

A platform for change:

How identifying and aligning technology building blocks
provides a digital platform of change in the construction
industry

By

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Abstract:

The construction industry is currently in turmoil, searching in every direction for that '*silver bullet*' or digital solution, to bring efficiency, productivity and in some ways stability to the sector.

It was the World Economic Forum report of 2016, that drew major attention to the industry, mainly because it highlighted some of the inadequacies of the sector and its inability to transform as so many other industries have. It also referenced so many megatrends that would ultimately impact over the coming years. Ironically construction is rated at 21 of 22 industries with respect to digitization deployment according to McKinsey Global.

Coinciding with this desire to better itself, it is also trying to eliminate data silos, incorrect information and integrate new technology, systems, as well as materials and products. It is, however, struggling to achieve results in order to cope with new pressures from Global trends, like urban migration, population increase and an emerging digital landscape.

The existing stakeholders are struggling with low margins, poor interoperability and the adoption of sporadic technology within industry silos to resolve the issues within their boundaries. Under these conditions, it is highly unlikely that a '*silver bullet*' will appear: therefore the industry should do what it does best on sites around the world and this is to problem solve. There are enough singular solutions in place and lead users to prove their capabilities, so rather than inventing a new digital solution, the industry must build it from existing pieces. This report aims to capture the pressures the industries forces, to identify significant problems and address these with a collection of solutions, which, when combined have the potential to be transformational platform for the industry. Having spent 13 years in construction, reinvention requires a review of global construction practices; highlighting the collaborations that exist in the field and office to identify technological tools required for transformation. The project will look at the factors impacting the sector, the changing environment of the industry, its lead users and changemakers in order to demonstrate that the solution to help the industry overcome its problems already exists and is just a matter of building it. However, before we build up the solution, one must first dig down to for a solid foundation, which can only be built of data.

“We shape our buildings; thereafter they shape us.” Winston Churchill

Dedicated to Aoife, Evie and Austin

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1.0 Introduction

Why this Research is Important

“As an industry, moreover, it accounts for 6% of global GDP. It is also the largest global consumer of raw materials, and constructed objects account for 25-40% of the world’s total carbon emissions.” [1]

“Multiple global megatrends are shaping the future of construction... first, 30% of global greenhouse gas emissions are attributable to; second, the population of the world’s urban areas is increasing by 200,000 people per day, all of whom need affordable housing as well as social, transportation and utility infrastructure. Such trends pose challenges but also offer opportunities; either way, they require an adequate response from the industry as a whole” [1]

The construction industry is under enormous pressure to adapt and accommodate to the rate of change in our world. If it is a global megatrend like population increase or a more local influence of affordability, there needs to be a solution. This solution will likely be digital. Examples of what could be called revolutionary changes to industry have recently come from companies like Uber and Airbnb. Larry Keely, (co-founder of Doblin Associates, and SingularityU) demonstrated that when deconstructed these companies have solved huge problems by simply taking existing utilities/applications/tools and bundling them in order to solve the problem at hand.

“In the modern world 21st Century Innovation is much more about the elegant integration of well-known things than it is about the primary invention of brand new things” Larry Keely 10 Types of Innovation |Larry Keeley | SingularityU South Africa Summit [1]

Over the past 12 months, as I embarked on a new role in digital transformation within in Kingspan, a large multinational insulation manufacturer for the construction sector, I started to look for the problems and the well-known technology solutions that might be bundled to address the industry challenges. While not exhaustive, there is a convincing argument to be made that there is enough existing technology to help kickstart the revolution that the industry needs.

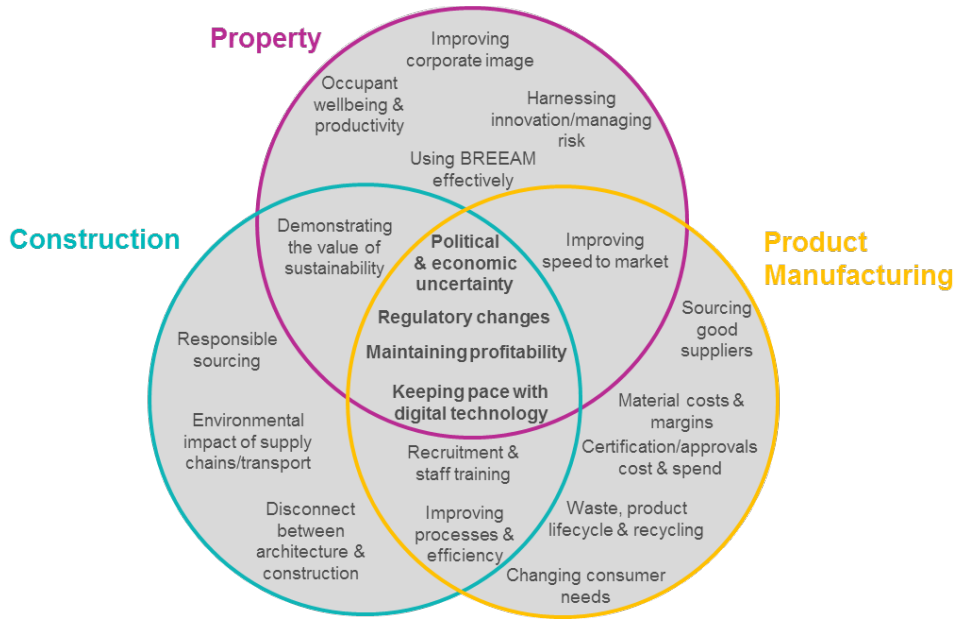


FIGURE 1 BRE, WHAT CHALLENGES IS THE INDUSTRY FACING SOURCE [2]

Methodology

The methodology utilized in the project was based on an autoethnographic experience while undertaking a new role in the Digital Built Environment. Innovation frameworks and a horizon scan were employed. Additionally, technology trends from the Architecture, Engineering and Construction (AEC) sector and lead user/disruptors were identified as those with the potential to accelerate change.

Primarily the literature review focuses on global trends, AEC specific trends in a technology capacity as well as some of the disruptors and their technology that can be utilized in the stack to potentially create an innovative solution to the problems at hand. Numerous discussions also aid this exploration and interviews with industry thought leaders and construction related events and conferences.

The Methodology road map

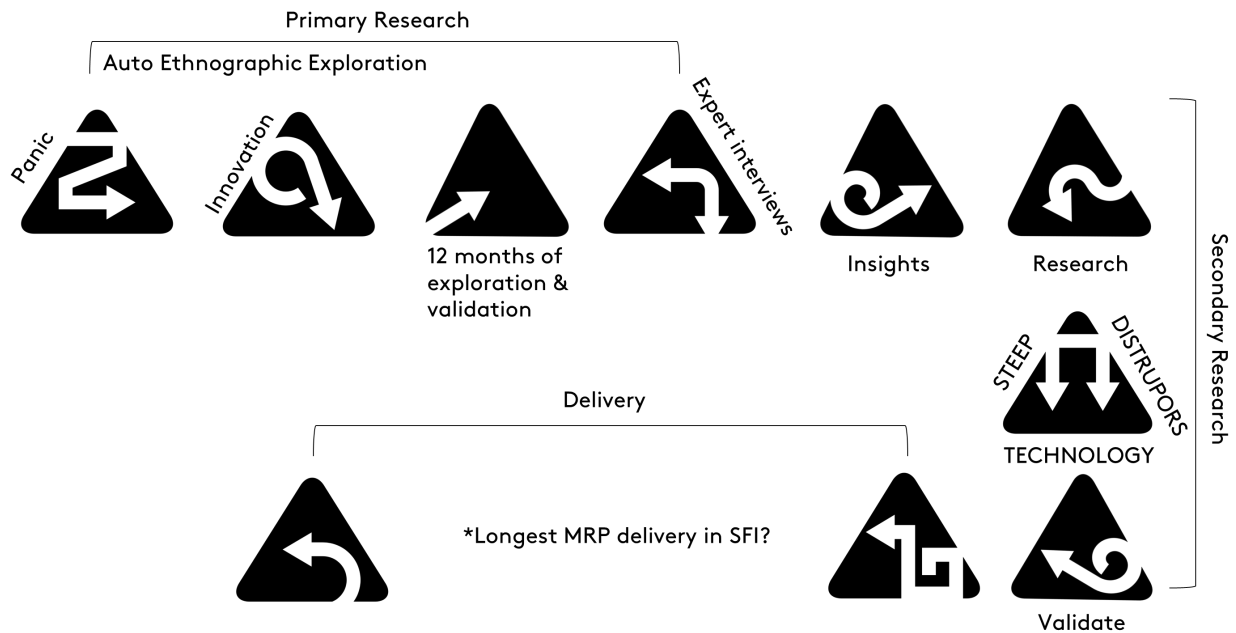


FIGURE 2 METHODOLOGY ROADMAP SOURCE [2]

From Caves to Little Red Bricks

I have always been passionate about objects that have meaning in our lives; history, memories and the sense of something that you can't quite put your finger on. In many cases the epitome of this is our homes, whether it is the building we live in, the house/apartment we own/rent or the broader community. To summarize it, our built environment and more specifically, our buildings.

The Built Environment, which likely began as picking the right cave to live in, has progressed to towering giant structures that dominate our cities, as we reach for the skies. The road to modern construction has been influenced by many factors; material choice and proximity to the natural resources, and by designers and architects from Buckminster Fuller to Frank Gehry and more recently starchitects like Bjarke Ingles. Also, by Investors, owners, occupiers, governments, regulatory bodies, urban planners and activists like Jane Jacobs, and let's not forget public opinion. Dramatic black swan events like Grenfell Tower Fire or the Oklahoma City Bombing have raised awareness of the industry practices, building design, regulation and have uncovered some insights that we would not otherwise have known.

Although these are just a small sample of influences in the system, there many more. The case could be made that everything is connected in some way to the built environment; it is what makes each building so amazing, the sector so unique, so important and ultimately so human.

Stewart Brand who is well known as a futurist and the author of How Buildings Learn sums it up quite nicely, “buildings are the wealth of nations, our largest capital assets, they are the ornaments of culture and they are where we spend most of our lives”. [3]

This human experience of the built environment is why in many cases it is so personal and individual, and perhaps for example, one of the reasons why we still love “little red bricks” on our homes. Some might say it is one of the most inefficient ways to build but still, they have a place in our hearts, and we love them. Perhaps we are influenced by childhood stories like the Three Little Pigs, or it is the craft in the industry that maintains a certain timelessness and nostalgia.

Irrespective of what it is, there is no denying that the building industry is complex, and this report is not set out to propose a fix, but more to show that solutions exist and that by combining them, we might create the transformation that is required.

When so much relies on it;

“the industry strongly affects the economy, the environment and society as a whole. It touches the daily lives of everyone, as quality of life is heavily influenced by the built environment surrounding people. WEF [2]

Cities as a reflection of the built environment are the epitome of design and function. Millions of people moving throughout streets, buildings, food, goods, services, lives and stories all rushing past each other in some form of orderly chaos. It is nice sometimes to stop mid stroll, to observe the interactions, sense the pace and see how seamlessly it all happens. How a 60-story skyscraper can somehow rise from the depths without affecting its neighbours and even if from a different decade, integrate beautifully to become part of the community.

These communities of buildings, their design, architectural presence, persuade millions of visitors to explore them, to appreciate their differences from place to place. We are enticed to visit, based on their architectural acumen. Perhaps from their linear design of modernism with pre designed grids and landscapes where buildings seem to compete for vertical presence as they reach for the skies. Or to the almost organic nature of some of Europe’s cities with their low rise cramped Renaissance style. Each offer something unique. Coupled with this design complexity is the incorporation of local materials and styles influenced by crafts passed down through generations.

The built environment is an ever-evolving canvas that captures humanity’s styles, materials, technological advances and mood. Styles range from American Colonial (1600-1900) to Venetian Gothic (1400-1500) or the imposing forms of Brutalist Architecture (1950-2000), to the now globally dominating styles of a new breed of starchitects. Bjarke Ingles and Daniel Libeskind push the boundaries of what was once possible. Each change brings something new, perhaps innovative, and continues to embellish this built environment tapestry before our eyes.

Innovation in Construction

When we look at innovation in construction, we might immediately be drawn to material advances, moving from wood in the form of large tree trunks to (RSJ) rolled steel joist I beams, and back again to embrace new forms of engineered wood like cross laminate timber. From single pane glass to double glazing, or the advances in insulation performance moving from simple sheep's wool, straw or newspaper to the evolution of PUR/ PIR sandwich panels, which were used on the Apollo capsule [3]. Likewise, cement is evolving, and now self-repairing varieties of self-healing Bio Concrete are available [4], which should lessen the constant repair work that is required. For example, consider elevated highways like the Gardiner Expressway in Toronto, which currently has a backlog maintenance cost of \$2 billion. [5]

It could be argued, however, that these material advances are merely step changes in the industry and the last great innovation in construction was the invention of the elevator, and the perfection of it by Elisha Otis in 1857.

“Riding in an elevator used to be dangerous business — until Elisha Otis, of Otis Elevator Company fame, invented a device that could prevent a passenger elevator from falling if its rope broke. It debuted precisely 160 years ago at the E.V. Haughwout and Company store in Manhattan on March 23, 1857” [2]

This innovation had the most significant impact on the built environment since those early days of simple huts. Prior to the mass adoption of the elevator from Otis's invention that ultimately gave people reassurance of its safety to travel in it, society constructed low to mid rise units that sprawled outward across the landscape. Since the innovation of the elevator in building design, we have reached for the skies with the world's tallest building; the Burj Khalifa now standing at 828 meters. This will soon be surpassed by the Jeddah Tower in Saudi Arabia in 2020, and the Dubai Creek Tower at 1300metres/1.3km. Due for completion in 2021, Dubai Creek Tower will become the world's tallest structure.

These remarkable structures are setting new “benchmarks in tall building engineering propelling mankind's seemingly endless race for the skies” and demonstrating the importance and development of one of the last great innovations in construction, that of the humble elevator. [3]

Letting Buildings Talk

If the elevator was the last great innovation in construction, what might be next? Our existing stock of buildings is somewhat dumb in comparison to technological development in other sectors and most buildings being erected currently are not a whole lot better. When it comes to the automotive industry, cars can identify faults, issue service alerts and are not too far from being fully autonomous.

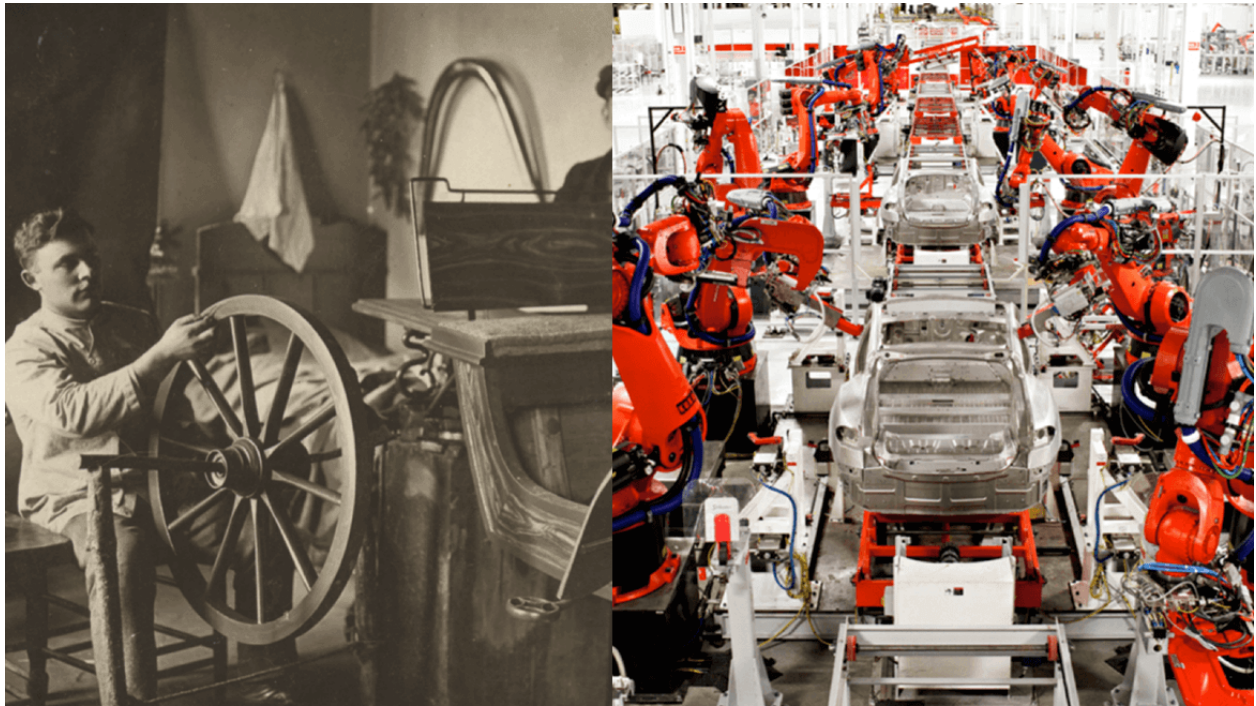


FIGURE 3 JORIS IDE PRESENTATION ON DIGITIZATION SOURCE [4]

Or consider the telecom for example; Long gone are the days of operators connecting our calls from fixed locations, now we are embarking on 5G networks with practically unlimited connect -ability delivered in smart, addictive devices that control our lives, [8] Managed from data centers that “are arguably the most important buildings in the world because they are at the hub of everything we do.” [9]

Most people rely on buildings to be adequately constructed and operate efficiently, however, the needs for human monitoring of mold, cracking or other defects would indicate that these structures also rely on us to maintain and keep them in good health. Poor design, incorrect choice and or combination of materials can also have drastic effects on a building. Ironically the building can’t tell us this, but its occupants are affected. Have you ever felt miserable after spending time in a building, seemingly blaming the weather, food or simply an off day, but perhaps never considering the space or building as the cause?

