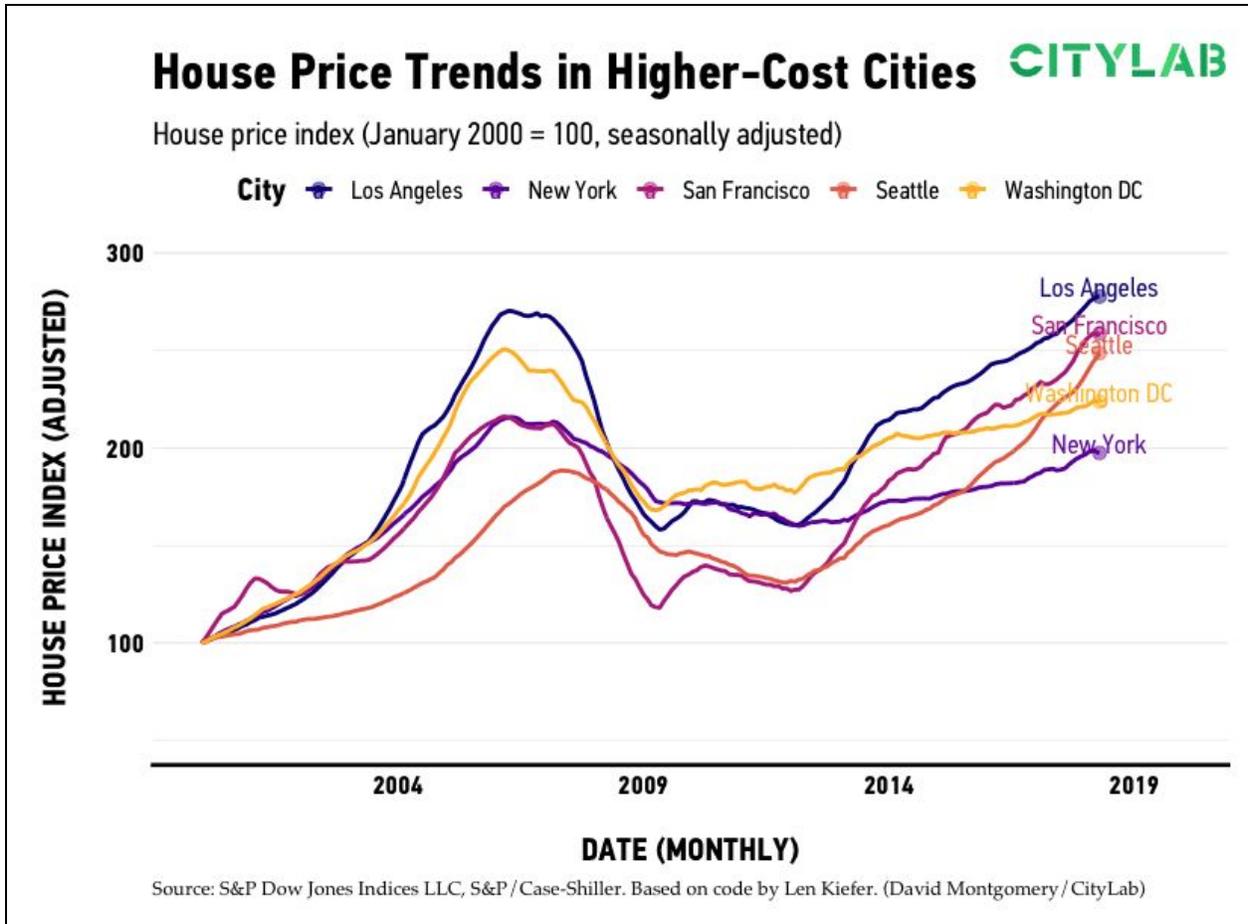


Figure 9.3: Housing Prices Trend since 2000

The inflection points visible on both curves show a clear relation between. IC firms targeting affordable housing were founded in increasing number just until the economic crash in 2007, when housing development fell drastically for several years and prices fell accordingly. However, now that housing prices have again risen to — and are likely to exceed — the pre-crash levels, the number of IC companies producing affordable housing has risen considerably as well. The responsiveness to demand seems clear. Of course, this is probably true of the affordable housing market at large, but it is only IC firms that promise to deliver more cost-effective housing at scale. Especially in the mid- and high-rise sector, this will give them a massive advantage compared to companies using traditional construction methods. And with cities continuously growing, the demand for affordable housing is growing as well. So as more cities plan to explicitly incentivize affordable housing development, well-integrated IC companies with their own real estate development arm will be able to benefit quickly and profoundly.

As a cautionary note, many believe that industrialized construction companies unlocking the cost savings enabled by such strategies are the key to developing affordable housing and finally bringing down the obscenely high costs of living in many US cities. Based on how property valuation operates, however, property costs can be very volatile; there is a chance that the cost

reductions produced by successful IC firms will be captured entirely by developers. By raising the value of land that could suddenly be built upon for a lower cost, a landowner could then prevent the construction cost savings from being passed on to occupants. In the worst case-scenarios, this would be vulnerable low-income renters. It would continue to hinder the open market's ability to meet demand for affordable housing by keeping the cost of development high (and perhaps keeping the rents high as well), effectively stripping IC firms of one of their major advantages by limiting the appeal of cheaper construction to would-be affordable developments. Therefore, the fate of IC companies targeting affordable housing may depend first on the policy and land use trends surrounding these developments rather than companies' ability to reduce the cost of construction.

Future Opportunities

From our review of the data and the trends presented above, we identify four future opportunities in the area of industrialized construction in the North American market.

1. City governments are increasingly interested in IC

