

Industry Agenda

Shaping the Future of Construction

Inspiring innovators redefine the industry

Prepared in collaboration with The Boston Consulting Group

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Forewords

Foreword from the World Economic Forum

In a world confronted with resource shortage, climate change and rapid demographic shifts in emerging and developed countries alike, it is more critical than ever to think about how the built environment can provide a lifestyle that is affordable, sustainable, healthy, peaceful and happy, for as many people as possible. Considering the accelerating urbanization and expansion in the Global South versus the shrinking middle classes in the Global North, and the fact that up to 80% of our ageing building stock will likely still exist in 2030, we need to be aware that the future of the Engineering and Construction sector is not solely about industry-specific issues but also, directly and indirectly, about the future of our built environment, of our communities and, ultimately, of the well-being and happiness of our societies.

While most other industries have undergone tremendous changes over the past few decades, and have reaped the benefits of process, product and service innovations, the construction sector has been hesitant to fully embrace the latest innovation opportunities and its labour productivity has stagnated or even decreased over the past 50 years. This mediocre track record can be attributed to various internal and external challenges: the persistent fragmentation of the industry; inadequate collaboration between the players; the sector's difficulty in adopting and adapting to new technologies; the difficulties in recruiting a talented and future-ready workforce; and insufficient knowledge transfer from project to project, to name a few.

At the World Economic Forum Annual Meeting 2017 in Davos-Klosters, the Governors of the Infrastructure and Urban Development community gave a strong mandate to continue with the Future of Construction initiative to holistically analyse the disruption of the industry through technological change and its implications on business strategy, skills and organizational design, financing and risk allocation. Since 2015, the initiative has successfully served as a platform for Forum Partners to shape the agenda of the construction industry and to find innovative solutions. These insights on innovation will help to accelerate advances in the construction industry and thereby achieve higher productivity, greater sustainability and enhanced affordability. In 2016, the project aimed to identify and describe 10 Lighthouse innovation cases – the basis for the report – to extract the key lessons for business and government. The discussions focused on how to address the construction sector's key challenges in the following fundamental areas:

1. **Project Delivery** – Creating certainty to deliver on time and on budget, and improving the productivity of the construction sector
2. **Lifecycle Performance** – Reducing the lifecycle costs of assets and designing for reuse
3. **Sustainability** – Achieving carbon neutral assets and reducing waste during construction
4. **Affordability** – Creating high-quality, affordable infrastructure and housing
5. **Disaster Resilience** – Making infrastructure and buildings resilient against climate change and natural disasters
6. **Flexibility, Liveability and Well-being** – Creating infrastructure and buildings that improve the well-being of end-users

This report is the direct result of a collaborative process led by the private sector; in particular, foremost engineering and construction, chemicals, building materials, real estate, urban services and technology firms. In this regard, we would like to thank and acknowledge the Forum's Partner companies that served on this initiative's Steering Committee. We also would like to specially acknowledge John Beck for his restless interest and commitment to serve as the Chair of this initiative, as well as his extended team for their exceptional support.

Furthermore, we would like to thank the many experts, in particular the working group leads from academia who contributed to this report through their leadership on the initiative's advisory committee. The experience, perspective and guidance of all these outstanding individuals and their organizations contributed substantially to a number of remarkable discussions during and following the World Economic Forum Annual Meeting 2017.

We hope that through the strategic dialogues led by the Working Groups the construction industry will come closer to becoming an inherently innovative sector, beginning to doing the impossible and redefining the ultimate frontier: its business models, products and services developed constantly requiring continuous innovation and improvement. Key to the industry's success will be that incremental change is not an option. Instead, far-reaching challenges or radical goals needs to be defined that demand leap-frogging or disruptive out-of-the-box solutions and execution. The construction industry needs to adopt a forward-thinking attitude, something which was nicely exemplified by John F. Kennedy in 1962: "We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard."

Michael Max Bühler

Head of Infrastructure and Urban Development Industries

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Foreword from the Co-Chairs

Responsive and Responsible Leadership – the theme of the Annual Meeting 2017 in Davos-Klosters – reminded participants of their responsibility to serve the public good and their constituents. As a provider of infrastructure and built assets, the construction industry is at the heart of the global economy and directly affects the quality of our lives. Several global megatrends will further strengthen the industry's importance. A new wave of cross-border and rural-urban migration, creating the need for affordable housing and social infrastructure, has put construction at the centre of public debate. Considering the recent push to build and upgrade infrastructure in an affordable way in North America and many other regions around the world, the construction industry has to step up by improving its productivity, environmental performance and social impact.

