



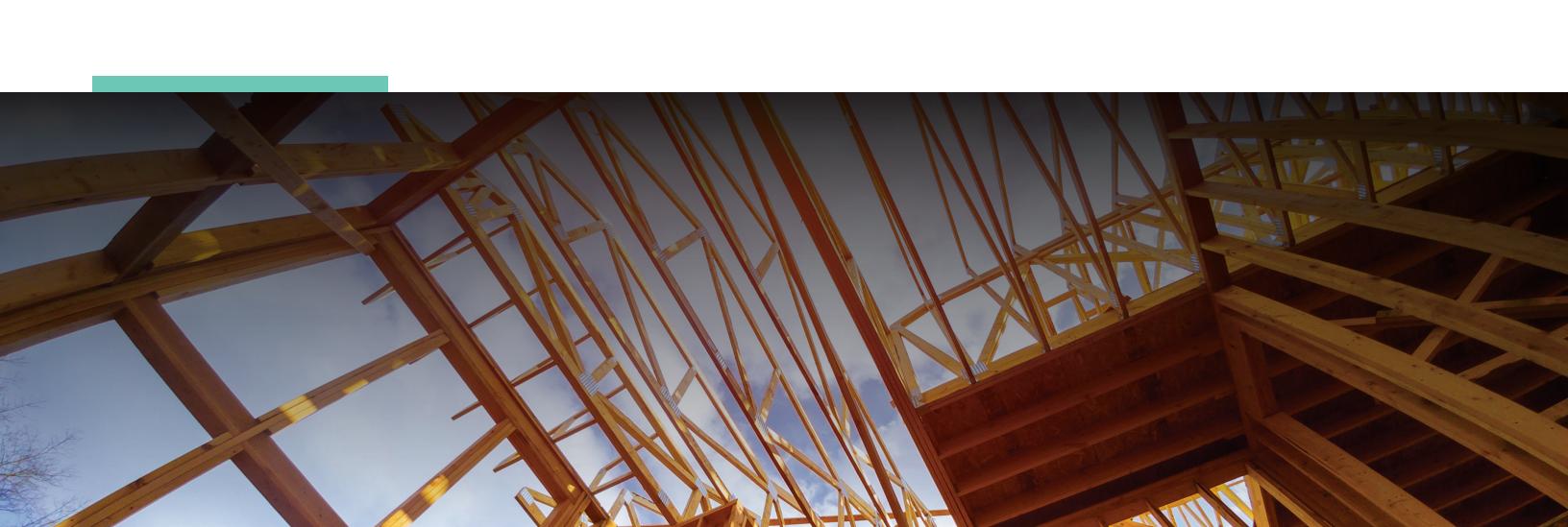
Prefabrication: Resilient, High Margin Business Models for a Cyclical Industry

Although construction is the largest industrial sector in emerging market economies and second in size only to the healthcare sector in OECD (The Organization for Economic Co-operation and Development) countries,

its productivity gains have lagged behind other industrial sectors since the 1960s. Modular construction through prefabrication is considered a solution to this productivity challenge, but there are three factors restricting its growth: market cyclicity; demand for customization; and market fragmentation.

Learning from Operation Breakthrough in the 1970s and Katerra's recent failure, Blackhorn is backing a new generation of firms in prefabricated or modular construction that take one of two differentiated approaches. The first approach leverages new technology, such as machine intelligence, computer vision, and robotics, to automate part of the work of a single trade using a capital-light and agile business model. The second combines physical and digital technologies, acting as a supply chain orchestrator, to outsource production while using software to generate fully engineered, costed and code-compliant housing schemes in real time.

The following case study provides insight into **Blackhorn's strategy** for addressing prefabrication's sustainability challenges so it can be successfully integrated into the construction industry.



