A Built Environment Innovation Whitepaper

Constructuring: An Unstoppable Trend

by Ian Howell

Construction and manufacturing have stark differences.

When we pass by a construction site we see tradesmen swinging hammers, tying steel reinforcement bars, pouring concrete, erecting frames, installing dry wall, laying bricks, tiling and painting. Workers are subject to the elements of weather with the expectation of rain delays written into building contracts. There are dumpsters full of building waste waiting to get trucked away. Large construction projects require long lead time ordering and use off-site holding yards to store materials until they are needed on the jobsite.

In contrast, driving past a manufacturing facility we simply see a building and a car park. We know however that inside those buildings there are also tradesmen, operating machines, conveyors, assembly lines, robots and other specialized equipment all in an environment with controlled lighting, filtered air quality and planned waste management. Manufacturing companies invest heavily in managing their supply chain to achieve just-in-time delivery to reduce inventory and increase the efficiency and output of their factories and plants.

"Construc-turing" is the marriage of these two very different worlds.

So what exactly is Constructuring?

It is how the international space station was built. High quality precision components that were manufactured in factories and pre-assembled as modules ready for transport that locked into place when they arrived at their final destination to create an entirely functional and sustainable "building".

A more earthbound example dates back to 1986, when the world headquarters building for the Hong Kong Shanghai Banking Corporation (HSBC) was "manufactured". Ahead of its time, this (still) iconic building was designed by Foster & Partners, a world-renowned design practice with a culture of innovation. The firm's website explains that "The requirement to build in excess of a million square feet in a short timescale suggested a high degree of prefabrication, including factory-finished modules ...". Norman Foster's HSBC headquarters "tore up the rule book" according to a profile of the project published by The Guardian. "It was to be a global assembly line, an international kit of parts that included 30,000 tonnes of steel modules made by ship-builders in Glasgow, along with service pods

from Japan, lightweight movable flooring panels from America, as well as components from Holland, Germany and Italy, all assembled in Hong Kong like a vertical jumbo jet, with a degree of precision never before attempted in a building".

For decades architects and engineers have been in denial, arguing that manufacturing methods designed to produce millions of repeatable widgets, thousands of cars, or hundreds of Boeing aircraft, don't apply to construction because every building or infrastructure project is a "one-off design" on a "unique site". Well, it just doesn't get more one-off or unique than the international space station!

Historically, naysayers have seeded skepticism, promoting the idea that prefabrication and modular construction limits the freedom of designers. They like to reference unattractive (albeit functional) industrialized buildings with tilt-up wall panels and flat roof trusses as proof points. But for the record, as a "manufactured building" HSBC's headquarters received no less than 8 awards for its architecture, technology innovation and engineering from leaders of industry including the American Institute of Architects, Institution of Structural Engineers, and the Royal Academy of London.

Why is Constructuring important?

In a single word, SCALE.

The construction industry is facing an unprecedented challenge: meeting the demands of global urbanization.

A Global Cities Institute whitepaper cites that "Currently, 757 million people reside in the 101 largest cities, with a population of 36 million for the largest city (Tokyo), and 3.5 million for the 101st largest city (Addis Ababa)". Further, that "The average aggregate population of the world's 101 largest cities is projected to increase from 757 million in 2010 to 2.3 billion in 2100: a three-fold increase in average city size. The 'average' large urban area would increase from 7.5 million in 2010 to about 23 million in 2100. Managing these 'large mega-cities', more than 35 in excess of 15 million (the top ten all in excess of 30 million), will place inordinate demands on urban managers and future populations."

How do we house this exploding urban population? How will a city's infrastructure expand to cope with this growth? Where will everyone go to work? How do we solve for mass transportation when today's peak hour traffic already paralyzes our roads? How do we enhance quality of life while increasing urban density? How do we manage the future built environment?

Constructuring versus conventional construction.

Traditional methods allowed 13th century stone masons to build highly complex structures such as monolithic gothic cathedrals one block of stone at a time with spectacular hand crafted stained glass windows and gravity defying flying buttresses; some taking more than 200 years to complete.

Conventional construction allowed 3400 steelworkers in 1931 to build the equally impressive 102 floor Empire State Building by erecting one steel girder at a time; which took 1 year and 34 days to complete.