New technologies – such as building information modelling (BIM), 3D printing, wireless sensing and autonomous equipment – offer the potential to transform the construction industry. However, adoption remains low as companies are uncertain about the value proposition of these new technologies and how to implement them in their organizations' strategy.

This report, therefore, addresses the challenge of implementation by describing and analysing 10 Lighthouse innovation cases: prominent flagship projects such as the Burj Khalifa, the world's tallest building, or the most sustainable office building, The Edge, in Amsterdam; and disruptive start-ups and pilot projects, including 3D-printed houses from Chinese company Winsun, design automation start-up Aditazz or Broad Sustainable Building, which applies manufacturing principles to the construction industry. Their stories serve as a source of inspiration and clearly demonstrate that the digital transformation of the industry is already happening. The case studies also show vividly the barriers innovators have to overcome, internally and externally.

The key success factors identified in this report provide valuable guidance for executives on how to accelerate innovation in the construction ecosystem. Using many examples from the case studies, industry leaders can trace all the necessary steps to stimulate innovation and turn ideas into reality for the purpose of succeeding in a market of cross sectoral needs.

Companies need to drive this industry transformation. Yet, governments have to play their part, too: As smart regulator, long-term strategic planner and incubator, and finally as forward-looking project owner, policy-makers need to create an enabling environment that turns urban challenges into business opportunities through the adoption of innovative solutions. Effective public-private collaboration is hence required to remove implementation barriers and successfully address the sector's key challenges from improving project delivery to enhancing the flexibility and liveability of the built environment.

Going beyond this report, in 2017, the Future of Construction project has also successfully fostered cross-industry collaboration and knowledge sharing – an essential precondition for transforming our industry. Bringing together leaders from industry, civil society, academia and government, six working groups have developed and shared solutions to address some of the industry's most pressing challenges. One recurring topic of the discussions – recruiting, retaining and developing young talent – will be key for accelerating innovation and is a high priority for everybody involved in the industry. Therefore, we are delighted that we also managed this year to engage students and young professionals through the project's ideas competition. The submissions not only revealed some fresh ideas for the sector's future but also showed the high interest of young talent to actively shape the industry.

We are convinced that this engagement and the sharing of ideas and leading practices via the knowledge-sharing platform www.futureofconstruction.org is important and will continue beyond the project life. Therefore, we invite you to actively engage in the discussion and share your expertise.

We would like to acknowledge and thank all members of the Steering and Advisory Committees as well as the Working Groups for their extraordinary engagement, contribution and continuous support. In continuing this close collaboration and embracing innovations, we can transform our businesses and our industry to even better serve our clients and the communities we operate in.

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Context and Objectives of the Report

Scope

This full report is the second publication of the multi-year Future of Construction project, guiding and supporting the Engineering and Construction industry in its current (digital) transformation. The first report, *Shaping the Future of Construction – A Breakthrough in Mindset and Technology*, was launched in May 2016. It described the state of the industry, assessed relevant global trends and their impact on the industry, called for action at corporate, industry and government levels and outlined a comprehensive industry-transformation framework with over 30 measures and best practices. A key finding is that many innovations have emerged but have not yet been broadly adopted.

The second report looks at possible remedies, drawing key lessons and policy recommendations from leading innovators and disruptors, with a focus on fostering wider adoption of innovation. By describing how flagship projects have implemented innovations, it showcases the transformative potential of innovations. The case studies on disruptive start-ups and pilot projects not only show what is already possible today but also give a glimpse of the future.

The Future of Construction project builds on the findings of an earlier World Economic Forum project – the four-year Strategic Infrastructure Initiative. That initiative identified and described the government measures needed to close the infrastructure gap – measures involving improved prioritization of projects, enhanced public-private partnership (PPP) models, improved operations and maintenance of existing assets, and better risk mitigation. During the research on that project, it became increasingly evident that important contributions to narrowing the infrastructure gap can also be made from the supply side – the Engineering and Construction industry – in improvements to and innovations in project delivery.

Audience

The report is intended for representatives of all organizations active along the construction value chain, including engineering consultants, architecture practices, contractors and suppliers of building materials, chemicals and construction equipment, as well as project owners and developers. Given the importance of Engineering and Construction as a horizontal industry, the report also has considerable relevance for other Infrastructure and Urban Development sub-sectors, such as real estate and infrastructure investment, and other sectors with large-scale capital projects, including energy, transport and even the manufacturing industry.

Another target audience is governments, as they can be key enablers of innovation, via regulation and public procurement.

Finally, in view of the socio-economic importance of the industry, this report is also aimed at members of academia and civil society. The industry will rely on effective collaboration with all stakeholders for its future success.