Though this trend does not yet have any tangible data, it is nonetheless worth mentioning. Several prominent US cities — namely San Francisco, Vancouver, and New York City — have expressed explicit interest in directly funding industrialized construction ventures. Driven primarily by the need for more affordable housing (especially for the homeless), each of those city governments claims to have secured or otherwise set aside funding to start producing modular housing on their own. San Francisco, in particular, has put out an open call for a professional consultant to advise them in their search to produce housing units out of a city-owned manufacturing facility to be constructed. They also preemptively secured approval and partnerships with local labor unions in order to avoid disputes over misallocating new job growth. Vancouver and New York City are slightly more reserved about their plans, but it seems there is a possibility they could use existing, local IC firms as direct producers for city-owned affordable housing developments. In any case, the publicly-announced willingness of major municipalities in the US to make such huge investments in new technologies and companies is a clear sign that industrialized construction has the attention and optimism of a growing number of public stakeholders.

Globally, London and other districts in the UK have already used government-driven partnerships with industrialized construction companies to rapidly produce housing in areas of notable growth. It remains to be seen exactly how these or other US cities will participate in IC: either by building their own production facilities, or contracting out the work to closely-aligned partners among existing IC companies. Regardless, the dire need prompting cities to seek out such specific business and technology strategies is unprecedented, and the IC industry at large can only stand to benefit from eager government partners moving forward.

2. Few companies appear to be involved in the operations and maintenance phase

Despite the high degree of vertical integration shown in Trend 7, less than 10% of the companies analyzed so far are involved in the maintenance and operations phase of their own projects. A number of the companies producing volumetric modular units offer a warranty of some sort, usually distinguishing between workmanship defects (often with 1 year of coverage), systems defects (often with 2 years of coverage), and structural defects (often with 10 years of coverage). This is at least somewhat indicative of the pivot towards thinking of their units as a “product” rather than construction as a “service”, but it is still far from a true extension towards opportunities in the life cycle management of that product. Warranty-based involvement in the use phase of a structure implies a purely *reactive* business mindset rather than a proactive mindset that would enable a company to benefit even after a project is delivered. This suggests there is still a massive opportunity for IC firms to expand their business model to capture value presented by a product throughout its entire life cycle. Such a change in mindset could drastically change the way we envision infrastructure delivery, let alone how facilities management is handled throughout buildings’ long lifespan.