Construction has evolved over this time span to become a unique combination of traditional methods (we still bake clay bricks and lay them one-at-a-time by hand) and modern capabilities (installing the communications mast on top of the 163 floor Burj Khalifa tower in Dubai by helicopter).

Today however, even with the incredible advancements that have been made in steel and concrete construction, innovations by building product manufacturers to produce aluminum and glass façade cladding systems, the use building information modelling (BIM), sophisticated structural and energy analysis software and project management systems, conventional construction cannot achieve the speed and scale required to meet the demands of global urbanization.

In an interview at the 2017 Techonomy Conference, Autodesk's CEO quantified the challenge we face as: "We literally have to build 1,000 buildings a day over the next 33 years" so that by 2050 we can accommodate the world's population of 10 billion people. He went on the say that "In the developed world, cities are not able to provide the capacity for this population. In the developing world, there's simply not enough roads and bridges to provide capabilities for these people to have the mobility they need".

When you also take into consideration the poor performance record of current construction methods it becomes abundantly clear that pursuing a conventional approach to creating our future built environment is a flawed strategy that will fail to deliver. A McKinsey & Company study found that "Large projects across asset classes typically take 20 percent longer to finish than scheduled and are up to 80 percent over budget".

A radical change in the way we create our built environment is required. "New market entrants such as Katerra represent potentially disruptive innovators …." writes FMI, a leading management consulting and investment banking firm dedicated exclusively to engineering and construction, infrastructure and the built environment. "Katerra's business model is to run a construction company the same way Toyota would operate a factory—fully integrated from architectural design through fabrication and installation. This allows the company to offer services faster, cheaper and safer than a traditional E&C competitor."

Constructuring represents the next era for the industry.

Drivers that make the Constructuring trend unstoppable:

Scale (Volume) - in manufacturing, assembly lines were invented to solve the problem of mass production. Completing 1,000 buildings a day for the next 33 years is a mass production problem. Factory assembly of buildings (pre-fabrication and modular construction) will play a huge role in solving for the scale required to meet the demands of global urbanization.

Speed - Zhang Yue, founder and chairman of Broad Sustainable Building (BSB) , a Chinese construction company is not just challenging but shattering the status quo. After successfully building a 30 story hotel in just 15 days, his company implemented their prefabrication system to erect a 57-story skyscraper in just 19 working days. BSB spent four and a half months fabricating the building's 2,736 modules before construction began. The resulting building called Mini Sky City has 19 atriums, 800

apartments and provides office space for 4,000 people. This office tower has proven that Constructuring can accelerate the industry best for conventional construction from one floor every 4 days down to three floors per day. Whilst many in the industry try to dismiss both projects as an "experiment", the results cannot be ignored. In fact, they redefine what is possible (and necessary) to achieve scale.

Cost - In other industries, in order to drive down costs to the end user, automotive companies have developed shared platforms for different vehicle models and the computer industry has adopted standard components (hard drives, graphic cards, memory chips, etc.). Pre-fabrication and more specifically, modular construction (defined as repeatable "building blocks") represent the equivalent strategy for the construction industry. Constructuring leverages the economies of scale and the efficiency (as documented by the Modular Building Institute) of repeatable modular construction to deliver high quality buildings not only faster, but also, more affordably. To provide perspective, a mere 1% reduction in construction costs would save society about $100 billion annually – which equates to approximately 25 times the cost to build One World Trade Center in Manhattan.

Quality - Two dirty secrets of traditional construction are "mastic and cover strips". Mastic to fill gaps and seal joints. Cover strips (which have become "architectural features" such as cornices, skirtings boards and architraves) to hide the rough edges between floor & wall & ceiling planes. Clearly the precision tolerances enabled by machine tools in a factory setting make these "cover ups" redundant. The controls of factory assembly ensure a much higher quality of construction and repeatable processes ensure consistency of the end product and conformity to building codes.

Safety - The U.S. Department of Labor, Occupational Safety & Health Administration publishes rules and oversees compliance for the safety of workers. They also track statistics for injuries and fatalities across all industries. Regrettably, "Out of 4,693 worker fatalities in private industry in calendar year 2016, 991 or 21.1% were in construction — that is, one in five worker deaths last year were in construction". Jobsite conditions and onsite work practices are much harder to control than factory conditions and processes. Constructuring can contribute greatly to lowering this unacceptable fatality rate for the industry.