Executive Summary

The construction industry plays a central role in society in both emerging and mature economies. It creates jobs, accounts for 6% of global GDP, and builds the industrial and civil infrastructure that enables other businesses to thrive.

In the years ahead, the industry will become even more important because of several global megatrends – migration into urban areas, climate change and a new global push for infrastructure. As a typical source of entry-level jobs for immigrants and as provider of affordable housing, the industry is sure to be at the centre of public debate. And if public budgets tighten further, the industry's cost-effectiveness will come under even sharper scrutiny.

Traditionally, the construction industry has been slow to adopt new technologies and processes and over the past 50 years has undergone no fundamental change. In contrast to almost all other industries, its productivity has hardly increased – or not all, in the case of the United States. Recently, however, new (digital) technologies – such as building information modelling (BIM), wireless sensing, and 3D printing – have begun transforming the way that infrastructure, real estate and other built assets can be designed and constructed. These new technologies have still not been widely adopted, however, and the gap between the innovation leaders and laggards is widening.

This report showcases and analyses 10 Lighthouse innovation cases – prominent flagship projects as well as start-ups and pilot projects – that demonstrate the potential of innovation in construction and give a glimpse of the industry's future. Their stories not only serve as an inspiration but also describe vividly the typical challenges that innovators face, and show how to engage and overcome those challenges.

From these case studies emerge some key success factors and recommendations for companies regarding innovation in the construction ecosystem:

- To *stimulate innovative ideas*, successful companies develop a vision and instil an innovation culture in their workforce; they create talented, multidisciplinary teams that bring in experiences from non-construction industries and devise agile organizations; and they take a customer-centric approach, starting from the asset users' pain points.

- To *turn their innovative ideas into reality*, innovative companies establish product platforms rather than taking a traditional individual-project perspective; they launch pilot projects and prototypes to show proof of value; and they nurture the broader ecosystem of suppliers and other partners – for instance, by forming an alliance of key contractors – to manage supply-side constraints and enable a broader adoption of the innovation.
- To *succeed in the market*, the companies embrace business-model innovation alongside technological innovation; they advocate new ways of contracting, that reward innovation and life-cycle performance, and enable early collaboration; and they work with government to shape the regulatory environment, for instance, for 3D printing in construction.

Although the industry's transformation is and must be driven by the private sector, governments also need to play an important role, by pursuing policies conducive to the adoption of innovation. Three key roles emerge for governments: *smart regulator*; *long-term strategic planner and incubator*; and *forward-looking project owner*.

1. The role of *smart regulator* involves harmonizing and updating building codes, for instance, and developing performance-based and forward-looking standards.
2. The role of *long-term strategic planner and incubator* involves defining a country-level strategic innovation agenda for the industry, investing in flagship projects and research and development, and enabling start-up financing.
3. The role of *forward-looking project owner* involves creating an innovation-friendly owner culture, introducing more flexible procurement and contracting models, and taking a lifecycle perspective to procure innovative solutions that provide the highest total value of ownership and not only contract the lowest cost.

To deal with the broader societal challenges – not only in project delivery and lifecycle performance but also in sustainability, affordability and disaster resilience – and to serve the public good, the construction industry needs to innovate more vigorously. By implementing the success factors and policy recommendations listed, companies and governments will accelerate innovation within the construction ecosystem and achieve higher productivity as well as social and environmental benefits.