“Sick building causes are frequently pinned down to flaws in the heating, ventilation, and air conditioning (HVAC) systems [10]. Other causes have been attributed to contaminants produced by outgassing of some types of building materials, volatile organic compounds (VOC), molds, improper exhaust ventilation of ozone, light industrial chemicals used within, or lack of adequate fresh-air intake/air filtration.” [11]

So, if buildings are ultimately connected to humans and house some of the most critical aspects of our lives, why then are they so inefficient and lack technological intelligence compared to other industries? It might point to the craft nature of construction, the macro effects of the cyclic bust and boom economy that affects large infrastructure projects or the lack of technology, but it shows an industry struggling to adapt to new pressures.

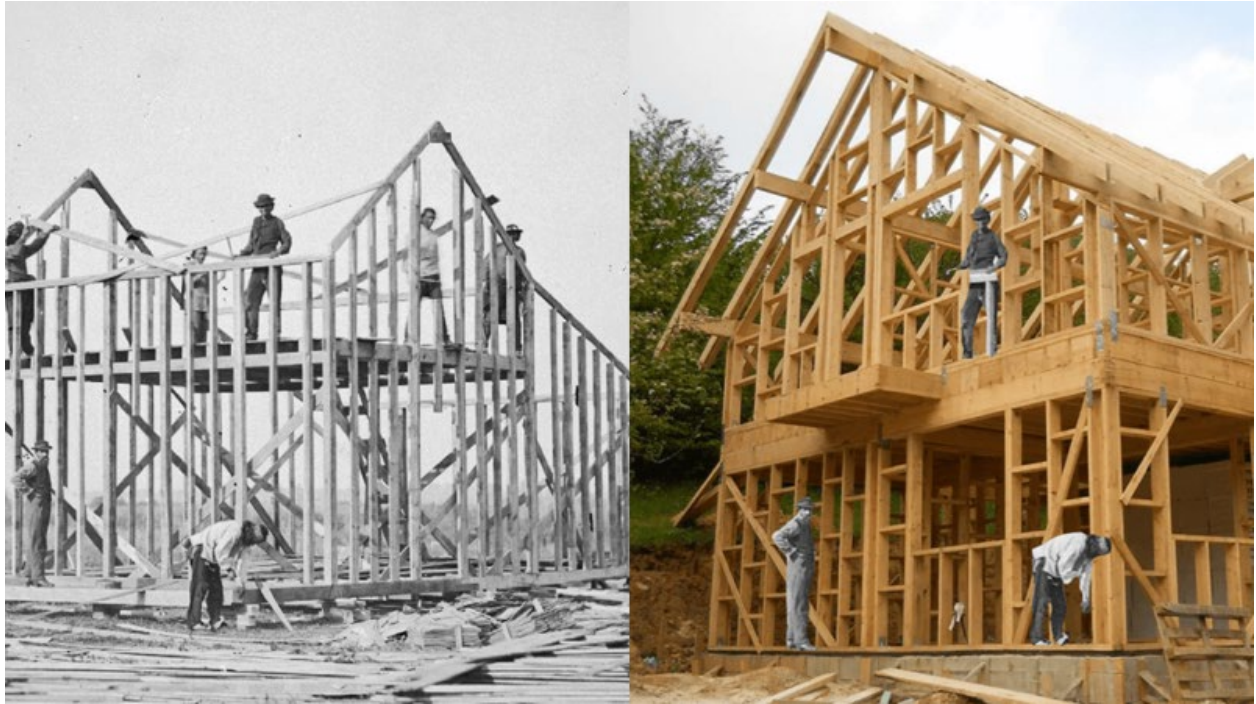


FIGURE 4 JORIS IDE PRESENTATION ON DIGITIZATION SOURCE [4]SOURCE [6]

Two new pressures

Stewart Brand author of the “Clock of the Long Now” and host of the television series “How Buildings Learn” has created a visual graphic to demonstrate the layers that construction (classified as infrastructure in the diagram) has in terms of pressures from influencing forces. The outermost layer fashion is essentially the quickest changing while Nature the innermost layer is the slowest. Each layer, therefore, interacts with its neighbour, and all supposed to have a balancing effect on each other.

As Brand explains

“The job of fashion and art is to be froth—quick, irrelevant, engaging, self-preoccupied, and cruel. Try this! No, no, try this! It is culture cut free to experiment as creatively and irresponsibly as the society can bear. From all that variety comes driving energy for commerce (the annual model change in automobiles) and the occasional good idea or practice that sifts down to improve deeper levels, such as governance becoming responsive to opinion polls, or culture gradually accepting “multiculturalism” as structure instead of just entertainment.” [4]

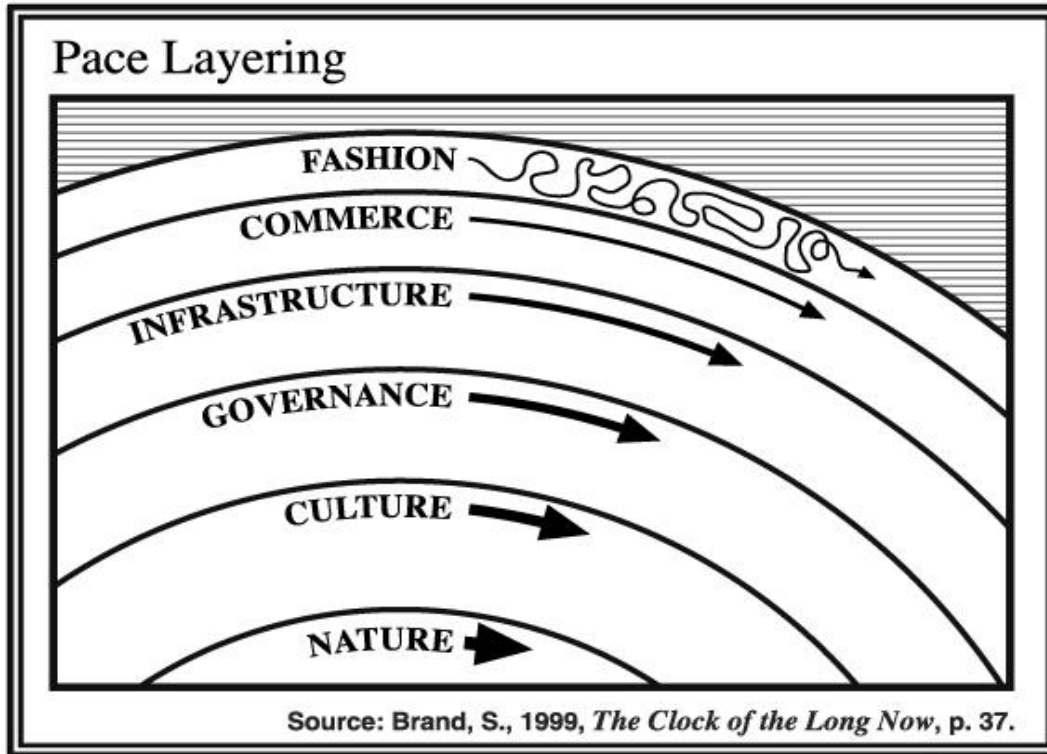


FIGURE 5 PACE LAYERING, THE CLOCK OF THE LONG NOW SOURCE [5]

“Ironically the inspiration came from a framework from Architect Frank Duffy who encouraged builders not to think of a building as a single entity, but as a set of layers operating at different timescales.” [12]

Brand subsequently “picked up on Duffy’s work and adapted it to a kind of proto-pace layer framework in his 1994 book *How Buildings Learn: What Happens After They’re Built*, expanding it to six S’s and including this handy diagram:” [12]

It might be suggested that Brand and or Duffy’s graphic could be altered to perhaps demonstrate the pressure that is on the two middle most layers, that of infrastructure and governance. Construction or infrastructure is intertwined with governance and codes in order to build. Planning, approvals, and governance are all key elements in a construction project and are key in determining the speed of delivery. While advances in technology can ensure products can be tracked to site and or simulated prior to building, you cannot use those products without rigorous testing and approvals.

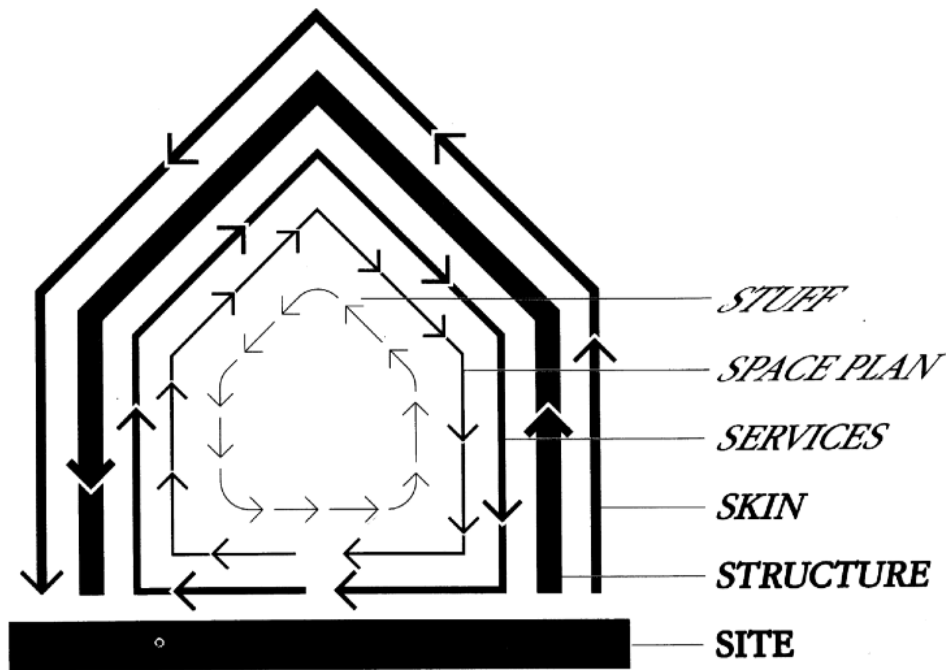


FIGURE 6 STUART BRAND; PACE LAYER DIAGRAM SOURCE [5]

I would hypothesize that infotech is now an additional force working its way down from Fashion and Commerce while Biotech is now influencing the rate of change in the Nature layer, thus the stabilizing state of the layers is now in flux and the inability for infrastructure and governance to adapt is causing problems. A prime example of this is simply the built environment, which is inexplicably linked to governance. The changing pace of interior fit out, reuse, redesign, the need to integrate vertical farming, new electrical systems etc. These two layers are simply not able to cope with the rapid changes.

I suggest that when some of the emerging trends examined later in this document are placed in their corresponding positions on the pace layer diagram that a combination of all factors is creating exhaustive pressure on our infrastructure to accommodate, change, adapt and ultimately move with increasing speed through the other layers. This is similar for other industries too.

If we place infotech as a pressure moving top down, it's influence on fashion and commerce is undeniable, while on the opposite end Biotechnology is redefining the slowest layer of Nature changing how we farm, grow crops etc. Moving farming from outdoors to indoors and in some cases horizontal to vertical is also influencing how buildings need to support our changing needs.

I would suggest that both of these influences on the outer and innermost layers are changing the balancing effects and thus putting increasing pressure on the inner layers to accommodate the changing factors from the other layers.

“The liberal political system was shaped during the industrial era to manage a world of steam engines, oil refineries, and television sets. It has difficulty dealing with the ongoing revolutions in information technology and biotechnology.” [7]

Compounding Effect

In summary, whether it is digital, infotech, biotech or simply the changing habits of society, our buildings are from a past era, slow to build, slow to adapt and ultimately now struggling to cope.

A new approach is required to identify a technological solution that can maintain protection of the existing stock while modernizing and creating new ways of building that allow for change and adaptation in the future.

2.0 Global Trends

There is no denying that nearly all trends can be traced back in either first or second order of magnitude to the built environment. The trends identified in the global section are not in any way exhaustive but represent some of the topics and conversations that I have had over the past 12 months while exploring this topic. In order to categorize and reference these trends, a methodology frequently used in the futures field was chosen. STEEP is a horizon scan that provides a 360-degree view of the current situation and is a way to categorize some of these trends that are having an impact on the sector. The acronym refers to Social, Technological, Environmental, Economic, and Political. Each heading is used to reference a trend or driver for change affecting the industry.

Social

Urban farming

There are any number of social trends that could be chosen to demonstrate an impact on the built environment. Urban farming was one that was perhaps close to my heart. I have fond memories of my childhood in Ireland when my grandfather would arrive at my parent's house and spend many long days tending to a vegetable patch that took up about ½ of the 100 or so feet of the garden. However, after his passing it stopped, and I would be conscious of similar conversations I had with friends whose grandparents did similar. Perhaps it was an economic reason, or a simple love of gardening but I think this tradition of utilizing ones back garden for food seemed to die away.

However more recently there has been a resurgence in urban farming. The Bowery project in Toronto is one such example, run by Rachel Kimel and Deena DelZotto, it "is a not-for-profit organization with a mission to create opportunities for urban agriculture through the temporary use of vacant lots." [1] It is both a social and economic movement where particularly in cities farmers are attempting to grow local, mainly organic produce for the city's inhabitants. Thus, reducing the costs to transport and also rejuvenating pieces of land that are lying dormant. There are many types, from rooftop applications to greenhouse and vertical farming which is becoming more prominent. Colleges such as U of T Scarborough will soon "be home to a net zero vertical farm and living lab, thanks to a partnership between UTSC and Centennial College. The two schools signed a memorandum of understanding in early 2019. The first of its kind in Canada, the farm is intended to be used for research into sustainability practices as they relate to the future of urban agriculture, waste management, clean tech, design, water conservation and more"

The growth in urban farming is complementary to the increasing numbers flocking to our cities and as a solution in which rooftops, gardens, walls etc. are used for the betterment of the city, it is very hard to argue. However, when food is produced for general consumption you require regulation and standards and irrespective of what food authority takes responsibility for the food. The planning departments need to be able to cope with the rate of change and design in new standards for such applications. It will be extremely hard to retrofit existing rooftops to accommodate food growth, if there is little information about the structure or loading capacities. The same can be said for new buildings, if greenhouses or

hydroponic applications become the norm, a building will offer so much more and considerations for this should be provided for. Lastly, imagine a dormant building like the many that exist in cities like Detroit being retrofitted to be vertical farms in the city. The costs to demolish and rebuild are eliminated when a building can offer an alternative use that it may not have previously been considered for.

Technological

Autonomous Vehicles

The concept of autonomous vehicles has long been a staple in science fiction, but there is some certainty now that it won't be much longer before they start to become mainstream. Already a standard option in most cars is the precursor features to fully autonomous options, called advanced driver assistance systems, which still require drivers to pay attention and take over steering, braking and acceleration in a pinch. Nevertheless, even in these early stages, today's ADAS technology can still ease the burden of a daily commute. [14] In general, most articles discuss the benefits of their introduction, from reduced traffic collisions, reduced congestion and emissions, or enhanced mobility for the physically disabled.

Less discussed is the potential impact they will have on our built environment. For example, planners say because driverless vehicles will drop off passengers and move on, prime real estate now consumed by vast parking lots and unsightly garages could be freed up for more housing, parks, public plazas and open space. [15]

Their introduction would also impact how our cities towers are designed and may eliminate the need to create underground parking with each residential or office tower, which could be freed up for a variety of other purposes. It will also put pressure on designers to start to assume the potential for more than one use of a building over its lifetime. "In Cincinnati and Los Angeles, some new parking garages have flat floors and higher ceilings so they can be easily converted into apartments or office space as the demand for parking dwindles." [15]



FIGURE 7 LAND NOW COVERED IN PARKING LOTS AND GARAGES CAN BE USED FOR "INFILL DEVELOPMENT" TO ADD HOUSING SOURCE [6]



FIGURE 8 WITH WIDESPREAD ADOPTION OF AUTONOMOUS VEHICLES, LAND NOW COVERED IN PARKING LOTS AND GARAGES CAN BE USED FOR “INFILL DEVELOPMENT” TO ADD HOUSING, OFFICE OR OTHER SPACE IN DENSELY DEVELOPED AREAS, EXPERTS SAY SOURCE [6]

It also means that general contracting firms will be forced to work more efficiently when converting these spaces in order to minimize impact on the city’s functions. As well they must find more innovative and practical ways to convert for new uses without adopting a tear down and replace approach as in some cases a third or more of a tower might serve as parking for the occupant's vehicles.

Autonomous vehicles may also force planning departments to review what can be done with laneway structures or how residents repurpose their parking spots.

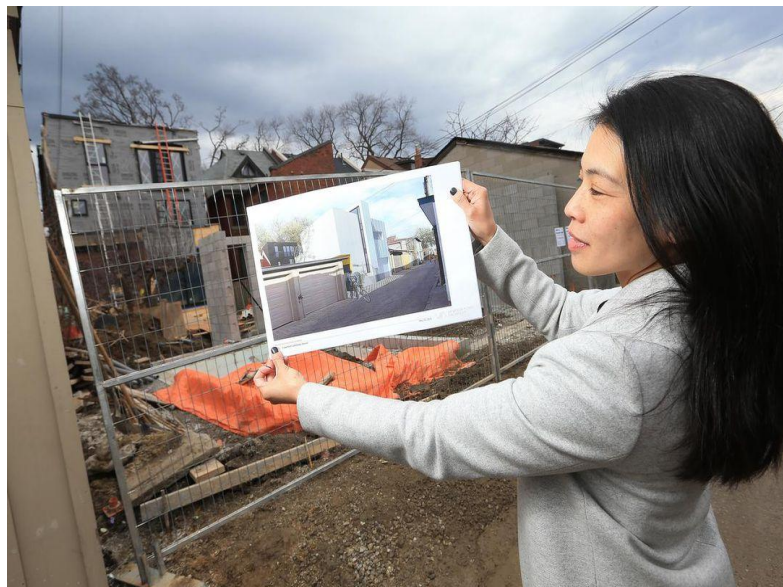


FIGURE 9 ARCHITECT VANESSA FONG, FOUNDER OF VFA // ARCHITECTURE + DESIGN, HOLDS THE RENDERING FOR A LANEWAY HOME IN THE LITTLE ITALY AREA. FONG'S FIRM IS OVERSEEING SIX LANEWAY HOUSES, IN VARYING STAGES SOURCE [6]

Counter to the repurposing of existing parking structures or replacing them with new functions, is the possibility that autonomous vehicles may accelerate urban sprawl. This, due to the fact that occupants might feel comfortable to sleep on a 2-3-hour journey to work, thus negating the requirement to live close to a city where their job may be

Smart House

Personal assistants are now commonplace on our handheld devices, from Siri to Google they have become a somewhat generic feature on our phones, and they have been widely accepted. This has led to the tech giants developing home based sister products, from Google Home or Amazon Alexa, there is a wealth of services they can offer from taking shopping lists to the weather forecast to reading your child a bedtime story. However, their true capacity is starting to come forth as they are the command unit for all things IOT or Smart products that we start to install. From smart switches and thermostats to automatic door locks and facial recognition home cameras, these tech companies have realized that there is a wealth of data to be gleaned from users. While they offer some of the IOT devices, the real prize seems to be to win out on the assistant to help you control them all.