DISRUPTING THE CONSTRUCTION INDUSTRY

The construction industry comprises approximately 13 percent of global GDP, accounting for \$11 trillion of annual value added. Yet its meager 1 percent annual productivity growth over the last two decades is less than one third the productivity growth seen in the manufacturing industry.¹ In addition, the construction sector is characterized by cost overruns and delays, with 98 percent of mega projects experiencing cost overruns at an average 80 percent cost increase and 20-month slippage.²

This has translated to an overall operating margin of just 5 percent or less for many general contractors, despite the high level of risk they assume.¹ Finally, construction is one of the highest emitting and most dangerous sectors, accounting for 39 percent of carbon emissions and more fatal work injuries than any other industry.^{3,4}

Prefabrication—the practice of manufacturing and assembling certain components offsite—offers a compelling opportunity to make at-scale construction more efficient, profitable, sustainable, and safe for workers. Prefabrication, often in the form of modular construction, is expected to speed up project timelines by 20 to 50 percent and realize more than 20 percent in cost savings.¹ With new real estate construction expected to reach \$130 billion in Europe and the United States by 2030, this would translate into \$22 billion of annual cost savings.¹ It is also expected to lower energy use and waste, increase quality control, and decrease at least 50 percent of construction-related fatalities.⁵

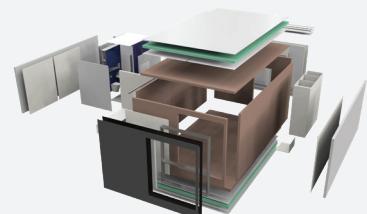
Given its potential to disrupt the construction industry, prefabrication has expanded from its common application in affordable housing to private and commercial real estate, where customization and quality take priority, and public infrastructure, which demands higher productivity in larger quantities.

CONSTRUCTION INDUSTRY BY THE NUMBERS

13%
of global GDP

\$11T
of annual value added

1%
productivity growth in
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¹ McKinsey & Company: "The next normal in construction" June 2020.

² McKinsey & Company: "The construction productivity imperative" July 2015.

³ International Energy Agency: "Global status report for buildings and construction" December 2019.

⁴ US Bureau of Labor Statistics: "Number and rate of fatal work injuries, by industry sector" 2019.

⁵ The Center for Construction Research & Training: "Fatal injury trends in the construction industry" February 2021.

WHY PREFABRICATION HAS FAILED IN THE PAST

Despite prefabrication's potential, past U.S. attempts at using it have failed spectacularly. The U.S. Housing and Urban Development's (HUD) Operation Breakthrough and the recent bankruptcy of SoftBank-backed Katerra serve as two key examples.

In 1969, HUD launched Operation Breakthrough to reduce housing costs and stimulate more housing production for all income levels. Operation Breakthrough sought to act as a market aggregator and promote economies of scale by applying mass production techniques to home-building. Similarly, Katerra's co-founder and CEO Michael Marks aimed to streamline the construction industry in the same way he streamlined the electronics supply chain as CEO of Flextronics. In 2015, he launched Katerra as a one-stop shop for managing the supply chain by shipping materials directly from factories via one vendor, thereby eliminating the middlemen.

Past prefabrication models have failed largely because of their capital-intensive and vertically-integrated approach, which do not account for market cyclicity, demand for customization, and the industry's fragmented nature. The following provides insight into each of these factors, using Operation Breakthrough and Katerra's experiences as examples.

CYCPLICITY

The market demand for new construction is highly responsive to changes in macroeconomic conditions and the resulting changes in interest rates and the availability of debt. The residential construction subsector is inherently "counter-cyclical" because demand falls when interest rates rise during an economic boom. When assuming significant debt or making large capital investments, the industry's cyclical nature is highly problematic. Modular firms that participated in Operation Breakthrough, for example, invested heavily to build plants that required large amounts of equity and debt. When demand unexpectedly fell and interest rates simultaneously rose due to "stagflation" in the late 1970s, the plants couldn't operate at full capacity, yet their overhead and debt remained high, resulting in stranded assets they could no longer afford. More recently, Katerra invested heavily in building new plants and acquiring multiple companies to achieve more vertical integration. The Covid-19 pandemic drastically exacerbated Katerra's project delays and cost overruns, and it was challenging to successfully integrate the cultures and work processes of multiple companies so they could seamlessly interoperate. Several prefabrication models in other parts of the world have been successful because they did not need to account for such cyclicity. In many European markets, demand for homes, especially in the homebuilding subsector, is driven by long-term government investment in affordable "social" housing, resulting in relative stability and predictability of demand. This relative stability makes it easier for firms to invest in new technology innovations, creating a virtuous cycle. In contrast, the U.S. market is largely driven by consumer demand.