Introduction

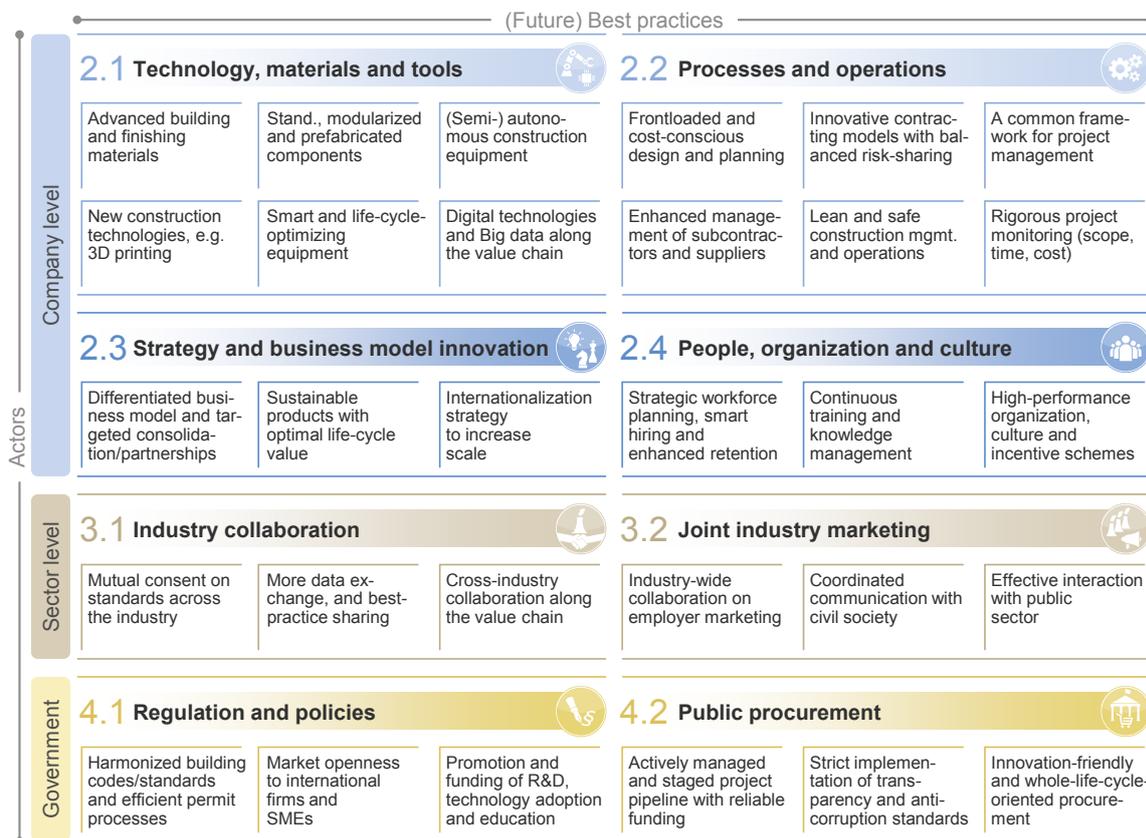
The construction sector is at the core of the global economy. As an industry, construction accounts directly for 6% of global GDP but, more tellingly, the sector serves almost all other industries, as economic value creation tends to occur within or by means of buildings or other built assets. What's more, these built assets – whether roads, hospitals, water and sewage systems or residential housing – profoundly affect the quality of our lives. Unfortunately, the impact of the industry is not solely positive. There are serious concerns: construction is the largest global consumer of raw materials, and the built environment accounts for 25-40% of the world's total carbon emissions.

The role of the construction sector is bound to become even more important owing to various global megatrends. Consider just one development: 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, transport and utility infrastructure. Such trends pose challenges but also offer opportunities; either way, they require an adequate response from companies, the industry as a whole and governments.

Compared to many other industries, the construction industry has traditionally witnessed slow technological progress. It has undergone no major disruptive changes, nor has it widely applied advanced processes such as “lean”. As a result, efficiency gains have been meagre. In the United States, for instance, labour productivity in the construction industry has actually fallen over the past 40 years.

Given the sheer size of the Engineering and Construction industry – generating total annual revenues of almost \$10 trillion globally – even a small improvement would provide substantial benefits for society. To capture such potential, the previous report, *Shaping the Future of Construction – A Breakthrough in Mindset and Technology*, presented an industry transformation framework listing 30 measures, supported by many best practices and case studies of innovative approaches to make a leap forward in industry productivity and innovation. It discussed in detail the actions that companies can take, the collective actions to be taken by the sector as a whole, and what can be done by governments – as regulators and major project owners (Figure 1).

Figure 1: Construction Industry Transformation Framework



Source: The World Economic Forum; The Boston Consulting Group

In describing the numerous new technologies – such as BIM, 3D printing, drones and augmented reality – the report noted, as a key finding, that there is no lack of innovation within the sector. The real challenge for companies is to identify which innovations are relevant for them and, most importantly, how they can integrate these innovations into their existing day-to-day operations and transform their organization and business model. Yet, adoption remains slow and is not broad-based, and the gap is widening between the innovation leaders and laggards.

This new report, accordingly, is concerned with ways of accelerating innovation and aims to identify the success factors for companies to successfully implement innovation. To that end, it analyses two types of Lighthouse innovation cases that demonstrate the potential of innovation in construction and show what the future of the industry might look like. First, prominent large-scale construction projects that have taken a state-of-the-art, innovative approach; and secondly, disruptive start-ups and pilot projects that pioneer new technologies. The two sets are listed in Figure 2.

For the case studies, site visits and in-depth interviews were conducted with the project managers, technical experts and company executives to examine the projects and companies along different dimensions: the underlying challenges to be addressed; the innovative ideas and new approaches; the eventual impact; the barriers to implementing the innovations; and the solutions to overcome those barriers.

By analysing the barriers that the Lighthouse innovation cases encountered, and the lessons learned, it was possible to identify nine key success factors for innovation in the construction ecosystem. These success factors are described in detail in the second section.