These developments are not being treated lightly by the tech giants, with Googles acquisition of Nest and Fitbit or Amazon's more stealthy investment in Plant Prefab. Amazon has spoken openly about the integration of Alexa functionality as part of the design stages of the house and not as a retrofit alternative once the house/building has been constructed.

There is one tech company that has decided to take a massive leap into the world of smart infrastructure, which is Alphabet, parent of Google, through one of its smaller consulting agency Sidewalk Labs. They identified a parcel of land on the Toronto Waterfront where they provided more than just tech. They took on the ownership of the entire development.

From smart buildings to intelligent cycle lanes to automated trash collection, technology is being integrated into every aspect of the project. Sidewalk Labs Toronto has struggled with some controversy and backlash from the counter movement block sidewalk [6] due to its association with its sister company Google. Although the data ownership and governance question has caused quite an uproar in the city. There are also several clever initiatives that are part of the proposal, from the ability to alter internal layouts of apartments as family size changes to considering the appropriate use for the ground floors of condo buildings which might be more suitably utilized as a school or fire department than a shop. Ultimately what the project has shown is the concept of personal data acquisition while in the home is now a hot topic and it might be the last line for people to push back against big tech. It has also demonstrated that policies and planning in the city are not suitable for a change of this magnitude. Ironically whatever side of the fence you choose, pro or anti Sidewalk, there is no denying that they are trying to find solutions for problems we as a global society are all facing. Perhaps as we digitize buildings and Sidewalk looks to be a forerunner, it might just force society as a whole to figure out a method/policy/governance to manage our personal data. I have on another occasion, presented a research team with a project where we were going to install some basic sensor rigs around their workspaces to understand special data. It was immediately met with pushback, after questioning the team about the fact their personal phone was doing much the same if not worse. The answer was that we have

already lost that battle. So as buildings get smarter and we create their digital twins, perhaps the solace and privacy of our homes will be lost, or it may provide us with a chance to be part of the solution.

Environmental

Solar Technology/Adoption of renewables

Whether it is a large pension fund or a single homeowner, the questions of service/maintenance costs in running your home or building are always something that will be considered during the project. It is worth noting that the Global Alliance for Building Construction (GABC) and the new European Performance in Buildings Directive (EPBD) both generate their strategic recommendations around Nearly Zero Energy Buildings (NZEB).

“A net zero energy building A zero-energy building (ZE), also known as a zero net energy (ZNE) building, net-zero energy building (NZEB), net zero building is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site” [16]

There are also many organizations and accreditations for buildings that are constructed to be more sustainable such as the Leadership in Energy and Environmental Design (LEED) program for buildings, giving them a rating from Certified, Silver, Gold or Platinum. The increasing awareness means that more and more effort is required to integrate energy saving and sustainable products/technologies into building design. Couple this with the rising cost of energy globally and Solar/PV becomes an interesting alternative/adding to building.

There are also technological developments in the area of PV, such as the Nanoparticle-based cells can be made with far less energy than conventional silicon solar cells [17]. Therefore, it is highly likely that Solar will become far more prominent in design in the coming years. This may lead to changes in design that influence how we look at buildings, in the cases of larger industrial units with thousands of square feet of flat roof space (which can be covered to a solar farm), may lead to buildings becoming mini power generators or power supplements to the grids. Which, in turn, may change how we view our electrical distribution systems of the future.

Sustainability Movement

The sustainability movement is somewhat omnipresent now from large corporations and their promotions on their strategic sustainability projects to Greta-Thunberg and her quest to better the world. All very much needed in order to have some lasting effect on the betterment of the planet. However, if we were to try and rank the impact as well as a top five things to tackle, it's likely that the construction sector would be in those five, considering the rather alarming statistics that are attributed to the sector.

Findings by the construction blog Bimhow demonstrate that, “the construction sector contributes to 23% of air pollution, 50% of the climatic change, 40% of drinking water pollution, and 50% of landfill wastes.

In separate research by the U.S. Green Building Council (USGBC), the construction industry accounts for 40% of worldwide energy usage, with estimations that by 2030, emissions from commercial buildings will grow by 1.8%. [18] The WEF fact that 30% of global greenhouse gas emissions, which are a core driver of climate change, are attributable to facilities constructed by the industry.

There are multiple reports and documents where all the impacts can be validated and offer excellent secondary research. However, there was an event held in February 2019 which as a primary research opportunity was one in which I was actively involved, called the Rotman Design Challenge. The Rotman school invites sponsors to offer an industry challenge in which the students from a postgraduate school globally can enter. Previous years have included Steelcase and Fidelity Labs.

“Kingspan’s ultimate business goal is to improve building performance and contribute to a more sustainable, energy-efficient future for its customers and the environment. That is why, during this time of evolution and change; where industries are being increasingly exposed to innovation-driven growth and where disruptive technologies are a key player, Kingspan is looking to leverage digital technologies to better align their offerings with customer needs, while simultaneously addressing key challenges facing the industry. As such, participating teams are being asked to answer the following question:” [19]

“Within the next 5-10 years, how can Kingspan the global leader in high performance insulation and building envelope solutions, and a company committed to sustainability, disrupt its own business model to be the leader in the future of digital construction?” [19]

A lot of the findings and presentations from the participants have been documented and catalogued as well as utilized to guide some of the company’s internal strategies. In this report, it is worth referencing “The Pivots” who won with their proposal called Struct. The idea of the proposal was that due to the changing climate and increased amount of global environmental disasters, buildings were facing new challenges and while LEED and other initiatives exist it would be beneficial if there existed “An impact assessment platform that measures resiliency of buildings across environmental, economic, and social measures, to better prepare the industry for future-proofing against climate change” [21]



An impact assessment system that scores the potential benefits of resilient buildings and increases transparency in the value chain.

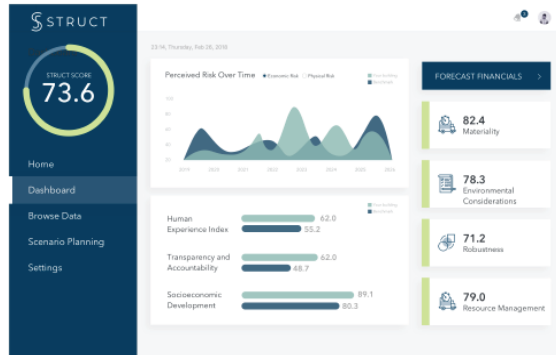


FIGURE 10 THE PIVOTS; STRUCT, SLIDE FROM ROTMAN PRESENTATION SOURCE [7]



FIGURE 11 THE PIVOTS: SLIDES FROM ROTMAN PRESENTATION 1 SOURCE [7]

The interesting about this winning presentation was not only the idea of an impact assessment tool, but some of the insights they obtained from interviewees. Which, with some synthetization, it can be determined that there is a desire to build more sustainably; that nothing quite like this exists. And that a tool for financiers of projects where it could have a ranking for long term performance and effectiveness across the five key areas (sustainable, threat-proof, robust, user-centered, consciously made, tech-forward) was highly sought after. This is certainly a potential governmental/global initiative where

buildings could, in fact, obtain a rank that would appeal to both investor, owner and more importantly, occupant. Thus, engaging society to be more interested in their built environment.

Certifications right now are too yes/no. They aren't sophisticated enough for the granularity needed in construction LEED won't exist in 8-10 years. -Adam, LEED Certified Architect, Partner, Architecture Studio

Economic

The Rise of the Micro Living



FIGURE 12 POLISH JAKUB SZCZESNY STANDS IN HIS HOUSE WHICH HE CLAIMS IS THE NARROWEST IN THE WORLD AT 122CM WIDE SOURCE [18]

There are many examples of people creating tiny homes for themselves, as small experimental projects, or to create additional income by putting habitable pods/spaces in their gardens or on top of their garages. In the case of Jakub Szczesny it was experimental and "It requires a sense of humour, as you cannot stay long in a place like this," [18]

It does, however, point to some emerging trends that space in cities is becoming increasingly expensive and what was once a laneway, section of a garden, roof of a garage or a gap between two buildings can now be a future home. Nothing is off limits and the public is in a lot of cases willing to accept this space limitation in order to live in a city.

Major cities like New York and Hong are now common places for tiny apartments at high prices. Recently, a development in Toronto called “Smart House” made the news when it started planning for the construction of its small living spaces. Called “micro-condos”, these homes are designed to provide all the necessities of a single-unit condominium in the smallest space possible, so they can be sold as cheaply as possible. The average unit is only 300 square feet, and it is marketed as having won design awards for efficient layouts. "Smart House Condos Toronto - Intriguing, Innovative, Smart Living at Queen & University." Smart House Condos Toronto - Intriguing, Innovative, Smart Living at Queen & University. [19]

The mass-urbanization and migration to cities have enabled developers to offer solutions like the micro condo to cope with demand; however, it is generally more lucrative to design smaller spaces than larger two+ bed family-oriented units. In addition, there is more demand for single occupant units.

The issues that this places on the infrastructure is that entire buildings are limited in their function for their lifespan. They cannot adapt to the changing needs of occupants as walls are not designed to be repositioned as families grow.

With more stock like this on the market, it will influence consumer expectations; that size is not something that you might expect from a condo or a home., or it may also drive people towards renting rather than purchasing to accommodate for lifestyle change. In some cases, with the increase in the sharing economy, perhaps it will not be seen as an issue for future generations.

More regulation is likely required in order to have some guidelines of acceptability on what square footage is tolerable but also safe physical and mentally for someone to live in. Pushing the boundaries of size and space conflicts with the buildings overall purpose to protect.



FIGURE 13 40SQFT APARTMENT IN CHINA, PHOTOGRAPHED BY CHINESE HUMAN RIGHTS SOURCE [8]

Political

Grenfell: The construction industries Black Swan

Around the world, there is mounting pressure on Governments to try and provide a solution to the problem of increasing real estate pricing, the reduction of credit and increased costs to build. Take nearly all global markets and plot the price of real estate since records began and bar a few key drops during the Great Recession of 2007/8, for example, the trend lines all go the same way. Real Estate is generally a good investment, particularly for previous generations who have been able to ride the market gains.

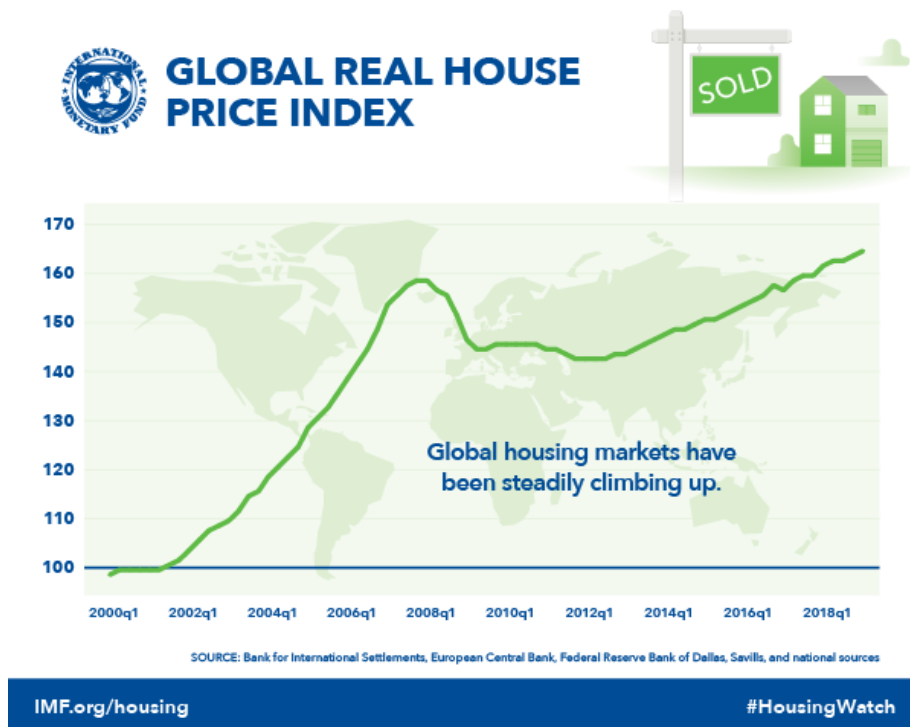


FIGURE 14 GLOBAL REAL HOUSE PRICE INDEX SOURCE [9]

However, in some cases, the inability to purchase or rent forces people to co-occupy properties that are not designed for increased numbers. This puts a strain on the building itself, wear on equipment and has the potential to impact safety should anything happen.

Unfortunately, this was one of the issues cited in the Grenfell Tower Disaster.

“On 14 June 2017, a fire broke out in the 24-storey Grenfell Tower block of flats in North Kensington, West London. It caused 72 deaths, more than 70 others were injured, and 223 people escaped. The fire was started by a malfunctioning fridge-freezer on the fourth floor and spread rapidly up the building’s exterior, bringing fire and smoke to all the residential floors. The rapid spread has been attributed to the building’s cladding, which is a type in widespread use, along with the external insulation. In the

aftermath of the fire, the national government commissioned an independent review of building regulations and fire safety, which published a report in May 2018. [4]

The Fire sparked a national outcry against the construction industry and led to the Government to commission the Hackett report to try and uncover the failings that led to the tragic loss of life.

One of the main findings from the report was to state that "the current system of building regulations and fire safety is not fit for purpose and that a culture change is required to support the delivery of buildings that are safe, both now and in the future." [20] The report mentions explicitly...

- the roles and responsibilities of those procuring, designing, constructing and maintaining buildings are unclear;
- the package of regulations and guidance can be ambiguous and inconsistent;
- the processes that drive compliance with building safety requirements are weak and complex with poor record keeping and change control in too many cases;
- competence across the system is patchy;
- the product testing, labelling and marketing regime is opaque and insufficient; and
- the voices of residents often go unheard, even when safety issues are identified. [21]

The event put a black mark on the industry and has forced the government to investigate multiple tower blocks in the UK for similar inefficiencies as well as prompting a ban on the use combustible products in certain types of buildings.

Coupled with the migration to cities and millennials preferring condos over larger suburban houses, the real estate market is seeing the impact. "Millennials values and approach to work-life balance is driving them towards buying condos. A significant shift from previous generations that saw house ownership as a life goal [22]

Governments are facing pressure to fast track building schemes to meet the demands but also to appease future voters. In some cases, the lack of affordable accommodation can result in increases in homelessness [23]

All these factors can spark protests for action, which puts governments under pressure to act quickly and can in some cases make decisions with limited foresight or awareness of the broader impact in order to appease the public.

Conclusions about the method

Based on the STEEP analysis it gives a good holistic view of the trends impacting the sector and ensures that all the major areas are defined. When analyzed it can be summarized that all the trends whether it be urban farming or smart houses are firstly increasing pressure on the sector to change, which results in questions, which require regulation and standards at a faster rate. Therefore, it can be hypnotized that a solution is required around standards and regulations in order to facilitate the rate of change. This cannot likely be achieved by humans and some form of algorithm will likely be required. However, none of this is achievable without structuring of the base data to being with.

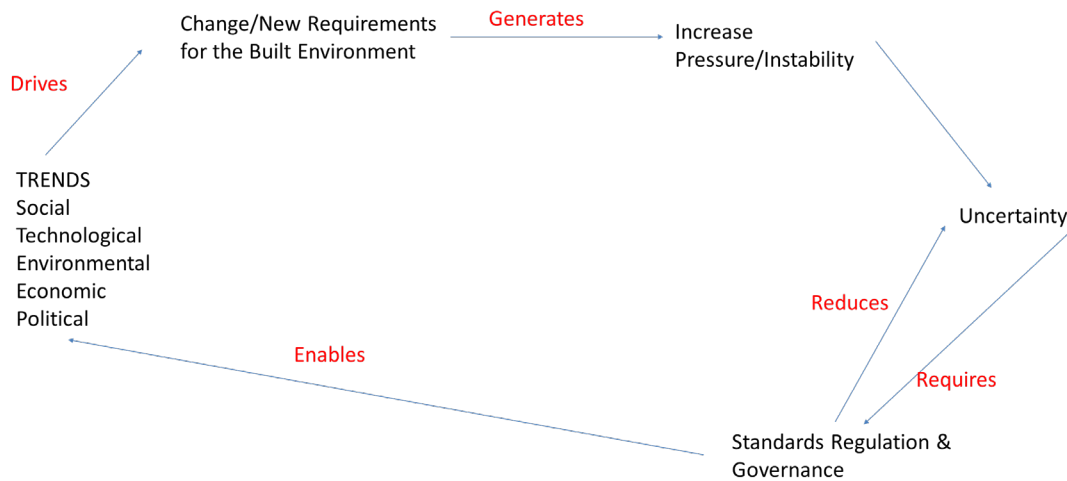


FIGURE 15 STEEP OVERVIEW

The STEEP analysis demonstrates that all categories have an impact on the built environment and that change is driving increased pressure to accommodate and bring efficiency, which is also leading to uncertainty, but that ultimately standards and regulation are the key elements that may be a cornerstone to allow for all of the societal, technological, economic, environmental and political factors that are influencing the built environment. However, the ability to regulate is failing due to the pace of technology, which calls for more technology to be adopted in the process of facilitating regulation and standardization.