CUSTOMIZATION

Modular construction is difficult because a high level of customization is needed to accommodate the significant differences in building design caused by local code requirements, geological and climate conditions, user requirements, and socioeconomic factors such as material and labor supply in highly localized markets. Conventional

modular construction fabricators have found it challenging to scale production while supporting customization. Operation Breakthrough failed to recognize the highly localized demand for customization in the housing market, and it began its mass production efforts before realizing there were conflicting building codes across states. It was also surprised when consumers didn't want identical housing, viewing it as inferior and lower quality. Similarly, Katerra overlooked the differences between local codes and regulations. While Michael Marks standardized consumer electronics production at Flextronics, Katerra was unable to use the same approach because each building product was inherently unique. As a result, Katerra could not accurately predict material and component needs, preventing it from reaching the economies of scale needed to be profitable.

FRAGMENTATION

Construction is a highly fragmented industry composed of many small firms, with the average U.S. construction company employing about four people.⁶ Half of the industry is made up of small, specialized firms that focus on one or two trades or "swimlanes" (i.e. plumbing, electrical, lumber). In addition, project delivery is dependent on many stakeholders, including architects, engineers and manufacturers who lack the experience of their counterparts and may have conflicting goals. Given the industry's fragmentation, systemic innovations across multiple swimlanes diffuse more slowly, at a 17 percent adoption rate, compared to the 40 percent adoption rate of innovations within a single swimlane.⁷ Both Operation Breakthrough and Katerra failed to recognize the stickiness of traditional processes and business models across value chain partners. When Katerra first launched as a one-stop shop for materials, it struggled to convince architects and designers to adopt their systemic approach to construction. Rather than adjust its approach, Katerra doubled down by acquiring architecture, design, and manufacturing firms in a failed attempt to control the entire supply chain.

⁶ IBISWorld: ["Commercial Building Construction in the US Employment Statistics"](#) September 2021.

⁷ Katila, Riitta, Raymond E. Levitt, and Dana Sheffer. "Systemic Innovation of Complex One-off Products: The Case of Green Buildings." *Organizational Design*. Emerald Publishing Limited, 2018. 299-328.

INVESTING IN THE NEXT GENERATION OF PREFABRICATION

To address these pressing challenges, Blackhorn pursues a differentiated strategy by investing in firms that adopt one of two capital-efficient business models:

- 1 a fractional prefabrication approach; or
- 2 a supply chain orchestrator approach.



Fractional Prefabricator Business Model

Fractional Prefabricators target just those parts of the work of a single trade or a small number of related trades that: (1) face a skilled labor shortage; (2) can be automated with a modest capital investment; and (3) generate high gross margins.

Through off-site automation, the fractionally prefabricated solution is more time and cost-effective than traditional onsite construction. Automating the skilled labor part of the work helps to address the skilled labor shortages. And the modest capital investment that the fractional approach to prefabrication requires can be paid back in months rather than years or decades, so this approach is more resilient to industry downturns than high cost, more vertically integrated, multi-trade prefabrication of entire modular rooms or entire houses.

Three Blackhorn portfolio companies—**Agorus**, **Hyperframe**, and **Toggle**—demonstrate Blackhorn's fractional prefabrication approach.