Waste – Building Magazine reports that "The average new construction project yields 3.9 pounds of waste per square foot of building area. *Example:* A 50,000-square-foot building = 97.5 tons of waste". This waste typically gets thrown into dumpsters that are hauled away as landfill. In contrast, Constructuring minimizes waste and allows extra materials to be recycled at the factory.

Labor Shortages – The 2017 AGC/Autodesk Annual Worker Shortage Survey found that 70% of contractors are having a hard time finding qualified craft workers to hire. The report concludes that "Over the short term, as construction firms struggle to find enough qualified workers, they will be forced

to be more selective in the number of projects they seek to perform, lest they find themselves unable to meet contractual obligations because of labor shortfalls". Also, that "over the long term, the labor market could experience significant changes as firms find new ways to perform more construction services using fewer people". Scarcity of labor is yet another major impediment to meeting growing construction demand. Importantly, Constructuring can leverage fewer experienced people in instructional and supervisory roles to train and oversee the work of many less skilled workers that can readily learn and master repetitive tasks, while still providing job satisfaction and sharing in the pride of creating our built environment.

Disruption – Every office or restaurant worker in Manhattan has experienced the disruption caused by a new building project. Street closures that can last months or years, resulting traffic jams, re-routing of buses and periodic subway closures. Constructuring significantly reduces the time for onsite assembly thus minimizing disruption to access and services.

Pollution – Sustainable Build UK reports that "The construction industry is a major source of pollution, responsible for around 4% of particulate emissions, more water pollution incidents than any other industry, and thousands of noise complaints every year". Factory based Constructuring can dramatically reduce the amount and duration of traditional work practices on a jobsite (such as the use of nail guns, jack hammers, power tools and diamond saws) that cause on-site pollution.

Is Constructuring just another name for pre-fabrication?

In recent months there has been a flood of stories, articles, infographics and editorial published about the importance of pre-fabrication and the increasing use of modular construction. However, it is important to understand that all of this "hot topic" media attention only focuses on the most visible parts of the Constructuring revolution.

Constructuring is better defined as an end-to-end solution. It involves sourcing raw materials, supply chain logistics, providing factory conditions, industrial design, creating integrated assemblies, pre-fabrication, quality control, inventory management, transportation, erection, commissioning and post occupancy analysis. It also involves data capture at every step to ensure process optimization and to provide feedback for continuous improvement.

Importantly, Constructuring can leverage and benefit from a myriad of technologies that can be applied to every part of this end-to-end system. Equally, there is enormous scope for innovation.

Can GC's (general contractors) master Constructuring?

Frankly the jury is out on this question.

According to research by FMI, "One of the biggest barriers to change and transformation as it relates to prefabrication is not technology, it's culture". As company leaders in every industry know, wholesale

change is always enormously difficult to manage. Organizations have antibodies that resist (and sometimes reject) the very changes that will allow a company to adapt and prosper in a changing business environment and avoid falling victim to innovative disruption by new competitors. FMI's research findings conclude that "Introducing an innovative concept like prefabrication requires curious, tenacious people who are willing to learn new things and take risks. It is also particularly important to develop a culture in which employees are not afraid to make mistakes and where everyone is open to learning from each other's mistakes".

Some established companies will fail to make the transition. Some projects will fail. One example of which is the Atlantic Yards B2 Tower. A published analysis of "What went wrong: The story behind the Atlantic Yards prefab tower" describes that "The building—delayed, stalled, and since re-started to reach half its ultimate height—will take more than twice as long as promised and cost far more than projected. B2, also known as 461 Dean Street, remains mired in lawsuits filed by Forest City and its former partner Skanska, with dueling charges of incompetent execution and flawed design". The story also describes that "It's not clear that the troubles encountered by B2 reflect on the potential for high-rise modular in general, the specific technology used in the project, or the execution by the companies involved". It is also worthy to note that "The developer chose to create a new modular company with the contractor, rather than working with established and experienced modular manufacturers".

Innovation often brings early failures. Those failures will provide lessons that allow others in the industry to learn from, adapt and correct for the mistakes made on these pioneering projects.