3.0 AECO SPECIFIC TECHNOLOGY TRENDS/DRIVERS.

It may be considered that most global trends will have some impact on the built environment in a direct or secondary order of magnitude. There are, however a certain set of emerging technologies that are paving the way towards a more digital, integrated and connected built environment. Its rapid growth is forcing all stakeholders in the construction process to digitize and digitalize their businesses and in some cases, reinvent themselves altogether.

Generative Design

“Generative design is a design exploration process. Designers or engineers input design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints. The software explores all the possible permutations of a solution, quickly generating design alternatives. It tests and learns from each iteration what works and what doesn’t.” [28]

While it is being leveraged in product design and material design from the likes of motorbike swing arms to brake calipers on Bugatti's, in the AEC community it's allowing computer algorithms the ability to define the functionality of a space in terms of performance/layout. As a result, it is impacting the aesthetics and perhaps the experience for an occupant in the building. It is a tool in Architecture that is slowly being embraced, as both a cost saving function but also for its educational feedback where varying degrees of change can be examined quickly.

Autodesk is the leader in Generative design for architecture. Their research team focused on this subject, The Living, which was previously a design studio based in New York and Founded in 2006 by David Benjamin, explores new design methods and materials born of living organisms and natural structures. [29]

The technology was utilized in the design of the MaRS offices to layout the interior organization of the spaces, coordinating multiple factors/design goals from the proximity of workspaces to washroom adjacency preferences, to cubicle type preferences. With over 10,000 possible layouts of the space, they were able to reduce these to 10 options for the staff and to present back various design solutions. The generative algorithm process doesn't replace the design intent, it simply gives more choice through a rapid way of defining the solution that meets the outlined goals while understanding the constraints.

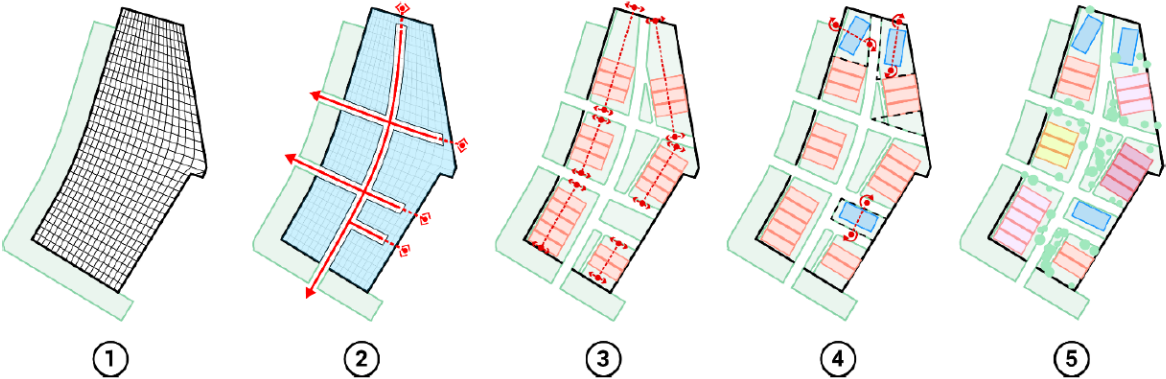


FIGURE 16 GENERATIVE DESIGN, HOUSING LAYOUT SOURCE [12]

Geometric system: (1) create mesh from boundary; (2) generate streets; (3) subdivide into lots; (4) place housing units; (5) place apartment buildings.

Another example; The Dutch Company Van Wijnen and Japan's Daiwas House Industry are also using these Generative tools. Daiwas' case which focuses on one of the most 'urbanized nations in the world, with more than 91 percent of its citizens living in its densely packed cities' [30] The goal was to maximize efficiency; "to optimize building on small parcels, in line with the country's urbanization patterns." [30]

Where such generative design modelling technology can be leveraged, it has the impact to drastically change how buildings are developed. Currently it is based around selected design criteria, managing functional floor planning etc., but it is feasible to assist architects in choosing products at later design stages as well as automatically navigating codes and compliance requirements, provided the data is available

GENERATIVE DESIGN

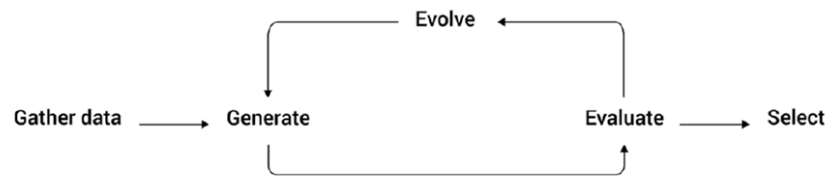


FIGURE 17 AUTODESK GENERATIVE DESIGN GRAPHIC SOURCE [10]

Imagine that an architect must design the most energy efficient envelope on a building. It would take an enormous amount of time to evaluate the many products offered, not to mention how each product may perform as a system in a built-up wall solution. However, if a manufacturer's product data (can be machine readable) and is computer accessible, program algorithms can assist architects in this decision-making process, comparing constraints of performance against price or compatibility.

What this may mean for building product manufacturers is that the tried and tested method of calling on an architect for lunch and learn may soon disappear. The ability to appeal to an algorithm in an application much like marketers must do with Google, will be critical to their products being in the final specification.

It also has the potential to allow performance-based manufacturers to compete on their strengths (span, u-value, fire properties), ultimately preventing them from becoming a commoditized offering. If product suppliers can learn to understand these generative design algorithms and how to appeal to them, they can design their product characteristics to be unique or superior. With performance metrics that others cannot match, and it may be feasible for them to be specified without having the specifier use the dreaded 'or equivalent' as it simply may not be possible.

While it is unlikely that machines will replace designers or specifiers in the future, there is no doubt that application algorithms will be assisting them in both the office and the field.

Virtual & Augmented Reality

Although Augmented Reality might be considered a sibling of Virtual Reality, they are both having a dramatic impact on the construction sector. Trimble for example with their Microsoft HoloLens hardhat is one such tool that allows you to position the 3D building model in the site and explore it spatially, correctly integrated with the space and site. Manufacturers are also embracing three-dimensional representations of their products, from interactive details in PDF, to the expression of a product in virtual space, or in situ in order to explain how it suits a context to a client/user.



FIGURE 18 TRIMBLE MIXED REALITY VIEW OF A BUILDING OVERLAID WITH MODEL INFORMATION SOURCE [31]

In many cases, the technology is being used to educate site crews about the buildup and installation of complex systems. More commonly defined as Remote Assistance, when it pertains to the efficiency of a current construction site, it primarily assists the problem-solving capabilities of the crew to address change orders and or clashes that appear on site. Remote AR by Scope AR, Chalk by Vuforia and XMReality are all application-specific market contenders for allowing manufacturers or any member of the project team to interact with someone on site in a far more immersive way.

In the case of XMReality, it allows you to call to someone and explain to them a complex task by simply superimposing your hand into their field of view, drawing on each other's views, or using pointers onto their screen. Both AR and VR technology trends are driving a more technologically connected construction site as well as tools for exploring and modeling the finished build before breaking ground. The adoption rate has been somewhat slow, likely due to cost, interoperability issues for data and software platforms, and the lack of connectivity on remote sites. Contractors like WinVic in the UK have recently launched a new Centre for Innovative Construction (CIC), which combines a 'BIM cave' with a 125in screen for 3D model viewing, an interactive meeting room allowing real-time design changes on an 86in smart screen, and a training space.

"The 2,000 sq. ft CIC allows Winvic staff, consultants and suppliers to interact with design models and undertake a range of activities from clash detection and dimensional design checks to spatial awareness assessment and data asset information retrieval." [32]



FIGURE 19 JEREMY WILLIAMS, LIDL GB'S PROJECT LEAD, EXPERIENCES WINVIC'S BIM CAVE SOURCE [32]

Furthermore, manufacturers like Kingspan are starting to create 3D versions of their detail sets, across multiple output file types. In the case below, a site manager is viewing a 3d detail set in their hotel, before heading to the site for a morning meeting. In many cases the tools are being used to get to the solution and /or explain the issue quicker.

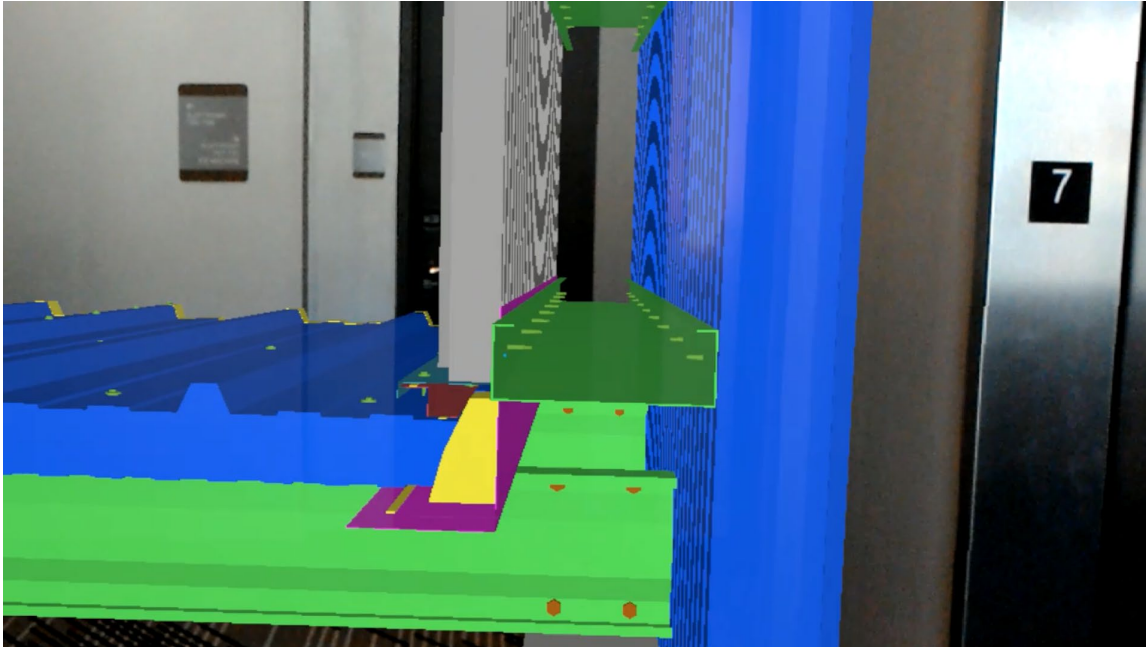


FIGURE 20 KINGSPAN PRODUCT VIEWED THROUGH HOLOLENS FOR CONSTRUCTION DETAIL AND COORDINATION IN A HOTEL LOBBY BEFORE GOING TO SITE SOURCE [12]

Laser Scanning Drones & 3d Capture

Laser scanning, drones and 3d capture while all independent of each other are becoming efficiency tools for site applications. Both Leica and Matterport are leaders in this field. Matterport is commonly used by realtors/estate agents to create walkthrough experiences for the purchase of a property. It has the facility to upload the model to Google street view so you will soon be able to explore the internal configuration of a building, navigating your way to the final position on a floor inside the building. The application lends itself perfectly for route planning. However, the technology is more adept at capturing the varying stages of a build and then used as a reference for future, identifying wiring hidden in walls, pipe routes or even structural elements. All represented in an accessible miniature digital view of the building more commonly referred to as a dolls house for ease of use.

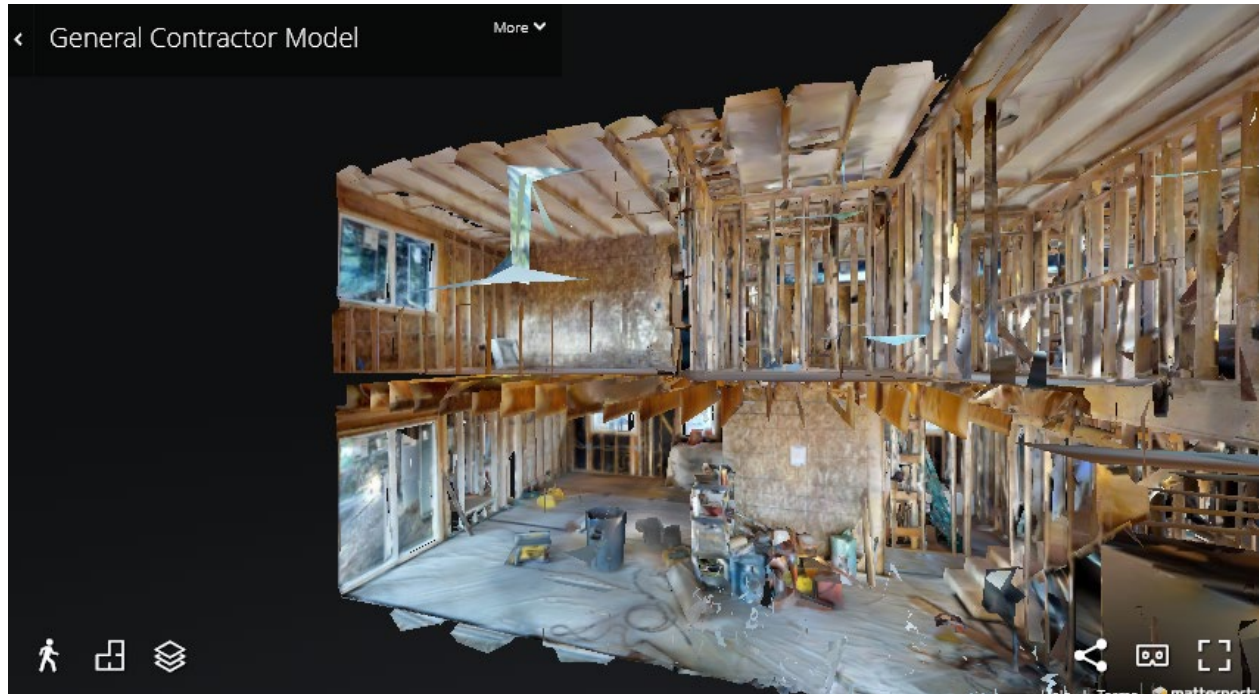


FIGURE 21 DOLLS HOUSE REPRESENTATION OF A CONSTRUCTION SITE, CAPTURED BY A MATTERPORT DEVICE SOURCE [33]

The ease of capture of point cloud information through the same technology allows for cross referencing of the virtual models and physical asset under construction. Coupling this with the functionality of the photographic recording / documenting of building areas by drones means that nearly all areas of a building can be captured, producing highly rich models.

These technologies are starting to be widely adopted even in smaller firms, as ‘Modern survey technology is more accessible than ever because costs have come down substantially. Lidar and real-time kinematic GPS are now available for about \$10,000. High-resolution cameras are small and light enough to be mounted on standard industrial drones; this is faster and cheaper than using helicopter-mounted cameras for aerial surveys.’ [1]

The benefits of capture technology also drive the adoption and output as part of the project deliverable of a Digital Twin. These future digital twins will be the link between the virtual and physical asset which can be used as a future reference for a building. Its map, repository of information, control mechanism and much more

BIM: Building Information modelling - The process for change

‘BIM is essentially value creating collaboration through the entire lifecycle of an asset, underpinned by the creation, collation and exchange of shared 3D models and intelligent, structured data’ – UK BIM Task Group [9]

Digital Twins could be the ‘nucleus of change’ for the Digital Built Environment if they are positioned as a focal point and required deliverable for all projects in the future. BIM or Building Information Modelling could then be considered the process of change as it is slowly becoming an industry framework for delivery and is being adopted by various governments around the world.



FIGURE 22 GLOBAL BIM REGULATION EVOLUTION SOURCE [35]

Since then the BIM is metamorphosing the construction industry. The world around is taking the technology hand on to get easy on the construction site. With urbanization taking new height every day and everywhere, and smart cities gaining momentum, countries around the world have now started paying more attention to its adoption. Adoption of BIM can make a country rich on the infrastructure side, making it set an example to others. [35]

The process of creating a “digital twin” involves the generation of digital representation of building projects to assist in both development and management at all stages in the built and operation of the final asset. While most would consider the process to be solely around design that is not the case, original CAD packages focused on geometry while the evolution of these platforms is now starting to value the information associated with the geometry. It is why the ‘I’ for information in BIM is positioned at the center and that most of the models are 80% data 20% geometric information. It was Robert Aish who, ‘published a paper in 1986 and documented the word ‘Building Modelling’ which became ‘Building Information Modelling’ or BIM that we now know today in a paper “Automation in Construction” published by G.A. Van Nederveen and F. Tolman in December 1992’. [35]

As in figure 21, adoption around the world has continued at different rates, but there are clear indicators that it is a recognized solution to some of the sector's problems. Essentially modern-day BIM Execution Plan (BEP's)? are about the management of information within a given project across all the stakeholders to minimize mistakes, miscommunication and to ultimately ensure that the occupant or building owner is not just given a box of mismanaged rolls of files and drawings at handover, but a searchable repository that can be utilized to manage and run their asset efficiently.

BIM is based in technology, evolving from CAD packages; it also has its complexities with file sharing, file types, formats etc. This is a topic, and there are many organizations around the world trying to find ways to solve this problem, the common term is that of increased interoperability. Ironically that is somewhat counter to the proprietary nature of the software companies as they do want to have some protection and IP around their offerings.