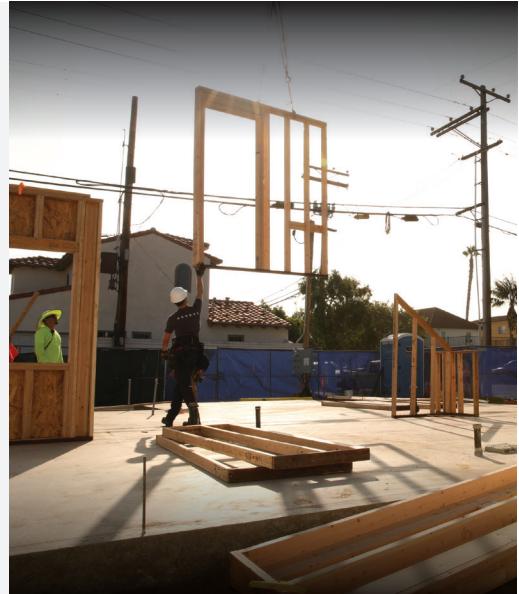


Agorus

Challenge: Homebuilding remains archaic, with 96 percent of data uncaptured, expensive labor costs, and stagnant productivity growth because of its many inefficiencies.⁸

Approach: Agorus is building a vertically-integrated automation system where developers can design, manufacture, and assemble a home using one software platform. Its software solution transforms 2D or 3D architectural designs into machine and human instructions for manufacturing custom wall, floor and roofing panels. This allows Agorus to segment the digital build into 2D panels that are constructed on an automated, just-in-time manufacturing line. By owning the engineering and using premium-grade specialized lumber, Agorus standardizes the components and engineering process while allowing for custom sizes and designs. These 2D panels are transported to the jobsite and assembled by field partners in a few days rather than the several weeks typical of the traditional approach.

Impact: Agorus' system offers customers a high degree of customization while facilitating seamless collaboration across developers, designers, engineers, and module fabricators. The integration between its software and automated production line reduces the cost of customization and enables just-in-time manufacturing for high asset utilization. Through strategic partnerships with established panel fabricators and onsite assembly teams, Agorus operates under a capital-light, high-margin, and low waste model. By capturing most of the value of design customization and shorter construction cycles, Agorus expects competitive market pricing and <3 percent final wastage compared with traditional framing, which aims for a 10 percent margin with 20 percent wastage.



96%

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⁸ FMI Net: "Big Data = Big Questions for the Engineering and Construction Industry" November 2018.

Hyperframe

Challenge: Interior wall framing, which has not evolved in decades, is custom cut and placed, then screwed by hand, resulting in a reliance on skilled workers for reading drawings and quality control. In addition, metal framing has the potential for traumatic and repetitive stress workplace injuries, exacerbating the current labor shortage in wall framing.

Approach: Hyperframe developed a sophisticated but highly adaptable steel framing system to offer customized solutions for a wide variety of customer needs. It combines digital design model integration software, mixed reality software, and semi-autonomous manufacturing to make wall framing simpler and more safe. Workers without extensive wall framing expertise can use a hardhat-mounted visor that provides a heads-up augmented reality display with Hyperframe's QR-coded metal studs to guide them where to connect the framing materials with easy snap-in connectors.

Impact: Hyperframe's integration of augmented reality wearables with its custom material packaging system enables hassle-free, 10 to 15 times faster on-site assembly without the need for wall framing specialists. Its software platform automates material orders for semi-autonomous manufacturing with partners licensing its technology and acting as distributors, reducing run-time and production costs. Hyperframe's system allows workers to assemble high-quality framing more quickly, with much less waste and with fewer workplace injuries than traditional wall framing. For example, its two pilot projects generated zero waste. These efficiencies translate to an improved profit margin throughout the value chain. Hyperframe's licensed operating model further elevates its profit margin compared with conventional framing suppliers, while still offering 15 percent savings and faster interior framing and finishing for customers. The system's adaptability and its value-based pricing have the potential to increase the addressable framing market threefold to over \$3B in U.S. metropolitan areas.