3. Few companies have adopted factory automation

Similarly to the last observation, very few companies analyzed appear to have adopted any form of automation in their factories. This is based on a simple yes-or-no methodology of whether or not a company’s website showed clear indications — either in text or visual media — that any degree of their in-factory processes are mechanically automated. Even with such a low threshold for earning a “Yes” in this category, less than 25% of companies analyzed fulfilled this criteria. Admittedly, this could be because many companies believe such technical process details are uninteresting and extraneous to the publicly available information on their website, or are specifically keeping some of their technical strategies secret. It might even reflect a hesitation to bring up automation given the growing fears of such technology’s effect on the manufacturing sector (particularly in regards to the loss of jobs). Alternatively, it seems intuitive that any company taking advantage of advanced innovation in automation technology would be keen on displaying such information to make their offering more unique and exciting — especially for startups in search of investment. Based on the fact that automation is still a nebulous venture even for the most advanced manufacturing companies in the automotive industry (see: Tesla), it seems reasonable to trust the data so far. Scaling up automated machines — even just from cars to physically larger buildings — is difficult and resource-intensive. Especially due to the variability in building codes and other requirements across every municipality in the US, attempting to standardize and then automate these processes is non-trivial. Thus, it seems entirely feasible that few of the still-young IC firms have been able to take advantage of this technology at scale. That being said, automation stands as a supremely interesting opportunity for growth and competitive advantage for IC companies with

their own factories. A particularly novel application of automation is in the design phase, as parametric design tools enable a large amount of design work to be performed efficiently and at scale. Demonstrations to this effect have been provided by such firms as Bryden Wood and WikiHouse in the UK, as well as Project Frog in the US in partnership with AutoDesk. As the accessibility of automation tools and technologies expand independently, this is a trend worthy of continued observation.

One likely obstacle to the adoption of automation across IC firms in the US in particular is the potential friction with local labor unions. Machines replacing human laborers (and potentially even skilled workers) in the factory translates — at least according to some — to a loss of jobs. Any company hoping to adopt automation in their factories in a major way will likely have to contend with politically powerful labor unions, who have the advantage of strong, long-standing relationships, massive public outreach, and stable financing for any manner of lobbying or campaigning (at least in the American form of democracy). Whichever company establishes agreements or positive relations with these union stakeholders will likely have a major advantage if and when automation technology is prepared to play a larger role in IC firms.

4. Chance to expand integration

Though IC firms have already been shown to be more vertically integrated, the research revealed even more opportunities for companies to vertically and horizontally integrate their business. Possible examples — some of which have already been taken advantage of — include:

- **Shipping and distribution:** Guerdon Modular Buildings has their own fleet of trucks uniquely tailored to transporting their modular units to projects across the US. This allows them greater control over their own projects by greatly decreasing the risk involved in getting units from their factory to the site, on time and undamaged
- **Raw material acquisition:** Several companies in China (with steel) and Switzerland and Sweden (with timber) have integrated raw material acquisition into their business model, representing an incredibly high degree of control over their own supply chain
- **Building Inspection:** Especially for firms with very specific geographic orientation, integrating the process of building code enforcement to allow for local city officials to code check structures before they even leave the factory could be incredibly powerful. California already has such a system for factory-built homes, but this program could be simplified and/or expanded, especially in the case of city-sponsored production facilities
- **Internet of things:** Many offerings (particularly those in the luxury single family home space) offer built-in “Smart Home” devices such as Amazon’s Alexa, Google’s Google Home, Nest, or digital security network technology. The implications of such inclusions — both good and bad — are myriad. They allow for unique partnerships with information and communication technology companies that suggest a high level of customer focus (a generally positive trend). And the tech that allows for data collection on building performance metrics like energy efficiency encourages an incredibly holistic product offering. But given the continuing concerns surrounding data privacy (some of which is

around Google, specifically), these may very well work against the IC firms encouraging the inclusion of such devices into their offerings. Time will tell what role these technologies might or might not play.