Digital Twins

“So we are looking at how to put the project data at the center of the process...and all the tools that use it at the perimeter. This is the inverse of what we have now where applications are at the center”

Phil Bernstein , FAIA, RIBA, LEAD AP,

The term Digital Twin has been around for a long time, although some would argue that no exact definition of the principle exists as it is frequently changing. Having visited Digital Construction Week in London, there were no fewer than seven distinct variations of what a digital twin is. The digital twin is the crucial and fundamental element in the Digital Build Environment (DBE). As a digital representation of its physical partner, it acts not only as an interpreter into the digital world but enables profound effects on business and society.

The Gemini Principles define a digital twin as “a realistic digital representation of assets, processes or systems in the built or natural environment”. [9] Developed by the Centre for Digital built Britain the principles set out a framework to guide towards the development of a national Digital Twin for the UK and the management of information that will need to be in place to deliver it.

Arup Associates defines the digital twin as a combination of a computational model and a real-world system, designed to monitor, control and optimize its functionality. Through data and feedback, both simulated and real, a digital twin can develop capacities for autonomy and to learn from and reason about its environment. [10]

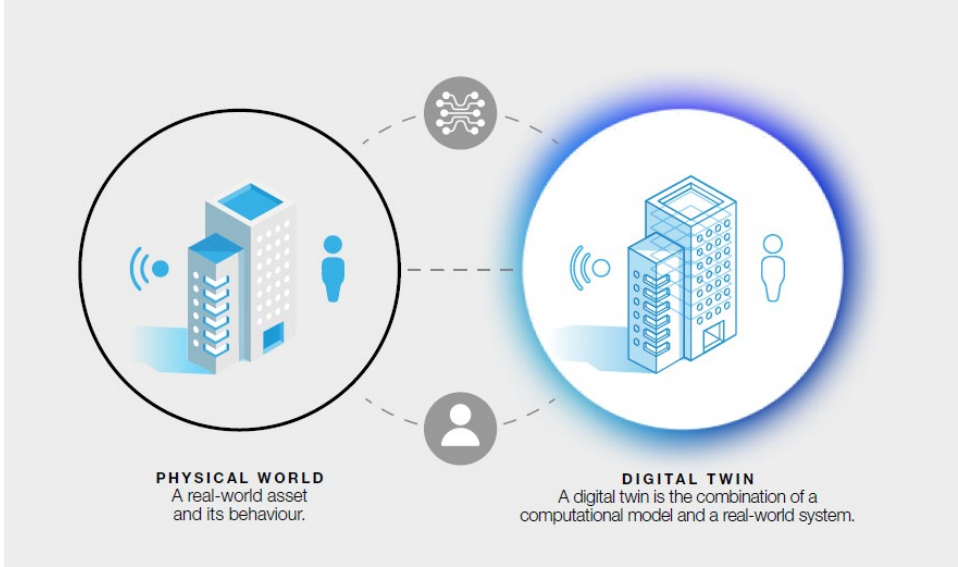


FIGURE 23 DIGITAL TWIN: ARUP SOURCE [13]

“A digital twin, as a means to link digital models and simulations with real-world data, creates new possibilities for improved creativity, competitive advantage and human-centered design. Digital twins can help deliver on the grand challenges facing society, including achieving the United Nations’ Sustainable Development Goals and addressing rapid urbanization, population growth, and escalating infrastructure costs.” [10]

Essentially, it is a digital representation of a real-world entity - an engine, a bridge, a rail network, even an entire city - aimed at making the curation of that entity safer, more efficient, and more resilient to change. The user interacts with the digital twin through applied intelligence while the digital thread connects the physical and digital worlds. In my opinion, the best definition is “An up to date digital representation of a physical space, object, or system with operational awareness” [11]

While its commonly thought to be developed in 2002, digital twin technology itself has been a concept practiced since the 1960s. NASA would use basic twinning ideas during this period for space programming. They did this by creating physically duplicated systems at ground level to match the systems in space. An example is when NASA developed a digital twin to assess and simulate conditions on board Apollo 13. [12]

A more mass-market twin would be the engines on a commercial airliner. While travelers are midflight, back in the engineering rooms at GE and Rolls Royce, they can visually look at the digital replica of any jet engine and examine it. In a way, the concept of Fitbit or the Apple watch tracking your performance and metrics is a first step towards the digital twin of an individual.

Autodesk leads in the field when it comes to Digital Twins for the built environment with their Project Dasher research, where live building data is presented in a visual format in the 3d model (dasher360.com). So rather than looking at graphs of temperature change, the viewer can see this represented as a colour change in the room in question. The user can also filter the information in the twin, much like a map to explore various elements/layers.

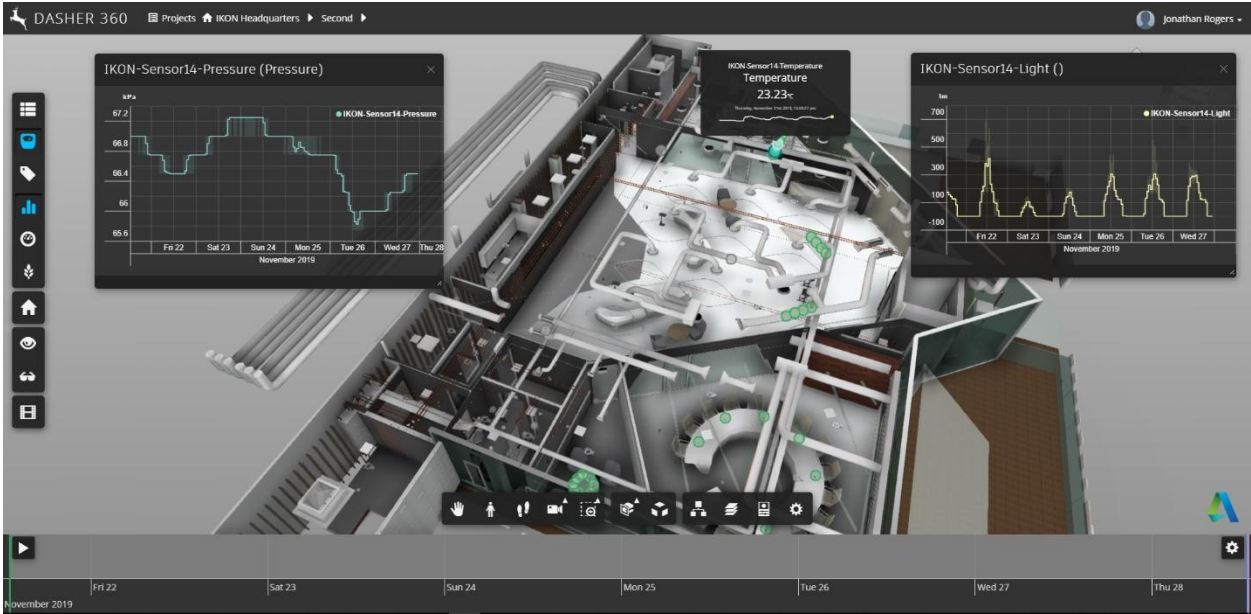


FIGURE 24 DASHER PROJECT VIEW OF IKON BUILDING BY KINGSPAN SOURCE [14]

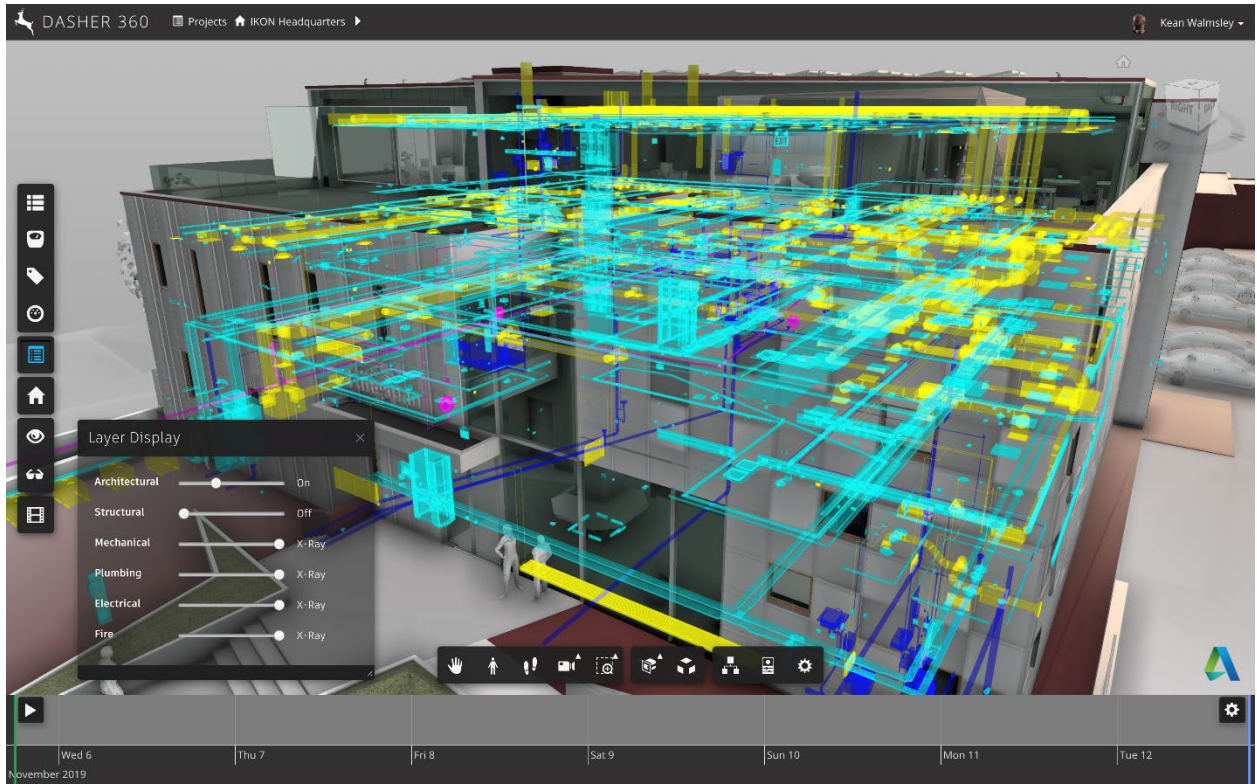


FIGURE 25 DASHER PROJECT VIEW OF IKON BUILDING HVAC ISOLATED SOURCE [14]



FIGURE 26 DASHER SKELETAL REPRESENTATION AT IKON

There are currently two leading buildings in this field, the NEST building in Switzerland and the IKON building by Kingspan in Ireland, both projects have been completed in collaboration with Autodesk. They are leading the way in terms of digital twin advancement and research.

The Digital Twin has the potential to be the *'nucleus of change'* for the construction industry as owners will likely want it as a desired requisite as part of the overall physical asset delivery. Couple the models

with sensor feeds, and analytical tools for post occupancy analysis and building control and you move into a more performance-based selling environment for manufacturers and designers.

Since 2016, Level 2 BIM is a requirement for all Government buildings in the UK. It involves the creation and management of digital assets in compliance with the PAS 1192-2 suite of documents by the British Standards Institution. [13] Other regions are following suit and there is some hope that there will be a global adoption of a BIM standard in the near future.

Therefore, it is highly likely that Digital Twins will become the norm for project delivery. If buildings in the future have a properly delivered Digital Twin, that can be dropped into mapping functions like what Google offers with Googlemaps then it can be used by a far wider audience than that of the facility manager and will become a far more generic tool in the industry.

However, we are still a long way from an industry landscape populated by reasoning models, machine consciousness, and full autonomy. As digital twins evolve, they will control more and more operations, increasing autonomy, intelligence, learning, and fidelity, providing value against a backdrop of minimal human intervention. [10]

All actors in the delivery of a project must start to realize the potential a digital twin can bring, for savings, efficiency, productiveness and most importantly traceability. If the Digital Twin can be positioned at the center, the nucleus, it has the power to provide profound changes to the sector.

While there are many companies promoting the use of Digital Twins, there is one company that is particularly advanced in their thinking and their strategy which is Invicara. They see it as a tool, rather than merely a project deliverable. Ultimately the adoption of Digital Twins in the industry will rely on several factors, reliable data and increased computing power, to create a browser based twin tool.

Architectural Practices

The changing role of architecture practices, from designers to technologists and innovators

In most industries today, roles and functions are in flux due to the changing technology at play, and this is no different for architectural practices. Phil Bernstein points to the changes that architects face having, “gone from hand drafting drawings to writing code for parametric design and artificial intelligence and that means that the role of a typical architect has to be redefined” [40]

This change is very evident as architectural practices start to develop new exploratory research functions around the technology that will slowly integrate into future buildings, both from design right through to

operation. Architects have always been advisors on materials and their uses, codes, and bringing it all together into a finished design. However, now they must embrace the changing landscape in order to maintain this authoritative position on buildings, their design and function. Otherwise, they forfeit their crucial connection to the owner and developer as trusted advisors.

Some leaders and disruptors in this field are WZMH Architects of Toronto, who have won awards for the development of their Intelligent Structural Panel and have “recently been recruited into Microsoft’s global Internet of Things (IoT) Insiders Labs; a program aimed at 'transforming how people, devices, and data interact in every sphere of life.’” The “firm’s Intelligent Structural Panel (ISP) offers a 'plug and play infrastructure' allowing a wide range of spaces and devices to be adapted, remotely-controlled, and optimized” [41]



FIGURE 27 WZMH ISP IN DEVELOPMENT SOURCE [42]

Perkins + Will, another architectural firm, are also exploring how robotic fabrication will affect the building site and how architects design. Having recently met one of their team at the Autodesk Technology Centre in Boston, it was evident that they appreciated that they too must understand how machines will play a role in the future of the digital built environment and what that would mean for the architect. “They utilized a new construction workflow, in which a digital parametric model is communicated directly to a robot fabricator. The robot, equipped with suction grippers, drills, saws, and nail guns, can manipulate generic 2x4 lumber into complex geometries with industrial precision. This workflow could drastically improve the sustainability, quality, cost, and time of construction.” [42]

Kieran Timberlake’s architectural practice seems to have their sights set on understanding buildings, their spaces and its occupants, even spinning out a new entity “Pointelist”, in which they have developed a ‘high density sensor network that you configure to collect data on spaces and places’ [44]

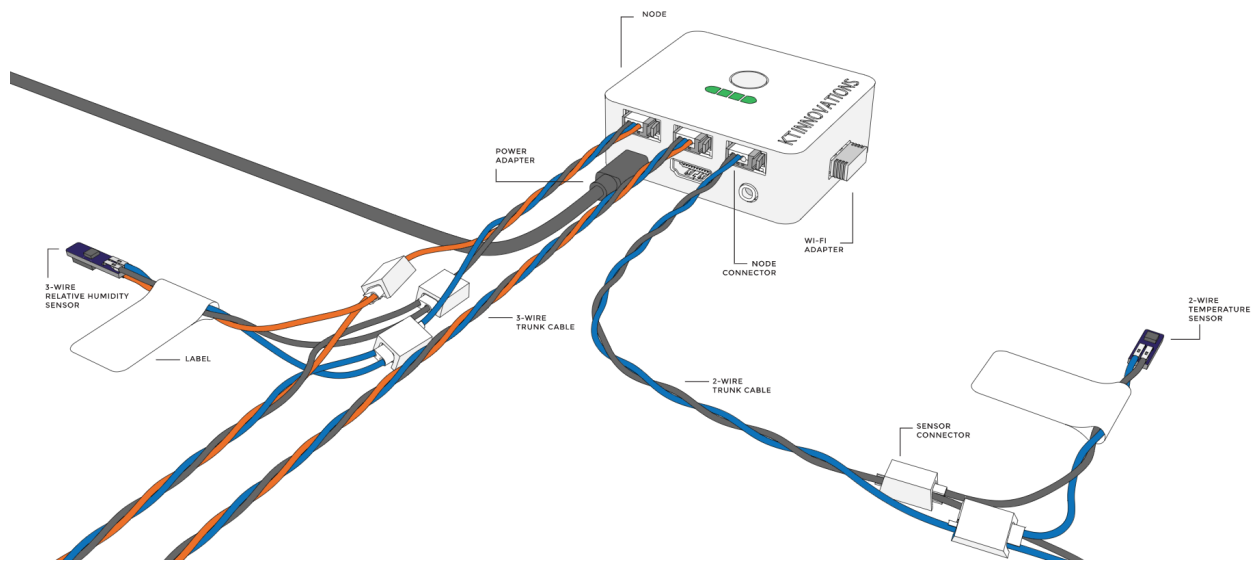


FIGURE 28 POINTELIST SENSOR RIG SOURCE [44]

While some of the big ten architectural firms like Gensler and Arup have entire research groups dedicated to these explorations, it is interesting to see the smaller firms position themselves in the technology space, as there is no question that digital is here to stay. Those who don't embrace it and all its facets for each of the project stages may not be around to participate in its wide scale adoption in the industry.

Data

“Starting to build large collections of data that can be accessible, if you think about what happened with the internet, it was constructed out of lots of information that was not standardized it was simply accessible. So, if lots of stuff becomes findable and there are platforms like BIM, then you have an organizing principle which are these models and information pipelines, and when information becomes fungible the relationship between all these players can change.” (Interview: Phil Bernstein)

Like most industries, data is power and the better that data can be managed, filtered, sorted, transferred and accessed means better information, efficiency and decision making. Data in the construction industry has long been a problem, mainly due to the inability of manufacturers to align themselves with terminology and the varying country, regional, and local standards and codes that come into effect on a project.