Other established companies will be proactive, set strategic objectives, make tough choices, manage cultural change, re-hire or re-train their workforce, suffer transition pains and survive and thrive as a result. For example, "Envisioning a radically more efficient future for the building industry", Skender has announced "its expansion beyond construction, becoming a vertically integrated company including construction, design and building component manufacturing functions". This radical change of business model includes "Launching a new, start-up advanced manufacturing company" and plans to "open a manufacturing facility on the southwest side of Chicago that will employ union labor to build modular building components". The company also shared its rationale for making these decisions which reflects many of the benefits that are described above. "Relocating some or most of the onsite construction process to the manufacturing facility will centralize and stabilize labor, realize a standardized assembly line process for higher-quality building components, and eliminate weather-related delays during much of the construction process. Among the many benefits are increased flexibility, shorter schedules, reduced costs and greater speed to revenue".

Constructuring Technology.

As in other industries, first attempts at automation for design and construction were developed to replicate manual tasks. For accounting, it was the adding machine. For design, it was computer aided drafting (CAD) to replicate "lines arcs and circles" to create an electronic drawing. Then came the pen plotter, with Rotring Rapidograph ink pens racing across a moving sheet of paper to reproduce a blueprint on paper. A second generation of innovation saw the progression to 3D computer aided design (CADD) and visualization to replicate physical scale models. Today leading design firms use very

sophisticated third generation building information modelling (BIM) technology for multi-discipline coordination and managing complex geometry. They also use powerful rendering software to capture the texture and color of building materials to covey the appearance of incredibly realistic finished structures and spaces.

For construction, it was all about automating how to track time and cost. The result was a long history of project accounting software systems (remember Timberline and Prolog) and gant-chart scheduling systems (industry specific tools like SureTrak and general tools like Microsoft Project). The adoption of the internet facilitated a second generation of collaboration software focused on document sharing via project portals (like Asite, Aconex and Procore) that allowed designers, GC's and sub-contractors to share documents and automate paper-based workflows for handling RFI's, submittals and change orders. Today the most advanced project delivery teams are using third generation technologies that leverage mobile access to information (like PlanGrid) and focus on process improvement, the best example of which, interestingly, comes from manufacturing - by applying lean methodology to eliminate waste (measured in time, cost and materials) as documented in the Last Planner® Production System Workbook published by the Lean Construction Institute (LCI).

Constructuring not only requires a different mindset as discussed above, it also demands a different technology platform. New fourth generation technologies are emerging to support the Constructuring trend that are open systems, interoperable applications and data-driven solutions. A good early example is Assemble Systems which bridges BIM from design intent to construction sequencing, provides mobile access, supports material take-off, imports point clouds and integrates with estimating (Sage), scheduling (Primavera P6) and data management (Power BI) applications. Further innovation that will help accelerate the Constructuring trend will come from cross-over technologies; fully immersive mixed reality enhanced by virtual world gaming technology; intelligent infrastructure driven by IoT (internet-of-things) sensors connected to 5G networks; sustainability optimized by performance measurement; continuous improvement resulting from post occupancy utilization using big-data analytics; production at scale by deploying robotics technology; and more.

Investment in Constructuring.

The McKinsey Global Institute estimates "that $57 trillion will need to be spent on building and maintaining infrastructure worldwide between now and 2030—just to keep up with global GDP growth" and to meet the demands of global urbanization.

This is a perfect storm for investors – a growing global market - a highly fragmented and extremely inefficient industry – the inertia of existing players trying to maintain the status quo - a massive number of projects - increasing pressure to improve productivity – and the opportunity to fund new technologies and innovative solutions that will transform project delivery through Constructuring.

According to CB Insights data, "With the construction industry primed for digitization, construction tech startups are focusing on emerging categories like collaboration software, marketplaces, and frontier tech applications. Last year (2017) saw more than $735M in disclosed funding across 95+ deals to construction tech companies". For 2018, this number has already been surpassed by $865 million of

venture funding (led by Softbank) in a single company (Katerra - a vertically integrated startup, which automates its design and construction processes).

In promoting its first Venture Conference event, BuiltWorlds reports that "Built tech focused incubators and accelerators are springing up left and right, helping startups develop products that aim to potentially disrupt the industry". They also report that major corporate players such as Caterpillar, DeWalt, Fluor, and Autodesk have all made strategic investments.

Owners are jumping on the bandwagon. In an industry first, Marriott International unveiled "a comprehensive expansion to its initiative to drive adoption of modular construction of hotels in North America". The company "expects to sign 50 hotel deals in 2017 that incorporate prefabricated guestrooms or bathrooms". Why? To achieve consistency of the Marriott experience for its guests, to control quality (versus being at the mercy of local subcontractors) and to achieve savings (through economies of scale as discussed above).