Presumably, as the number, scope, and creativity of IC companies being founded and operating grows, the innovation in regards to business model will as well. These four observations serve just as an initial set of observations as to the opportunities unlocked by IC methods in terms of expansive integration potential.

Conclusion and Future Work

Both in this research and in the industrialized construction field, there is enormous potential. For the industrialized construction industry, it is clear that the explosion of activity has garnered the interest and ambitions of many companies and stakeholders. The wide variety of technical approaches and business models is reflective of the lack of maturity of the industry and dominance by any one strategy. But the robust offerings available and surge of venture capital imply that it is not just a fleeting trend. As more companies' continued expansion and project completion proves the success in their business models, industrialized construction approaches may carve out more than just a small niche in the broad realm of infrastructure development.

It should be reiterated that this white paper is only a preliminary view of ongoing trends in the IC market in the US. The database itself is incomplete, and other companies are either unaccounted for or not yet using widely publicized IC strategies. Not all of the US companies have been fully analyzed yet, and a massive wealth of firms founded around the globe could ultimately be analyzed for undoubtedly fascinating insights as well. Furthermore, with more data and time, more correlations and industry-wide trends will likely be found even within the established information. Of specific interest are insights regarding automation, obstacles to scaling, and strategic differences between companies of different origins. In the far future, outreach to individual companies may fill in and validate the gaps of knowledge and data on their distinct approaches and offerings. Especially for the larger companies pivoting towards IC techniques in small but substantive ways, more transparency in those endeavors could reveal extremely interesting patterns that provide insight as to where the industry is headed overall.

References

- Barbara Downe-Wamboldt RN, PhD (1992) Content analysis: Method, applications, and issues, *Health Care for Women International*, 13:3, 313-321, DOI: 10.1080/07399339209516006
- Capps, K. (2018, August 08). America's Back to Peak Housing Prices. Now What? Retrieved August 15, 2018, from https://www.citylab.com/equity/2018/08/home-prices-index/566768/?utm_content=edit-pr-omo&utm_campaign=city-lab&utm_medium=social&utm_source=facebook&utm_term=2018-08-09T14:12:26
- Least Improved: The Construction Industry. (2017, August 19). *The Economist (US)*.
- Lessing, J. (2006). Industrialised house-building. *Licentiate Thesis, Division of Design Methodology*,
- Lessing, J., & Brege, S. (2015). Industrialized Building Companies' Business Models: Multiple Case Study of Swedish and North American Companies. *Journal of Construction Engineering and Management*, 144(2), 05017019. doi:10.1061/(asce)co.1943-7862.0001368
- Piece By Piece: 14 Offsite Construction Companies Transforming The Building Industry. (2018, May 21). *CB Insights*. Retrieved August 17, 2018, from <https://www.cbinsights.com/research/offsite-construction-tech-startups/>
- White, M. D., & Marsh, E. E. (2006). Content Analysis: A Flexible Methodology. *Library Trends*, 55(1), 22-45. doi:10.1353/lib.2006.0053