If we start where the information is likely most relevant, that of the manufacturers; then for some future platform to exist, manufacturers must gain control of their data. Currently, there are varying methods they can use to distribute their data to the industry; data/specification sheets, PDF's, BIM Models, brochures, third party files sharing hosting sites, like BIMObject, BIMStore, National Building Specification

in the UK (NBS) Nevertheless, in all these cases, there is no real link back to the manufacturer through any application (API) or other. Therefore, the data cannot be truly claimed to always be correct or up to date. One of the first industry reports to call manufactures out on this issue was the UK BIM Alliance (now the UK Chapter of BuildingSMART International) To shed light on the current state, through straight-forward and everyday language communication they produced a much-needed report named “ A fresh way forward for product data: State of the nation” [46]

The report summarized some of the critical problems around product data concerning the UK client/contractor and manufacturer perspective. However, at the international level, there has been minimal effort to try and get engagement on the topics of product data and or digital supply chains. The work in the European Union likely the most progressive at present.

McKinsey’s report ‘Strength in unity: The promise of global standards in healthcare’ discusses how digital supply chains employed by the most progressive industries such as retail have already set out the steps to derive the most value from IT. How? By using standardized information management processes to streamline the relationships between devices, products, locations and customers, and by using shared information resources, information modelling, smart analytics and by adopting automation. In short – the industries with the highest maturity of their digital supply chains have utilized standardization of information management at a global scale.” [47]

The topic of data and standards in the construction sector is extensive and far too complex to go into depth for this report but in summary, there needs to be a defined structure for data in the industry in order to drive towards interoperability and the ability for machines to assist in the process. Data is an enabler to make informed decisions, but unstructured non regulated data does the opposite. It inhibits communication, impairs transparency and prevents traceability. That is why data is meaningless unless there is a standard to support or align it too.

Standards

Like most industries, there are standards, designations, markings that make the consumer or user aware of information related to the item. They are also the basis of communication networks, protocols to assist in information transfer. They are ultimately essential in the construction for products to work together smoothly and for people to communicate easily while facilitating global trade.

Formats like MPEG or JPEG enable users to share video and photos with family and friends using technology from different vendors. In a standard-less world, routine activities we take for granted, like marking a call or surfing the web, or using a credit card would be far more complicated and, in some ways, impossible.

Standards have been in existence for many years, perhaps at one point considered as being the lowest common denominator, restrictive and of little importance. This, however, has changed, today standards are recognized as being essential to helping companies be innovative, reduce costs and improve quality.

An important enabler for the Digital Build Environment (DBE) is interoperability. Data and information must be exchanged smoothly and seamlessly with all parties involved. Today, however, the DBE is

characterized by an abundance of different international and national standards and specifications, classifications such as COBie or Omniclass as well as company-specific characteristics.

In various committees and working groups, experts from product manufacturers and authorities are working on harmonizing product data for the DBE. The first step in this direction is the ISO standard 12006. [48]

Its most relevant item is the Global Unique Identifier (GUID). As a language-neutral element, this GUID ensures on the one hand side the same worldwide understanding of a specific product characteristic (i.e. thickness), and on the other side the assignment of this characteristic to a specific product group.

Another, if not even more important aspect is the possibility to track each product during its whole planning, construction and operation life cycle. GS1, a non-for-profit organization and “owner” of the EAN barcode is proposing the sGTIN (serial Global Trade Item Number) as a perfect tracking indicator for each specific product. With this serial number, each product can be easily tracked throughout its entire life cycle.

“The definition of uniform, consistent and repeatable processes that would allow for access to accurate and trustworthy data across the industry is only possible when the actors responsible for this data participate in the process of mutual agreement which is standardisation.” (*Digital Supply Chains in the Built Environment – (DSCiBE) User Group*)

Overview

The previous examples demonstrate the value and importance to supporting digital tools to enable the philosophy of a digitized building industry and more importantly the use of digital twins. Companies that are leveraging these technologies are becoming more recognized as changemakers and leaders in their field.

4.0 Industry Disruptors/Leaders and their benefits

In most industries it is the disruptor and or lead users that start to define and or drive the change that is required. Their importance cannot be underestimated. They are also a source of valuable insights for innovators and entrepreneur trying to create future solutions.

It is now universally recognized that the construction sector is under extreme pressure to embrace change to try and overcome its shortcomings; this has been detailed in many of the global industry reports from McKinsey Productivity Sciences Centre, the Singapore report on Imagining construction's digital future (LINK) to Roland Bergers Turning point for the construction industry.

The disruptive impact of Building Information Modeling (BIM) or the World Economic Forums report on Shaping the Future of Construction [2]. All the reports have mentioned the pressure to find both productivity, efficiency, innovation and the potential savings in doing so.

'This slow pace of innovation matters, because of the great scope and scale of engineering and construction. The industry accounts for about 6% of global GDP and is growing. In parts of the developing world, such as India, it can account for more than 8% of GDP. E&C is the largest consumer of raw materials and other resources, using about 50% of global steel production and more than 3 billion tonnes of raw materials. Any improvement in productivity and successful adoption of modern innovative processes will have a major impact. For example, a 1% rise in productivity worldwide could save \$100 billion a year. [2]

Where there are gaps for innovation and the potential for profit in solving the industry's problems, brings many players to the table offering digital assist solution. The CB insights report 'Building Blocks: 100+ Startups Transforming The Construction Industry' breaks down the entrants into understandable categories. [49]

Some from the list have recently been purchased by industry heavyweights, like the Autodesk purchase of PlanGrid in November 2018 for \$875 million. [50]

PlanGrid started in 2011 with a simple mission: to make construction paperless. One of the foundational problems of construction is that there is this massive disconnect between the people who design buildings and structures and the people who build them, even though design is the front end of every construction project in the world," says Tracy Young, PlanGrids CEO. [50]

Last year saw more than '\$735M in disclosed funding across 95+ deals' [49] to construction tech companies. Start-ups in the space are attacking the industry across diverse areas ranging from field management to equipment and materials marketplaces. Construction has seen a surge in the applications of mobile and cloud technologies, AI and robotics, AR/VR, and CAD software. [49]

Several startups can be defined as industry disruptors as they are addressing significant problems head on as well as heavily marketing that fact, in order to try and build a potential platform for the construction sector and examining how these businesses have tackled the issues is key, as their success can no doubt be replicated across the broader audience.

Katerra: Collapsing the delivery model

Katerra was founded in 2015 and defined itself as a technology company. The company's CEO Michael Marks, former CEO and Chairman of Flextronics, has set about taking manufacturing excellence into the construction space. The business strategy is to leverage technology across several key areas, to create modularized solutions for the various industry segments, commercial, industrial retail and residential.

They are acquiring firms like Michael Green Architects from Vancouver in 2018 [51], for vertical integration and because the firm specializes in Cross Laminate Timber buildings (CLT), which is seen as a solution to modularization of the industry.

They are also starting to develop their range of windows and KOVA; its range of interior products, in order to control the quality but also the delivery. Couple this vertical integration with the addition of custom software programs like Apollo*

Apollo – This is Katerra's software vision. Apollo is an operating platform with applications delivering persistent data so teams can better execute timely decisions as well as increasingly automate tasks. This software provides a source of persistent data with zero loss from program inception, across design, construction, and the duration of the building's life. [52]

They are leveraging a digitally enabled supply chain to tackle the productivity problems in the industry as well as delivery issues by eliminating the multiple stakeholders that exist in the current system. A recent second significant investment from Softbank of \$700M in addition to the previous \$865 million has likely reassured CEO Michael Marks and the broader industry that there is undoubtedly potential for Katerra to be a major player in the near future. "The Softbank deal would pull Katerra's total equity capital past \$2 billion and may make it one of SoftBank Vision Fund's biggest bets in the U.S., behind WeWork and Uber," [53]



FIGURE 29 KATERRA VISION SOURCE [54]

The Katterra Model

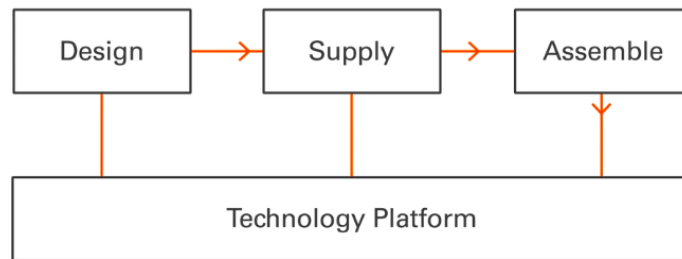


FIGURE 30 THE KATERRA MODEL SOURCE [55]

Invicara: The Future of Digital Twins

Invicara is a recent entrant to the construction sector appearing in 2013. However, they have a wealth of knowledge on their board from CEO Anand Mecheri who has previous experience with Siemens Building Technologies and DATS India [56] focusing on technology integration in buildings and IP based solutions for integrated security management. Couple that with John Lynch whose 'Previous experiences include roles as vice president of product development and chief technology officer at Autodesk, and senior vice president of portfolio development at Bentley Systems, [57] and it is likely that they have a vision/strategy that will be integrated into the future of the industry.

Core to their offering is the Invicara platform, a schema less solution that focuses on "allowing building information to be aggregated from multiple, diverse sources and managed. The ability to build relationships between those data sets brings unprecedented context and insights into building performance and business processes" [58] Primarily focused on the delivery of rich information models for long term Digital Twins, they have developed a five-stage strategy for Digital Twin maturity that has promise to be an industry norm, provided their target customer, the owner, starts to mandate BIM on their projects.

DIGITAL TRANSFORMATION

- 05** **A Platform for Continuous Improvement:** Automate existing and new processes involving asset, operations or performance data for a building or an entire portfolio. Continually optimize building performance and real estate business operations.
- 04** **Performance Twin:** Asset Twin integrated with Maintenance Management, Building Automation and IoT systems to join data across adjacent processes, to generate Business Intelligence and insights.
- 03** **Asset Twin:** Asset information management processes and system implemented to bring together building graphics, data, documents, to create a unified and living Asset Information Model.
- 02** **Project Twin:** Model data management processes and system implemented to get data relating to building elements to drive design optimisation and sustainability.
- 01** **Digital Twin Strategy:** Business outcomes clearly defined with well-structured owner information requirements for the full building lifecycle: design, construction, commissioning, and operations.

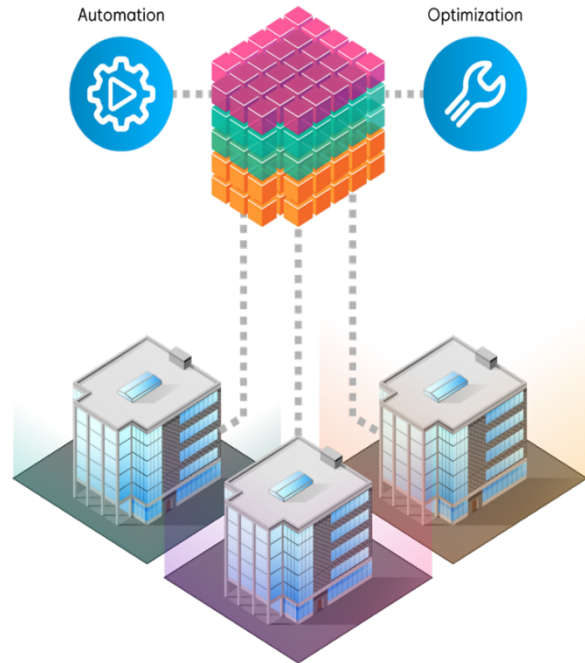


FIGURE 31 SLIDE FROM PRESENTATION AT DCW IN OCTOBER 2019 SOURCE [16]

CoBuilder: Solving the industries Code and Standards Complexity

Cobuilder is a Norwegian based software company founded in 1997. It specializes in creating PDT's (product data templates) based on industry standards to enable collaboration and translation of this information into various regions and languages. It is heavily integrated with the multiple standards bodies that exist in the industry. It is driving for the BuildingSmart data dictionary (bSDD) [59] to be utilized to try and solve the industries data problem.

“In a nutshell, the BuildingSMART Data Dictionary is a library of 'everything' to do with construction. It allows users to identify objects in the built environment and their specific properties. The dictionary works as a semantic mapping tool that connects like-terms based upon their meaning as it pertains to construction. By way of example, whether we call a door a 'door' or a 'doorset' the tool understands that these words are both connected to the same core concept - 'a hinged, sliding, or revolving barrier at the entrance to a building, room, or vehicle, or in the framework of a cupboard.' It is these kinds of connections that give the bSDD its ability to translate. The dictionary does this by separating the words (in any language) from their meaning by identifying the concepts that the words represent.

[60]'

CEN/TC 442 and ISO/TC 59 - BUILDING INFORMATION MODELLING



FIGURE 32 SLIDE FROM COBUILDER COMPANY PRESENTATION SOURCE [17]

Cobuilders goal is to take product information and leverage schemas and translation tools to develop GUID's (Global Unique Identifiers) for each product so that they can move from PDF based digitized information to accurate machine-readable information. An essential step in leveraging Generative Design for product and material selection in the process.

CADENAS: The MultiCad approach

One of the major issues, as identified by the UKBIM Alliance, was the fact that manufacturers/suppliers to the built environment require more control of their product data. This was again also mentioned in the Hackett report. Where complications arise is the management of data. Most organizations utilize file sharing sites, like BIMObject or BIMStore and while they are probably the most logical choice now, there are issues. All these 3rd party sites are file hosting sites. Meaning that the provider of the data/file, sends it to the 3rd to host. Each provider must choose what file type to host, for example, .dwg, .rvt etc. This leads to complications with data management, file versions and ultimately, where the files are being used.

Figure 35 demonstrates the current issue, no real connection to the data, little management and the data and geometry are intermingled, ultimately meaning that a supplier must maintain and manage potentially thousands of files based on the variants of their products and their attributes or performance characteristics.

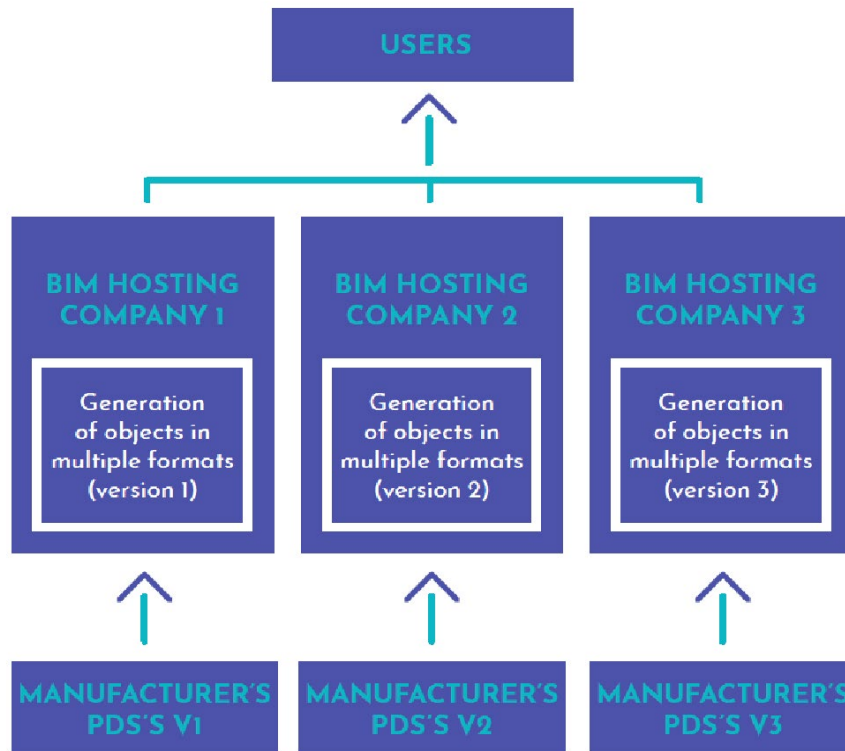


FIGURE 33 THE CURRENT SITUATION WITH BIM HOSTING SITES SOURCE [18]

Figure 36 identifies the proposed solution, which fundamentally starts with a connected and managed repository of information from the supplier/manufacturer. On the next level the data has been split from the geometry, thus allowing the geometry to be distributed in multiple CAD types/software without the need for the manufacturer to maintain file versions in each format. This is achieved by a technology called MultiCad and more specifically, a provider in question CADENAS.

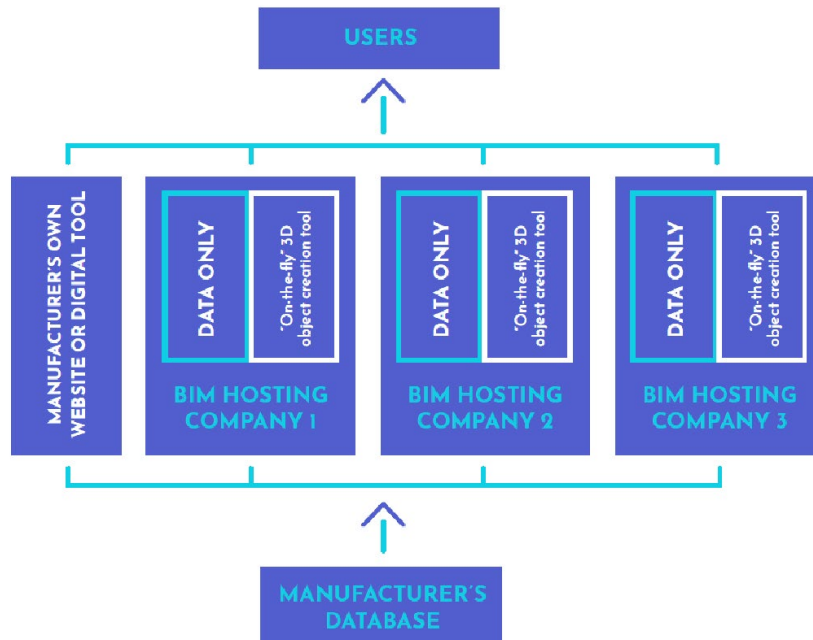


FIGURE 34 PROPOSED SOLUTION TO HOST BIM DATA SOURCE [18]

CADENAS is a Germany company founded in which has been developing CAD software to take this new approach to the current market problem. They do not specifically focus on the data but more so the manipulation of the geometry. Meaning that the user does not download a specific file, but a piece of script/code that generates the product on the fly natively in the users' preferential software. Currently, they are the leader in BIM download globally, facilitating over 38million per month to a global customer base.