While companies can, and must, spearhead the transformation of the industry, governments also have an essential part to play. Policy-makers need to respond to changing demands by devising policies and creating an enabling environment conducive to the adoption of innovation. Various recommendations have emerged in that regard, based on the case studies and on the discussions held with industry leaders and government representatives at the World Economic Forum Annual Meeting in Davos and at the project’s roundtable meetings in New York, London and Hong Kong (see Figure 3). The third section takes a close look at the role government should take, as smart regulator, long-term strategic incubator and investor, and forward-looking project owner.

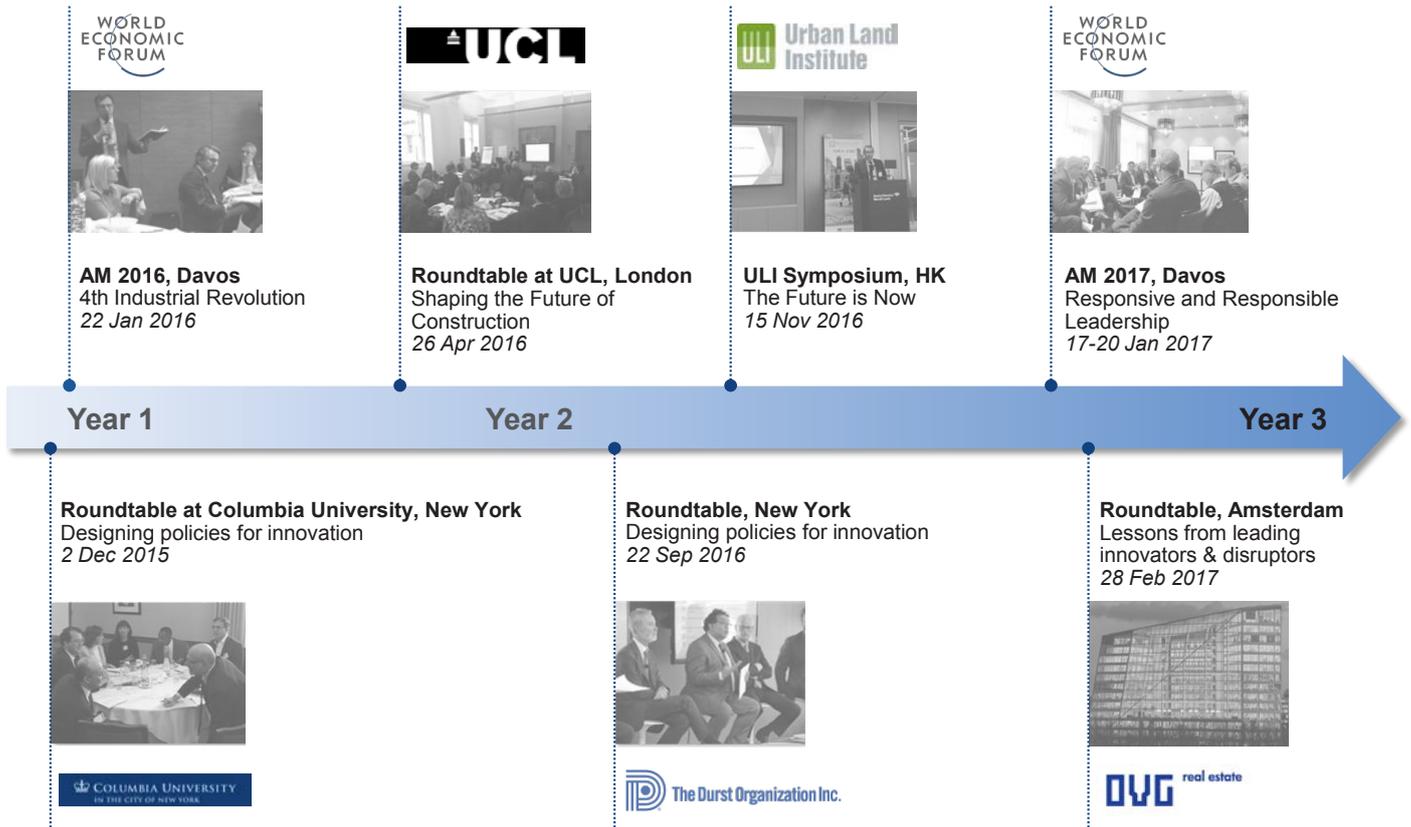
The fourth section describes the case studies in detail. Finally, the fifth section outlines the innovative solutions developed in six Working Groups by industry leaders, discusses fresh ideas for the sector’s future from students and young professionals, and discusses a way forward for the industry.