Tech giants are also getting in on the act. Google's parent company Alphabet is paying about $30 million to provide temporary prefab housing for 300 of its employees. Facebook has announced that it is planning to include 1,500 housing units in the plans for its' new Willow Village campus in Menlo Park. Why? They are trying to solve for the acute shortage of available and affordable housing in Silicon Valley. New entrants like Blokable are also dedicated to helping municipalities and non-profits meet the housing challenges facing cities today by delivering a high-performance "configurable, connectable and stackable" factory built modular building system for developers of residential, retail, and mixed-use projects that can be completed faster and more affordably than traditional construction projects.

Retailers and eCommerce giants are not letting the opportunity to solve the affordable housing crisis pass them by. Japanese retailer Muji is selling minimalistic prefab micro-homes. China's ecommerce king Alibaba sells prefab house kits online (or you can choose from a full range of shipping container homes if you prefer). Not to be outsold, there are "the 11 best tiny houses" that you can buy on Amazon. These are all examples of mass production - manufactured housing that has evolved from the idea of an Ikea "flat pack". These platforms provide an online shopping experience (research, comparison and selection), the convenience of distribution (product is delivered to your specified address) and offer competitive pricing (transparent and affordable).

So, it is "game on" when it comes to the disruption that will force the construction industry to reinvent itself in order meet the demands of global GDP growth and to accommodate global urbanization.

Constructuring and the future Built Environment.

Pew Research Center reported that Millennials became the largest generation in the labor force in 2016. "As of 2017 – the most recent year for which data are available – 56 million Millennials (those ages 21 to 36 in 2017) were working or looking for work. That was more than the 53 million Generation Xers, who accounted for a third of the labor force. And it was well ahead of the 41 million Baby Boomers, who represented a quarter of the total."

As baby boomers retire their construction experience will be lost. Millennials will own the next era of construction, untethered by traditional assumptions and highly motivated to "make a difference" by changing the status quo.

Millennials do not want to be master builders, but masters' of technology and innovation. Instead of relying on past project experience and traditional methods they automatically turn to a building information model to visualize a design, to virtual construction to understand construction sequencing, to augmented reality to communicate to a client, to a laser scanned point cloud to reference existing structures, to deploy a drone to inspect the jobsite and to using a 3D printer to produce a scale model for wind tunnel testing. This next generation of building designers and engineers is also adept at data analysis to determine structural integrity, predict energy consumption and manage environmental impact. They want green buildings and they hold themselves accountable for sustainable design.

The construction industry is ripe for disruption. We are seeing increasing investment in new startup companies, many with founders coming from diverse backgrounds such as Google and Amazon. These new actors bring a completely different mindset to the industry. These companies are being funded to drive innovation, create technology and execute Constructuring strategies that will deliver the new buildings, smart cities and intelligent infrastructure that we need to meet the challenges of global population growth and urbanization at an unprecedented scale.

About:

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Ian is currently an Executive in Residence at Borealis Ventures, a designX mentor at MIT and principal consultant for Built Environment Strategies. As former CEO of Newforma, Vice President of Product Marketing for internet collaboration startups Blueline Online, Cephren & Citadon, Director of Industry Marketing at Autodesk, Australian distributor for Rucaps and Sonata (the predecessors to today's BIM systems), and as Managing Partner of an architectural practice in Sydney, Ian has devoted his career to applying technology and driving innovation to improve our built environment.

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Borealis Ventures

Borealis is an early stage venture fund that has made over 20 investments and multiple exits in the built world space since its founding 17 years ago. We are uniquely focused on investments at the convergence of design, construction and real estate technologies and the harnessing of frontier technologies to deliver a better, more sustainable Built Environment. During the past year the team has made investments in SmartVid.io, Measurabl, Blokable, Dandelion Energy, and Assemble Systems. Notable prior portfolio companies include SketchUp (acquired by Google), Newforma (acquired by BV), Vico Software (acquired by Trimble), FieldLens (acquired by WeWork), SpaceClaim (acquired by ANSYS), SketchFab, TinkerCad (acquired by Autodesk), Flux, Builtr Labs, Honest Buildings, and Courbanize.