The next step is to leverage the technology so geometric search can be used in order to identify a bolt from a picture or a chair from a hand sketch. They are currently testing this solution in a beta launch on 3dfind.it where anyone can play with the software by sketching something freehand, taking a picture or uploading a cad file where the system with search the web and find items matching that geometry with varying digress of percentile accuracy.

WeWork: Reinventing Coworking & Real Estate through Generative Design

WeWork is an American real estate company that provides shared workspaces, and although it is currently marred in some controversy around senior executives and has recently cut 20% of its workforce due to poor performance and a failed stock market debut. [61] However, it cannot be argued that their rise and growth is rather impressive. It was founded in 2010 and as of 2018, manages over 4 million square meters. [62]

However, apart from trying to revolutionize the shared office/coworking space, they are developing their own set of tools for maximizing efficiency in the fit out and design of interior spaces, while trying to link the space and its functions to its users. Andrew Heumann and Gui Talarico discussed how WeWork is utilizing these internal tools for these purposes in their talk at AEC Tech Symposium 2018. Covering their platform Genome and how it benefits the company by allowing designers to use standard based design principles and layouts to create faster fits out of office spaces. Enabling the workforce by sharing real time information through the organization is key to the speed of their growth.



FIGURE 35 SCREEN GRAB FROM WEWORK YOUTUBE PRESENTATION SOURCE [63]

Progressive Governments: Estonian Government

The issues related to efficiency in the construction industry are not exclusive of governments; municipal and regional departments, like planning or building inspections can also start to look towards platforms for improving the efficiency of processing requests, and planning approvals.

A thought leader on this issues is the Estonian Ministry of Economic Affairs and Communications, Jaan Saar recently spoke at the CitA BIM Gathering 2019 in Galway Ireland. [19]

where he outlined how the Ministry was pursuing a solution to reflect how digitized the country already was. [20]The Ministry recognized that as a stakeholder in all projects, they are also a critical factor in delivery efficiency, and could improve the process, through a simple way of processing applications quicker. Their e-Construction platform is their solution, and it is a way to exchange standardized and trustworthy data between all stakeholders throughout the building lifecycle. [19] Essentially it is like iOS from Apple; a core set of foundational elements that will enable other stakeholders to create applications to service their needs. Core to their solution is Xroad the same system that runs their e-Government solution. It is essentially an integration platform.

This technology enables connection to a distributed network of databases and registries and to exchange information between them securely, including solutions like Blockchain. They have all the pieces in place from their e-Government solution; therefore, it is highly likely that in connecting the built environment data. Ironically, they mention the Digital Twin as the key aspect of the platform. “In one way the digital twin is already existing, but it is fragmented, spread around different systems.”

Summary

If we examine all the industry disruptors and leaders in their relevant fields, there are some conclusions to be drawn. Firstly, all are leveraging data, the weather is be CoBuilder who derives value from moving data into different schemas or WeWork who leverage it to outfit offices more efficiently. Data is at the core of all the businesses. The in all cases, we are looking at technology, while Invicara, CoBuilder and CADENAS are technology companies, both Katerra and WeWorks success can be attributed to utilizing technology to gain advantage in their respective markets. This is also comparable to the Estonian Government who are reinventing interaction for their citizens with the Government using technology.

Disruptor/Leader	Cobuilder	Invicara	Cadenas	WeWork	Katerra	Estonian Government
Industry/Service	Standards Management	Digital Twin Platform	MultiCAD Software	Real Estate	Manufacturing & Construction	Policy & Services
Core to Solution	Data Management	Data Management	Geometry Management	Leveraging Data for Design	Integrated Technology	Managing Citizens Data
Offers	Efficiency	Efficiency	Efficiency	Efficiency	Efficiency	Efficiency
Relies on	Own Technology	Own Technology	Own Technology	Own Technology	Own Technology	Own Technology
Required	Structured Data	Structured Data	Structured Data	Structured Data	Structured Data	Structured Data

FIGURE 36 SUMMARY OF LEADERS/DISRUPTORS

5.0 A potential Solution?

In order to build up a potential solution we must recap the issues identified in the report as well as the requirements for the future, the tools, innovations and solutions the disruptions are offering to the market. If we address the broader issue, inefficient, siloed data, lack of interoperability, multiple standards across regions, software incompatibility and models lacking information we can see that the solution has many issues to address.

The graphic in figure 39 is a framework of how a solution might be achieved, it is in no way exhaustive and there are likely key considerations around integration and APIs the base level elements are there.

Technology Building Blocks

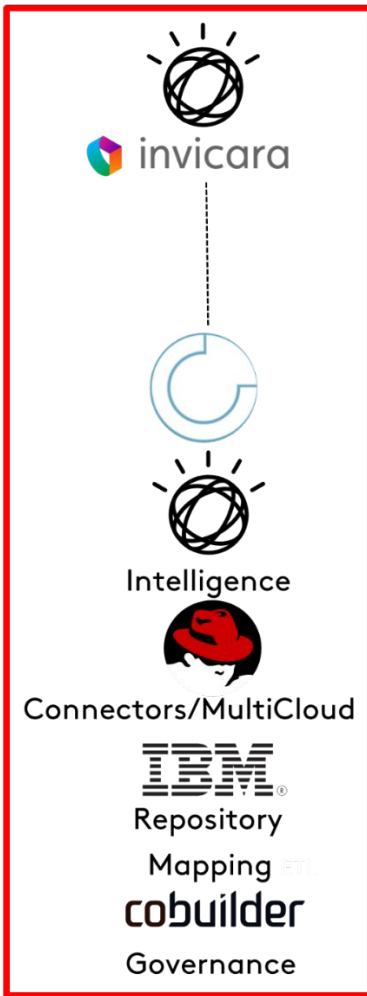


FIGURE 37 TECHNOLOGY STACK FOR INDUSTRY PLATFORM

LAYER 1

On the very first layer, everything revolves around mapping, standards, regulation and governance, so based on the Estonian Governmental Data Base solution we would need a multi cloud variant for the various markets; however it must be managed by a governance technology like CoBuilder, which means that in order to change an attribute there must be a consensus and agreement on the definition. This will require an approvals process and sign off amongst the participating standards, products and governmental organizations with approval hierarchy. The CoBuilder solution would be the master cog for the management of the data bases ensuring compliance and mapping. Basically, the foundation of the system.

LAYER 2

If we start from the bottom up, with data. The core data for a building is primarily the components, their geometry and performance characteristics. In order to provide clarity to the stakeholder group, we must first recognize that manufacturers of building products are one of the core data providers to the industry alongside, standards bodies. Therefore, we must develop a searchable database of product data from all entities. This specifically requires manufacturers to populate common structure PIMs (Product Information Management) with their data in order to properly manage it as well as allowing for API connectivity for future functions. There are various choices of PIM providers, the example in Figure 39 utilizes the option of a solution from IBM that might sit on a Mongo Database.

In populating the data, the manufacturers must adopt industry schemas and follow a global regulatory solution like ISO for addressing these shortcomings. Once the data has been populated to the desired schema then filters and search functionality can be provided to the broader stakeholder group to analyse their content and compare and contrast products.

LAYER 3

In Layer 3 it simply proposes that some sort of multi cloud solution is adopted to ensure there is connectivity between the data bases that exist.

LAYER 4

Sitting on top of the data bases is some sort of AI functionality, the Watson symbol is utilized in Fig 39, but there are other variants that could be utilized. It is critical that some form of AI is leveraged in the stack. Mainly because it will be imperative that rudimentary comparison and recommendation be obtained in the future to make the decision and selection process easier for the end user.

LAYER 5

Once the data has been searched and filters applied in order to address selection criteria, it must now be provided in multiple formats for use. There is simply no point and it is highly inefficient for data providers to have multiple output types, datasheets, 2D cad, or 3D formats. There must be a way to manipulate the core data and provide it to the industry platform. This solution does exist in multcad providers like Cadenas.

The dotted line in figure 39 indicates the standard process that might exist in the delivery of a building, whether it be Revit or Tekla or PlanGrid there will be various technology utilized in coming the products/components and ultimately finalizing the design. Provided the information is taken from the platform it should be able to service most industry tools

LAYER 6

In layer 6, the data must be utilized to start the process of creating the initial project model to asset model to digital twin. This is where an industry agreement needs to be adopted that models should serve as tools to build the project but also as a method to supply manufacturers data back to them in the form of the api which would allow model data to be connected to ERP systems for a model to manufacture methodology. The culmination of a Digital Twin as an output will ensure that all the relevant data on the project is captured for future use specifically related to transparency and traceability. This will ensure that better information is provided by suppliers in order to deliver better Digital Twins. Lastly it is important that there is some sort of AI that sits with the final Digital Twin to ensure efficient operation of the asset as well as allowing stakeholders to interrogate the model for educating themselves on future developments or key decisions.

There also needs to be feedback loop from the functioning twins in order to educate manufacturers on the performance of their product and location for traceability as well as information for the building occupants. It would be extremely beneficial if the final models at least some levels of data could be made available for the general public to understand. What is a good building in their minds, energy-efficient, carbon neutral? Public pressure for choosing buildings and using buildings based on these criteria will ensure better buildings in the future.

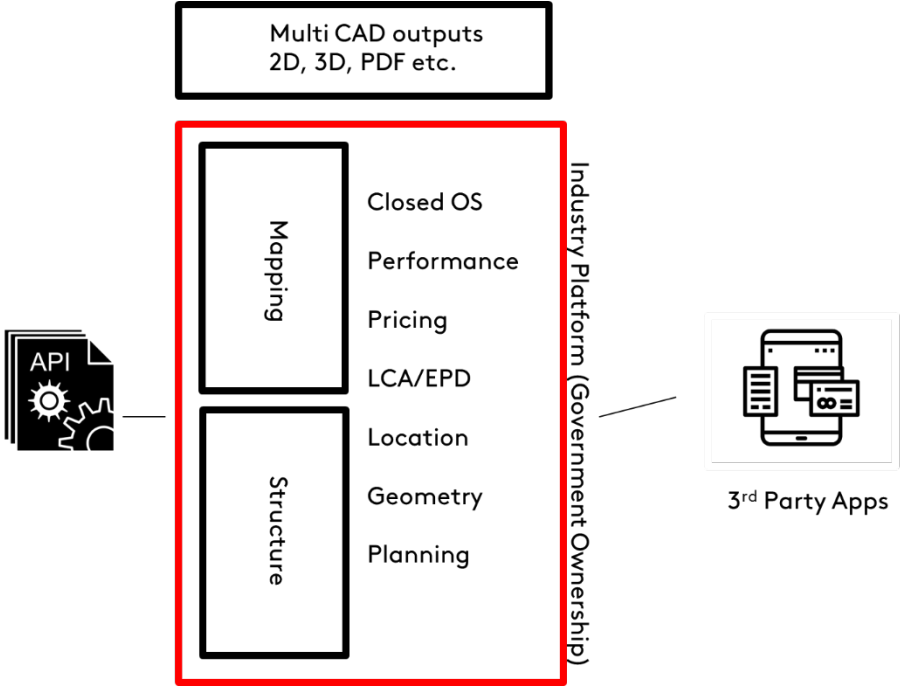


FIGURE 38 PLATFORM FUNCTIONALITY

The Base Platform

In Figure 40 it outlines the core functionality of the base platform. It would likely be a closed OS like that of iOS to ensure control of the functionality. This would have the key mapping and structure. On the left would be the API link in order for the key stakeholders to provide their information from their individual data bases or PIMs. On the right, it demonstrates the opportunity to allow 3rd party development applications to access the base data to develop specific tools/ requirements.

A specific example of a 3rd party application from an insurance provider might be a highly interactive data manipulation tool that allows architects/designers to assess the fire characteristic of a selection of products and understand how their selection would impact the final insurance costs on the building.

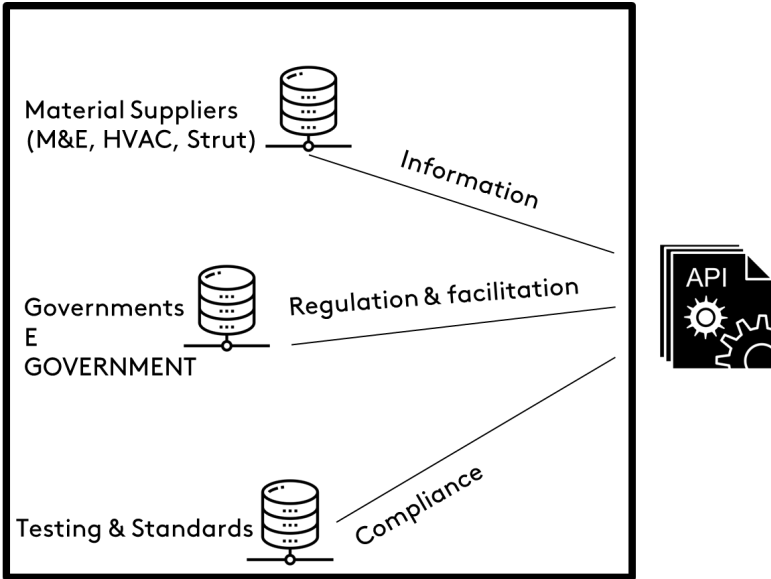


FIGURE 39 KEY INFORMATION PROVIDERS

Figure 41 outlines some of the key information providers to the platform.

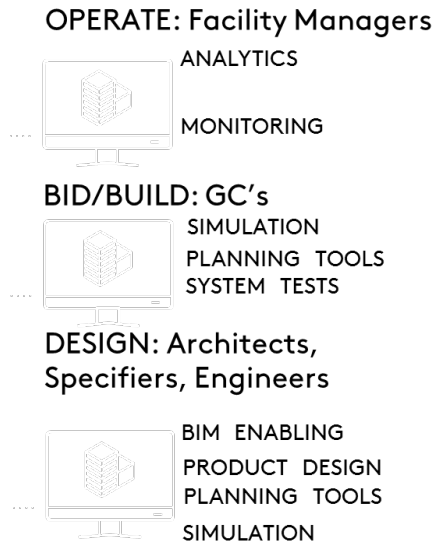


FIGURE 40 DESIGN BUILD OPERATE STAKEHOLDERS

Figure 42 shows the main providers in the delivery of a building. On the design side the architects and the tools they would utilize. In the construct/build process the General Contractors and their tools and lastly in Operation the Facility Managers.

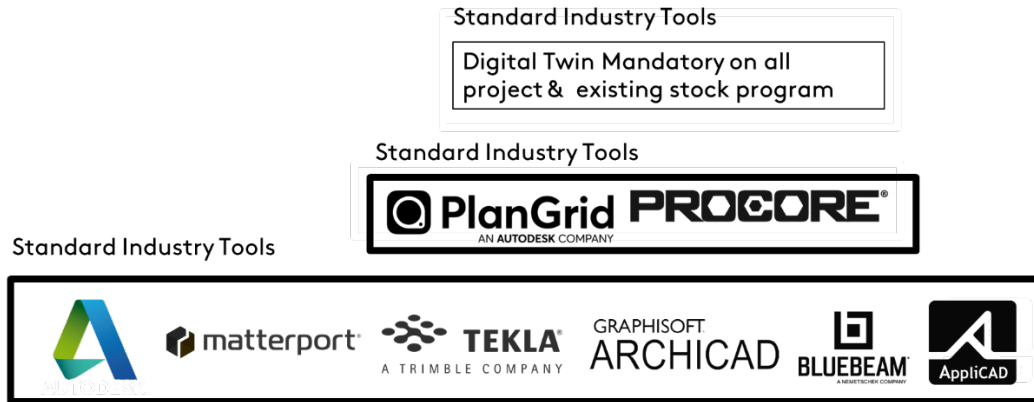


FIGURE 41 STANDARD INDUSTRY TOOLS

Figure 43 demonstrates some of the industry tools that are used by each of the delivery providers.

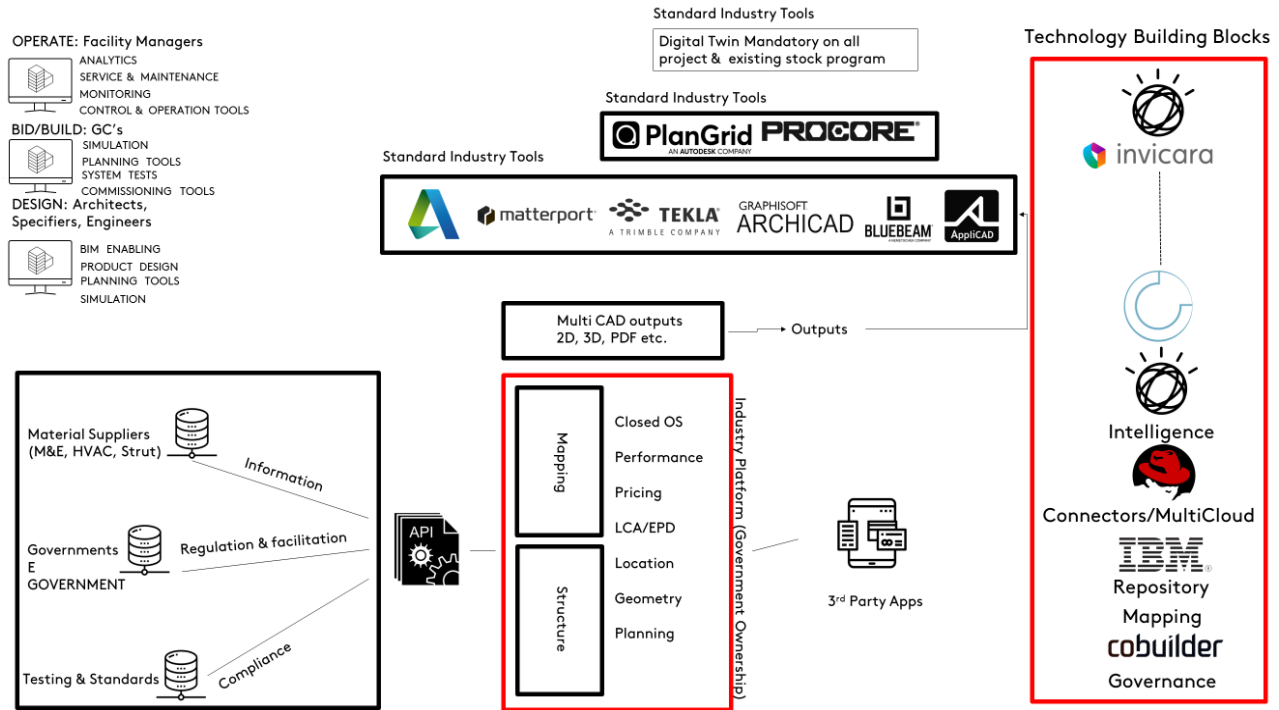


FIGURE 42 PLATFORM OVERVIEW

6.0 Conclusion

It has been demonstrated that there is enough technology in the current construction ecosystem to potentially create a platform of change from the pieces required that offer individual solutions to the problems at hand. However, the complexity arises when you consider who should own such a platform; government or private sector, and how should it be managed? There is massive importance to all in society for both people and planet on how we maintain a stable and sustainable built environment for the future. It might just be one of the planets greatest assets.