Appendix 1 - Methodology

To generate these insights, researchers conducted a content analysis of IC company webpages to create a database of the firms currently exploring the IC space. We created high-level categories to compare firms in relative terms. The variability in the quality, detail, and format of information and sources necessitated the use of content analysis — using individual IC companies as the unit of analysis — as the dominant methodology for this report. The methods used to collect and aggregate data was driven by the fundamental research question: to trace broad trends across the IC industry, into which investment is currently being driven by a sizable number of recent startups. The lack of maturity or dominance of any one strategy among these companies would allow for meaningful distinction even between surface-level traits. Also, based on the short-term duration of this research project's first phase, source collection needed to be limited to publicly available information. This requires acknowledgment of the inevitable gaps this would leave in the aggregate data, but nonetheless would serve a useful purpose if a majority of information on a specific topic could be collected. Content analysis strategies further allow for a combination of qualitative and quantitative information, as well as iterative feedback loops for determination of the most pertinent (and available) categories of company characterization (Downe-Wamboldt, 1992; White & Marsh, 2006). Due to the open-ended nature of the research question, this method enabled periodic refinement and consolidation of the observable traits initially proposed. This was necessary given the cumbersome number of categories originally suggested, as well as the difficulty in procuring pertinent data from only publicly available sources.

To start, an initial set of five broad primary categories by which to qualify individual companies was established. These five areas are summarized as follows:

1. **General:** Includes basic info like year founded and location of HQ
2. **Size:** In terms of employee base, project capacity, and funding amount (if from venture capital)
3. **Market:** Describes target market/demographics
4. **Strategic Orientation:** Describes methods of IC and levels of horizontal and vertical integration
5. **Technical/Performance:** Summarizes reported effects on price and time vs. traditional construction

These categories were largely determined using the personal experience (in the fields of IC and entrepreneurship) and resulting professional intuition of the research team. Relevant sub-categories were then added after reviewing various academic literature on industrialized construction (e.g. Lessing, 2006). The broad approach led to numerous categories to start, but most of them were too theoretical or abstract to be easily or objectively determined using only publically available data. After a first round of 10 companies was analyzed, the team added and removed several sub-categories based on meaningful distinction across companies or what was unavailable from public sources.

As for the early task of collecting a sizable and reasonably thorough listing of IC companies, the team began with a list of companies with which they had existing connections through the Stanford University Center for Integrated Facility Engineering (CIFE) and the annual Industrialized Construction Forum, started at Stanford in 2014. Other companies were added via case studies in the literature reviewed. The list was then expanded via prolific professional networks and online databases, namely LinkedIn and Crunchbase, which both provided links to competitors and related companies using the initial list as a baseline. Lastly, to fill in any major gaps, the following keywords were used in those databases as well as Google.com:

- Industrialized construction
- Modular construction
- Off-site construction
- Manufactured housing
- Prefabricated construction

These keywords were informed by the personal and professional experience of the research team. The last two steps of the company discovery process were repeated iteratively to achieve a high level of confidence in the coverage of the most relevant and active companies. Because the research intent was to analyze widely-sweeping trends, the companies not captured via these informal methods are assumed to be inconsequential in the observation of the most important trends in the industrialized construction field. Additionally, companies dealing exclusively in the “mobile home” market were deemed extraneous to the primary purpose of the research (though companies targeting this market are occasionally characterized as “modular housing”).

Due to the short time span of the first phase of this research as well as the desire for general trends among the diverse companies practicing IC, a combination of primary and secondary data — all of which can be accessed by any individual with internet access — provided sufficient information for meaningful analysis. These almost exclusively comprised of information on the websites of the individual companies and from news articles by verifiable journalism sources. All of these information was accessed between June and August of 2018, with slight additions to the funding portion of the research in February of 2019.

Other relevant or significant methodological choices are explained during the discussion of individual trends and categories of analysis mentioned throughout the report.

As a reminder, the research project is intended to be ongoing, and so only a partial survey of the US industrialized construction market (which in and of itself, is only a partial survey of the global IC market) has been completed and is presented thus far. However, the reliance on funding amount as a principle data piece, as well as the nature of publicity regarding this information, should imply that all of the most prominent activity in the industrialized construction field has been captured in this report. Thus, the trends presented are not expected to be

exhaustive or rigidly representative of the industrialized construction field at large (even just in the US). However, at a minimum, the findings are suggestive of certain trends that are perceivable and informative at this stage of the industry's development.

Appendix 2 - List of companies included in content analysis

An abbreviated version of the ongoing database will be released in version 2 of this white paper