10-15x

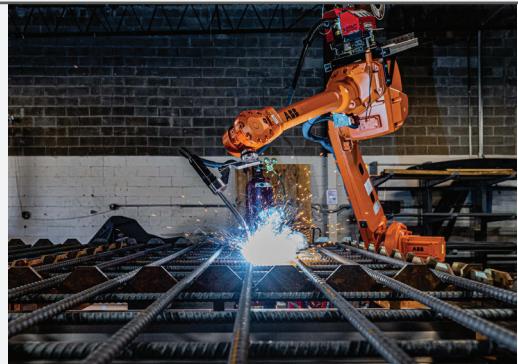
faster on-site assembly
without the need for wall
framing specialists

Toggle

Challenge: Reinforced concrete traditionally uses rebar cages assembled manually on site in an inefficient, expensive, and dangerous manner by highly skilled workers, who are currently in short supply.

Approach: Toggle partially automates the assembly of rebar cages using its patented robot-enabled solution done in a controlled factory environment. Toggle's software-driven approach offers real-time order progress tracking and optimizes customer design with modular detailing. Its emphasis on human-robot collaboration enables increased production efficiency and improved flexibility to satisfy various design needs. Toggle's use of proprietary robotic and mechatronic systems combined with industrial automation hardware from manufacturing leaders like ABB results in a purpose-built, efficient, and scalable platform.

Impact: Toggle aims to become a labor multiplier by using robots for highly repetitive, error-prone and fatigue-inducing tasks so that experienced rebar workers can focus on the more value-additive assembly, increasing value for customers, workers and suppliers. Toggle's off-site pre-assembly provides a 4X increase in productivity and can accelerate job site rebar installation timelines by as much as 90%. By relocating skilled rebar workers from on-site, often at height with access constraints, to Toggle's off-site, safe working environments, Toggle drastically reduces the risk of injury or fatality on construction sites. Toggle supplies preassembled customized rebar cages for both on-site reinforced concrete placement as well as off-site pre-cast concrete production. Toggle's production facilities are strategically located next to transportation hubs for major markets to minimize logistic costs and further improve its profitability.



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Supply Chain Orchestrator Business Model

Companies pursuing the supply chain orchestrator approach design the system and modular components while outsourcing the production of each element, such as pre-assembly, manufacturing, and final installation. This allows companies to take a lifecycle perspective to cost management without assuming all the debt necessary to own each element of the supply chain. This is in direct contrast to Katerra's model, which sought to control the supply chain by acquiring and owning every segment, making it highly vulnerable to the market's cyclicalities.

Blackhorn's portfolio company,
Modulous, serves as a good example
of this approach.

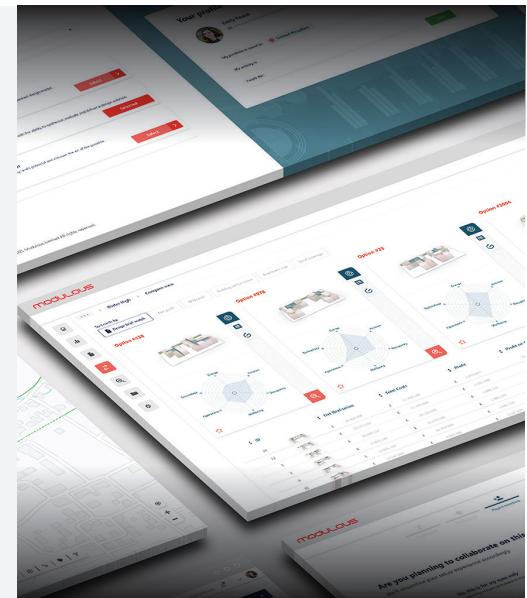
modulous

Modulous

Challenge: There is immense pressure to increase affordable housing stock, but past vertically-integrated modular solutions have been too capital-intensive and debt-leveraged to be resilient to high levels of demand fluctuation.