There are many actors who might benefit from this research, governments, large scale technology providers and in some cases simply building product manufacturers and occupants. While it will take considerable investment to launch a potential industry platform. It is not inconceivable that it might be the next Uber or Airbnb if it was approached correctly.

There is no denying that on the software/technology front both Autodesk with their recently launched Construction Cloud [64] and ProCore with their construction management technology are two well positioned players to embark on a potential offering. Although they have solutions that cater to the design/build/project management side, they all cannot obtain a trustworthy and connected source of data from manufacturers.

Therefore, the most logical candidates for the base levels of a new platform would be the component manufacturers as they make up all the materials that are in a building. Orchestrating them to work together to develop something is likely impossible as it is against their nature to share product data with competitors and each will see it as a threat to their distribution/customer connection. Therefore a 3rd party approach is more likely suited

It is worth mentioning that like all large technology platforms, data must be considered as the foremost priority, specifically in relation to users/occupants as buildings become smarter and connected. There would be merit in assessing the notion of a potential “data trust” in relation to the built environment, that would also work along with standards, data formats etc. which would ensure integrated interoperability.

Only a major player like Amazon, Google, Microsoft or more aligned IBM might have the potential financial power to build or vertically integrate the tech components of a solution and the onboarding of data from material supplier. Furthermore, from the Pace Layer diagram, infrastructure sits right beside governance. Perhaps if policy is put in place to put product suppliers at the center, then technology could exist to feed the chain from the base layer data. Ultimately bringing construction product manufactures to the table earlier on all projects. With Data being the core principle for the platform it is likely that Blockchain technology should be utilized.

Principles on Why a Platform is Required

- Unless there is some dramatic change in the construction sector, small efficiency gains will be achieved in silos. Where to truly impact change, we must look at the problem globally.
- The change can happen in several ways but logically it relies on the data providers which are generally the product manufacturers. Therefore, they are the crucial stakeholder to get aligned first.
- Then when this base layer data is aligned products to standards, it can be orchestrated to feed the platform.
- Mapping the data is key for operating in different jurisdictions and governance protocols
- Interoperable formats for the technological design tools should be mandated
- Once this is completed the current delivery process can be used
- Lastly, the culmination of the data/delivery should be in the form of a mandated Digital Twin.

Further Research

There are plenty of further research opportunities that relate to this major research project (MRP) that could be investigated. The further opportunities might be around

- validating the efficiency gains and understanding the potential impact a platform might have from a financial perspective.
- Examining the best standard to take forward as a potential global offering
- Conducting further exploratory primary research by interviewing key stakeholders on how the solution might benefit them
- Correlating the impact of the proposed solution on occupants and relevant future business models where a city/building is truly digitized
- Finally starting to ask the bigger questions. What if a building could function like a tree? Grow its own foundation, support life, be more organic

And lastly exploring how when buildings are fully digitized will our perception of value and love for them change, perhaps with Digital Twins giving them a voice will finally allow us to interact.

“I have always believed, manufacturers play a vital role in digitalization of the Built Environment.....In a way, manufacturers are an asset owner, sourcing raw materials, producing products which form part of assemblies, buildings, infrastructure and form a foundation of a future digital twin. Manufacturers play a vital role in the creation of information models with clear, concise, structured and relevant product data, all allowing for customers (being it an architect, investor, contractor, merchant, builder or even DIY) to make an informed investment decision.” Paul Surin, IBM

Bibliography

- [1] McKinsey&Company, Rajat Agarwal, Shankar Chandrasekaran, Mukund Sridhar, "Imagining construction's digital future," McKinsey&Company, 2016.
- [2] WEF, "Shaping the Future of Construction A Breakthrough in Mindset and Technology," World Economic Forum , Geneva, 2016.
- [3] Larry Keeley 10 Types of InnovationSingularity U South Africa Summit, "YouTube," Singularity University Summits, 2017. [Online]. Available: <https://www.youtube.com/watch?v=GvROINjLbrA>. [Accessed 12 November 2019].
- [4] Futurism, "Youtube," [Online]. Available: https://www.youtube.com/watch?v=laqACVY1U_k. [Accessed 4 December 2019].
- [5] T. Mok, "blogto.com," BlogTo, [Online]. Available: <https://www.blogto.com/city/2019/02/gardiner-repair-cost/>. [Accessed 30 November 2019].
- [6] O. B. WAXMAN, "<https://time.com/4700084/elevator-patent-history-otis-safety/>," Time Magazine , March 2017. [Online]. Available: <https://time.com/4700084/elevator-patent-history-otis-safety/>. [Accessed 12 November 2019].
- [7] B1M, "You Tube," 27 March 2019. [Online]. Available: <https://www.youtube.com/watch?v=IVTkDp-qR8s>. [Accessed 20 November 2019].
- [8] B. Scudamore, "The Truth About Smartphone Addiction, And How To Beat It," Forbes, 30 October 2018. [Online]. Available: (<https://www.forbes.com/sites/brianscudamore/2018/10/30/the-truth-about-smartphone-addiction-and-how-to-beat-it/#7a3054f24232>). [Accessed 10 November 2019].
- [9] M. Kanellos, "Western Digital Blog," Western Digital, 2 November 2015. [Online]. Available: <https://blog.westerndigital.com/9-interesting-stats-on-the-growth-of-data-centers/>. [Accessed 25 November 2019].
- [10] Wikipedia, "wikipedia.org," Wikipedia, 2019. [Online]. Available: https://en.wikipedia.org/wiki/Heating,_ventilation,_and_air_conditioning. [Accessed 17 November 2019].
- [11] Wikipedia, "Wikipedia - Sick Building Syndrome," Wikipedia, 26 November 2019. [Online]. Available: https://en.wikipedia.org/wiki/Sick_building_syndrome. [Accessed 28 November 2019].

- [12] S. Brand, "NoahBrier.com," 21 August 2018. [Online]. Available: <https://www.noahbrier.com/archives/2018/08/framework-of-the-day-pace-layers/>. [Accessed 11 November 2019].
- [13] Y. N. Harari, 21 Lessons for the 21st Century, New York: Spiegel & Grau, 2018.
- [14] K. Mays, "cars.com - Which Cars Have Self-Driving Features for 2019?," 22 May 2019. [Online]. Available: <https://www.cars.com/articles/which-cars-have-self-driving-features-for-2019-402645/>. [Accessed 8 November 2019].
- [15] K. Shaver, "www.washingtonpost.com - City planners eye self-driving vehicles to correct mistakes of the 20th-century auto," www.washingtonpost.com, 20 July 2019. [Online]. Available: <https://www.washingtonpost.com/transportation/2019/07/20/city-planners-eye-self-driving-vehicles-correct-mistakes-th-century-auto/>. [Accessed 4 November 2019].
- [16] U. D. o. E. N. I. o. B. Sciences, "A Common Definition for," The National Institute of Building Sciences, 2015.
- [17] CBC News, "CBC," Canadian Broadcasting Corporation, 4 October 2013. [Online]. Available: <https://www.cbc.ca/news/technology/cheap-spray-on-solar-cells-developed-by-canadian-researchers-1.1913086>. [Accessed 21 November 2019].
- [18] Gocontractor, "GoContractor," 21 June 2017. [Online]. Available: <https://gocontractor.com/blog/how-does-construction-impact-the-environment/>. [Accessed 30 November 2019].
- [19] R. UofT, "Rotman," 5 February 2019. [Online]. Available: <https://www.rotman.utoronto.ca/Connect/MediaCentre/NewsReleases/20190205>. [Accessed 30 November 2019].
- [20] R. B. School, "RotmanBDC," 10 February 2019. [Online]. Available: <https://www.rotmanbdc.com/rotman-design-challenge#challenge>. [Accessed 18 March 2019].
- [21] Parsons New School , "Newschool," Newschool , March 2019. [Online]. Available: <https://blogs.newschooledu/news/2019/03/parsons-team-wins-10000-rotman-design-challenge-in-toronto/>. [Accessed 20 June 2019].
- [22] A. Frearson, "Dezeen," Dezeen, 31 October 2012. [Online]. Available: <https://www.dezeen.com/2012/10/31/worlds-narrowest-house-by-jakub-szczesny/>. [Accessed 3 November 2019].
- [23] Smart House , "Smart House," 2014. [Online]. Available: <http://smarthousetoronto.com/>. [Accessed 26 November 2019].
- [24] D. J. H. D. FREng, "Building a Safer Future," May 2018. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/707785/Building_a_Safer_Future_-_web.pdf. [Accessed 1 November 2019].

- [25] M. Mores, "Michelmores.com," 12 June 2018. [Online]. Available: <https://www.michelmores.com/news-views/news/hackitt-report-overview>. [Accessed 27 November 2019].
- [26] Simply Condo Advice, "Simply Condo Advice," November 2019. [Online]. Available: <https://simplecondoadvice.com/why-millennials-prefer-condos/>. [Accessed 1 December 2019].
- [27] H. Halpin, "The Journal," The Journal , 28 February 2019. [Online]. Available: <https://www.thejournal.ie/european-commission-housing-ireland-report-4516958-Feb2019/>. [Accessed 30 October 2019].
- [28] Autodesk , "Autodesk, Generative Design," 2019. [Online]. Available: <https://www.autodesk.com/solutions/generative-design>. [Accessed 14 November 2019].
- [29] K. Maher, "Graphic Speak - New and commentary for CAD and DCC Professionals," Jon Peddie Research Publication, 11 July 2014. [Online]. Available: <https://gfxspeak.com/2014/07/11/autodesk-acquires-studio/>. [Accessed 30 November 2019].
- [30] Y. MATSUNAKA, "Redshift Daiwa House Industry," Autodesk Redshift , 18 July 2019 . [Online]. Available: <https://www.autodesk.com/redshift/daiwa-house-industry/>. . [Accessed 15 November 2019].
- [31] E. Derra Adolphus, "Snips - Seeing is believing in Trimble XR10 with Microsoft HoloLens 2 technology," SnipsMag, 26 February 2019. [Online]. Available: <https://www.snipsmag.com/articles/93703-seeing-is-believing-for-the-trimble-xr10-with-microsoft-hololens-2-technology>. [Accessed 7 November 2019].
- [32] N. Gerrard, "Construction Manager," Construction Management Magazine, 17 October 2019. [Online]. Available: <http://www.constructionmanagermagazine.com/news/winvic-launches-centre-innovative-construction/>. [Accessed 22 November 2019].
- [33] EvolveBIM, "EvolveBIM," October 2019. [Online]. Available: <https://www.evolvebim.com/3dproperty>. [Accessed 10 November 2019].
- [34] BAMB, "BAMB (Buildings as Material Banks)," 2016. [Online]. Available: <https://www.bamb2020.eu/topics/data-decision/bim/>.
- [35] P. Shimonti, "BIM adoption around the world: how good are we?," geospatialworld, 15 December 2018. [Online]. Available: <https://www.geospatialworld.net/article/bim-adoption-around-the-world-how-good-are-we/>. [Accessed 1 December 2019].
- [36] E. M. S. J. e. a. Bolton A, "'The Gemini Principles: Guiding values for the national digital twin and information management framework'," 2018 Centre for Digital Built Britain, 2018.
- [37] Arup, "Digital Twin Towards a Meaningful Framework," Arup, London, 2019.
- [38] H. Larsen, "Digital Twin," Autodesk, Toronto, 2019.

- [39] C. Miskinis, "Challenge.org," CHALLENGE ADVISORY LLP, March 2019. [Online]. Available: <https://www.challenge.org/insights/digital-twin-history/>. [Accessed 20 November 2019].
- [40] B. S. I. BSI, "bim-level2," BSI, 2016. [Online]. Available: <https://bim-level2.org/>. [Accessed 1st December 2019].
- [41] E. Keegan, "Architect Magazine," 11 January 2018. [Online]. Available: https://www.architectmagazine.com/practice/the-prophet-phil-bernstein-envisions-new-roles-for-architects_o. [Accessed 4 November 2019].
- [42] WZMH Architects, "WZMH & Microsoft in Arch Daily," 17 October 2018. [Online]. Available: <https://www.wzmf.com/news/wzmf-microsoft-in-arch-daily/>. [Accessed 22 October 2019].
- [43] WZMH, "Design Source Guide," 13 August 2018. [Online]. Available: <https://www.designsourceguide.com/2018/08/intelligent-structural-panel/>. [Accessed 30 November 2019].
- [44] Autodesk Technology Centers, "Autodesk," 2019. [Online]. Available: <https://www.autodesk.com/technology-centers/projects/perkins-and-will>. [Accessed 7 November 2019].
- [45] KT Innovations, "Pointelist," 2016. [Online]. Available: <https://www.pointelist.com/#Pointelist>. [Accessed 9 October 2019].
- [46] U. B. Alliance, "A Fresh Way Forward for Product Data - State of the Nation," London, 2018.
- [47] T. Ebel, K. George, E. Larsen, E. Neal, K. Shah and D. Shi, "Strength in Unity: the promise of global standards in healthcare," McKinsey, 2012.
- [48] International Standards Organization, "iso.org," [Online]. Available: <https://www.iso.org/standard/61753.html>.
- [49] CB Insights, "Building Blocks: 100+ Startups Transforming The Construction Industry'," CB Insights, 2018.
- [50] E. pollock, "Autodesk Buys PlanGrid in \$875 Million Deal," Engineering.com, 26 November 2018. [Online]. Available: <https://www.engineering.com/BIM/ArticleID/18046/Autodesk-Buys-PlanGrid-in-875-Million-Deal.aspx>. [Accessed 2 November 2019].
- [51] M. Teo, "Michael Green Acquisition and the Future of Tall Wood Buildings," Azure , 1 June 2018. [Online]. Available: <https://www.azuremagazine.com/article/michael-green-acquisition-katerra/>. [Accessed 1 December 2019].
- [52] Katerra, "PR News Wire," 19 February 2019. [Online]. Available: <https://www.prnewswire.com/news-releases/katerra-introduces-expansive-suite-of-new-products-at-katerra-take-off-300797675.html>. [Accessed 12 November 2019].

- [53] Global Construction Review, "Global Construction Review," 16 January 2019. [Online]. Available: <http://www.globalconstructionreview.com/news/prefab-start-katerra-get-another-700m-softbank/>. [Accessed 25 October 2019].
- [54] Katerra, "Katerra," 2019. [Online]. Available: <https://katerra.com/en/about>. [Accessed 7 October 2019].
- [55] Sumave, "Sumave," [Online]. Available: https://www.sumave.com/20180322_3459/. [Accessed 4 November 2019].
- [56] A. Mercheri, "LinkedIn," 4 November 2019. [Online]. Available: <https://www.linkedin.com/in/anandmecheri/?originalSubdomain=ie>. [Accessed 4 November 2019].
- [57] Invicara, "Invicara," 21 October 2019. [Online]. Available: <https://invicara.com/about/leadership/>. [Accessed 5 November 2019].
- [58] Invicara, "Invicara Platform," [Online]. Available: <https://invicara.com/technology/invicara-platform/>. [Accessed 5 November 2019].
- [59] "The National Building Specification," 10 November 2019. [Online]. Available: <https://www.thenbs.com/knowledge/what-is-the-buildingsmart-data-dictionary>. [Accessed 19 November 2019].
- [60] The NBS, "The NBS Knowledge," NBS, 1 November 2019. [Online]. Available: <https://www.thenbs.com/knowledge/what-is-the-buildingsmart-data-dictionary>. [Accessed 1 December 2019].
- [61] A. Olson, "Canadian Business," The Associated Press, 21 November 2019. [Online]. Available: <https://www.canadianbusiness.com/business-news/wework-cuts-nearly-20-of-workforce-in-restructuring-effort/>. [Accessed 1 December 2019].
- [62] K. Morris and E. Brown, "The Wall Street Journal," 18 September 2018. [Online]. Available: 'WeWork Surpasses JPMorgan as Biggest Occupier of Manhattan Office Space'. [Accessed 4 October 2019].
- [63] WeWork, "YouTube," 3 December 2018. [Online]. Available: https://www.youtube.com/watch?v=Qbdt8kMj2Eo&feature=youtu.be&fbclid=IwAR0pXJ0a8ENDvSq9qs93wdjahH5ldD2WvT_PCLDXVZZgk2FM-gRTUaCfCo. [Accessed 29 November 2019].
- [64] Autodesk, "Construction Cloud," [Online]. Available: <https://construction.autodesk.com/gb/>. [Accessed 2nd December 2019].
- [65] IMF, "imf.org," [Online]. Available: <https://www.imf.org/external/research/housing/>.