Figure 2: Overview of the 10 Lighthouse Innovation Cases

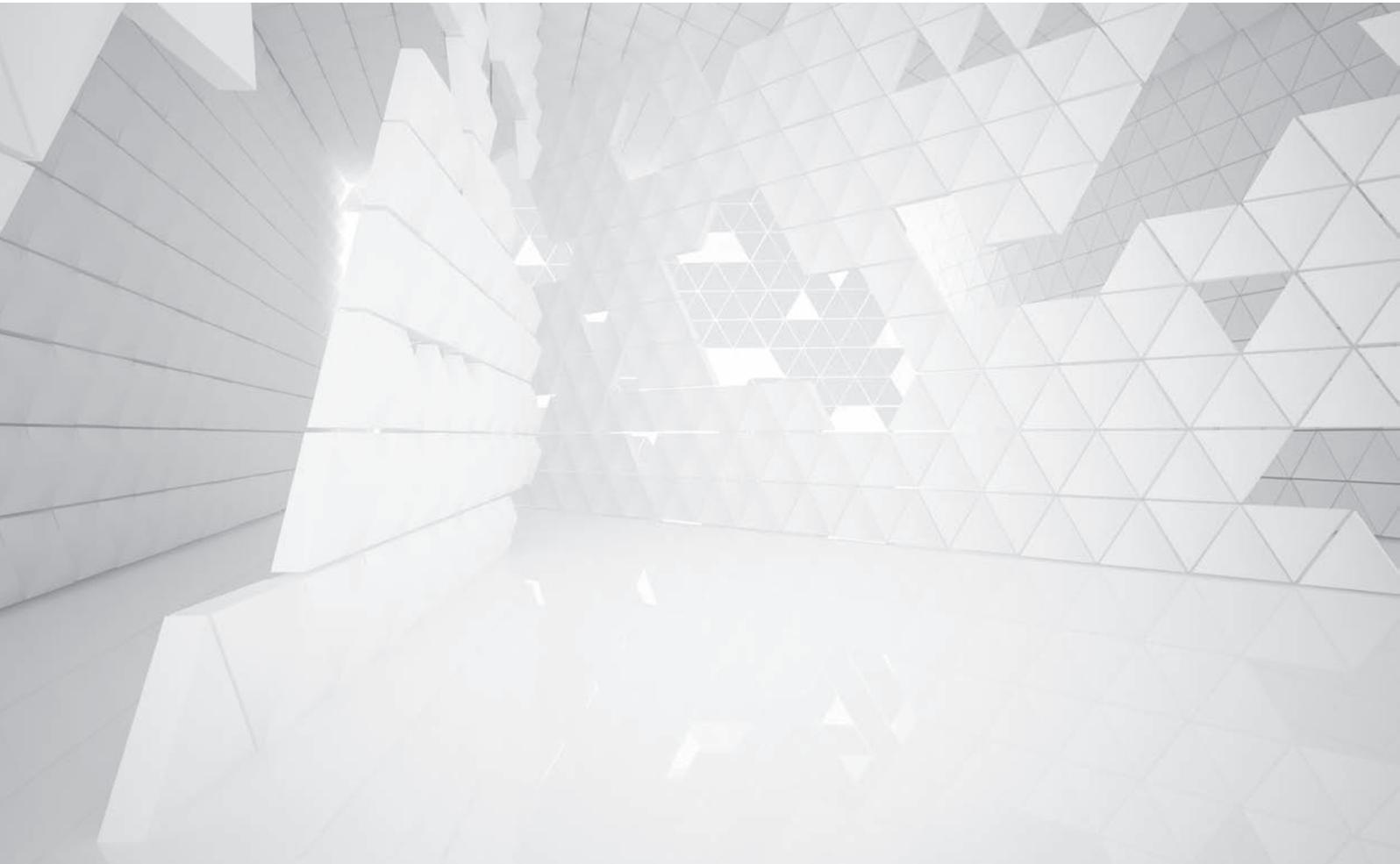


Source: The World Economic Forum; The Boston Consulting Group

Figure 3: Overview of Project-Related Events



Source: The World Economic Forum; The Boston Consulting Group

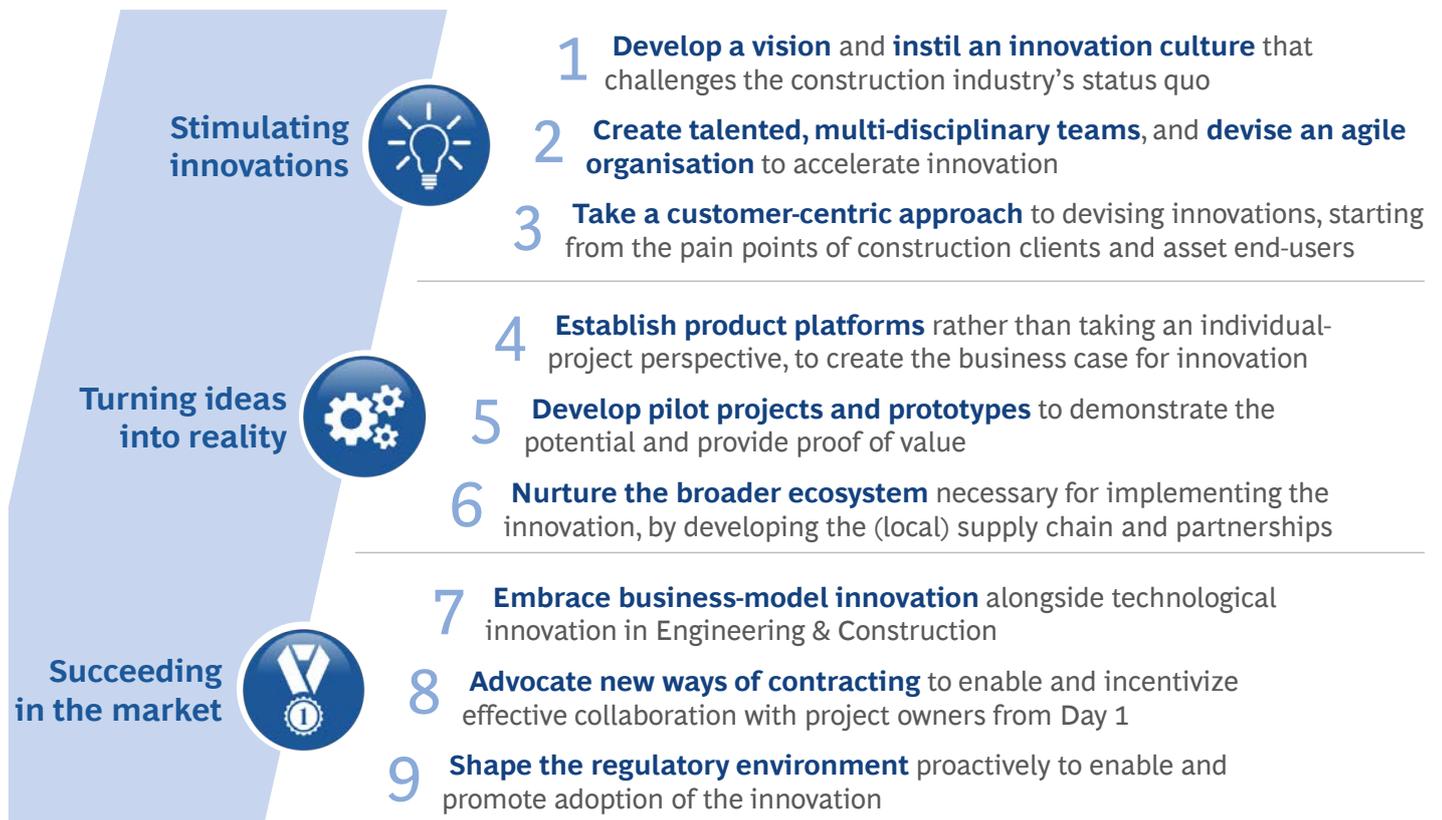


Key Success Factors

The Engineering and Construction industry has been slow to move away from its traditional approach, though new (digital) technologies are generating major changes and offering great potential. The Engineering and Construction industry has been slow to move away from its traditional approach, though new (digital) technologies are generating major changes and offering great potential. Adoption remains slow, however, and is not broad-based; and the gap is widening between the innovation leaders and laggards. What distinguishes the innovation leaders and what can other companies learn from them?

To answer those questions, we analysed 10 prominent Lighthouse innovation cases and identified a set of key success factors for innovation in the construction ecosystem. These factors can be grouped into three main steps – *Stimulating innovations*; *Turning ideas into reality*; and *Succeeding in the market*, as shown below (figure 4). The figure lists the success factors, and the following discussion describes in detail the lessons from the Lighthouse innovation cases.

Figure 4: Key Success Factors for Innovation in the Construction Ecosystem



Source: The World Economic Forum; The Boston Consulting Group

1. Develop a vision and instil an innovation culture that challenges the construction industry's status quo

When the aim is to change the approach of a large and inherently conservative organization, it is crucial for the leadership to develop a vision to mobilize the entire organization. That is where **Anglian Water's @ one Alliance**, unlike many others in the Utilities and Infrastructure sectors, has succeeded. It has modified the mindset of its employees, inducing them to think beyond individual projects – a concept that most experienced construction professionals tend to struggle with. The Alliance leadership has developed a vision of becoming a continuous-improvement organization and it has created the momentum for change as well as stimulating new ideas by setting clear targets and communicating success stories openly among the workforce.