Approach: Modulous created a digital platform to synchronize the design, approval, procurement, and logistics of multi-family homes, shortening the delivery lead time by general contractors of building modules to typically one week from order. Project designs are based on Modulous' standardized Kit of Parts, which is a series of sub-assemblies from its distributed supply chain that offer a broad range of options for customers. Since the Kit of Parts is manufactured by third parties, Modulous doesn't use fixed factories, allowing for just-in-time delivery and assembly by local contractors. Over time, Modulous aims to serve as a digital marketplace among module manufacturers, building component suppliers, architects, engineers and developers, allowing information flows and transactions across the network.

Impact: By adopting the Kit of Parts concept, Modulous can significantly shorten the design cycle, enabling fast delivery and easy installation through its distributed supply chain. The technology-centric, outsourced manufacturing and assembly approach allows Modulous to operate at over 25 percent gross margins at maturity. The company not only helps customers capture the high housing demand ordered by the UK central and local government agencies but also offers a highly versatile platform to meet the requirements for various types of construction projects, providing cost and schedule assurance for customers to stay competitive in this fragmented market.



25%

gross margins at maturity
due to technology-centric,
outsourced manufacturing
and assembly approach

WHAT OUR PORTFOLIO COMPANIES SHARE IN COMMON

Whether through the fractional prefabrication business model or supply chain orchestrator model, Blackhorn's portfolio companies set out their growth trajectory based on deep understanding of the fragmented construction market, lessons learned from Operation Breakthrough, and failed last generation prefabricators like Katerra.

Our portfolio company founders focus on specific pain points instead of trying to "solve them all." This allows them to develop capital-light, agile business models, and to generate higher profit margins through strategic partnerships with material suppliers, manufacturers, technology enablers, architects and developers. This approach is expected to improve the construction sector's worker safety and job quality amidst an unprecedented labor crunch, and its environmental impact by reducing waste and energy use.

While most traditional VC investors have shied away from investing in manufacturing/service enterprises that prefabricate buildings, Blackhorn is aggressively stepping into this underinvested niche in the construction sector, and we have seen strong initial results from our investments in these capital-light, high-margin startups.

ABOUT THE AUTHORS



Julia Chen

Julia Chen works with Blackhorn Ventures to continue her passion for construction innovation and technology application for sustainable development. Prior to moving to the U.S. in 2019, Julia worked as a project manager delivering large-scale infrastructure and construction projects in Hong Kong. She holds professional building engineer and certified energy manager qualifications, a BSc(Hons) in Building Engineering and Management from the Hong Kong Polytechnic University, and master's degrees in Civil and Environmental Engineering and Business Administration from MIT.



Dr. Raymond Levitt

Dr. Ray Levitt joined Blackrock Ventures in 2017 as an Operating Partner, focusing on identifying new investment opportunities from his extensive Built Environment network. Prior to Blackhorn, Dr. Levitt served five years on the faculty of MIT's Civil Engineering Department. For more than 30 years, he held the Kumagai Professorship of Engineering, and he founded and directed Stanford's Global Projects Center. From 2008-2014, Dr. Levitt served as a Commissioner of California's Public Infrastructure Advisory Commission. He is current President of the Farmers Investment Club, an angel investment group of Stanford faculty, staff and affiliates. He has co-founded multiple companies. Dr. Levitt was elected a Distinguished Member of the American Society of Civil Engineers in 2008 and was inducted into the National Academy of Construction in 2013.



Amanda Rohrer, CFA

Amanda Rohrer joined Blackhorn Ventures in October 2021 and will become a Senior Associate in summer 2022 after completing her MBA at MIT Sloan School of Management. Prior to MIT Sloan, Amanda was a Summer Associate at Spring Lane Capital, a venture and growth equity firm investing in early-stage companies, and she spent six years at Cambridge Associates, where she helped guide over \$2 billion in capital commitments across the energy, real estate, infrastructure, and agricultural sectors. Amanda received a B.A. in International Relations from the University of Virginia and received her CFA charter in 2019.