Another example for a vision that rejects the status quo is **Burj Khalifa**. Emaar Properties' Chairman, Mohamed Alabbar had the vision to create one of the leading urban destinations and an urban landmark with the tallest tower as a centrepiece – fully in tune with the ambitious plans of Dubai's ruler, Sheikh Mohammed Bin Rashid al Maktoum. Their unwavering vision inspired the project team to go beyond the known limits – increasing the building's height by implementing still-unproven processes and technologies.

For outsiders or recent graduates joining the industry, it is much easier to take a fresh view of the status quo and to challenge it. In general, start-ups have a lot to teach established companies, when it comes to adopting an outsider perspective and an attacker mindset. Gijs van Velden, Chief Operating Officer and Co-Founder of the robotics 3D-printing start-up **MX3D**, considers that he and his colleagues “were lucky not to have too many ‘builders’ in the group” and so were able to take a fresh view and embark on the venture to revolutionize construction. And consider the design-automation start-up **Aditazz**: with a background in semiconductor design, Co-Founder Deepak Aatresh and his team were able to question the basic assumption of the design process – manual drawing of plans – and to generate a visionary alternative.

Many successful innovators apply winning principles and concepts from other leading industries. The Chinese construction company **BROAD Sustainable Building (BSB)**, with its background in manufacturing (of non-electric chillers and heat exchangers), developed a new vision of the design and construction of high-rise buildings using industry-scale prefabrication, applying the techniques, quality standards and lean principles of the manufacturing industry to enhance both efficiency and quality.

As these two examples show, vision and mindset matter: without the right vision and mindset – laying the foundations for the right innovation culture – companies will struggle in vain to implement innovation. Creating that innovation culture is not a simple process. It takes patience and a long-term agenda to overcome deeply ingrained traditions.

2. Create talented, multidisciplinary teams and devise an agile organization to accelerate innovation

The popular belief is that innovations are developed by lone geniuses, who work in isolation and then emerge one day with a revolutionary idea. In fact, as successful innovators know, the most promising approach is to create multidisciplinary, multifunctional and multitalented teams to knock down barriers between units to end siloed thinking.

The power of interdisciplinary teams is evident in the case of **Aditazz**. The challenge that Aditazz took on, to revolutionize design and engineering, was so complex that it could be overcome only by a unique combination of diverse skills – semiconductor technology, mathematics and design. In pursuing and highlighting its purpose-driven focus on improving healthcare design and delivery, the company succeeds in attracting young talent. Similarly, with **The Edge** office building, its core team included representatives from the developer, designer, contractor and client, who brought their varied talents together in a highly creative way, aided by their shared enthusiasm for innovation and their commitment to an open-discussion culture. The company **Uptake**, a leading big data and predictive-analytics start-up, sets out to demolish data siloes within client organizations to integrate disparate data sources. When developing and tailoring the platform for a client, Uptake's diverse team members – software engineers, big data specialists and construction industry experts – have to work hand in hand.

Construction companies, traditionally a project-based industry, can likewise greatly benefit by fostering knowledge-sharing between teams, departments and countries. Witness the **New Karolinska Hospital** in Stockholm. It is an enormous and daunting project, but Skanska, as the construction contractor, leveraged its global expertise in delivering hospital PPP projects, and brought experts from the UK, the US and Poland into strategic roles. In addition, the overlapping project phases benefit from knowledge exchange, which is fostered through personnel rotation. In other words, some of the staff move from one phase (which is close to completion) to a newly launched phase to transfer the expertise they have just acquired. It was this systematic knowledge transfer that enabled, for instance, a mobile-accessible BIM solution and accelerated the later construction phases of the hospital.

Another example for effective knowledge transfer and innovation acceleration through experienced, best-in class teams is the construction of the **Burj Khalifa**. When the developer Emaar Properties and its chairman Mohamed Alabbar assembled the team to construct the tallest building, their aim was to create an expert team that had deep experience of super-high-rise structures. Hiring Turner International construction manager David Bradford, who had already been involved in the construction of Taipei 101, and super-structure expert Samsung heading a group of contractors as well as more than 40 specialty consultants ensured rigorous and innovative planning and delivery.

In addition to internal formation of teams and knowledge-sharing, companies in the construction sector need to forge effective collaboration and knowledge-sharing that go beyond company boundaries. The 3D-printing start-up **MX3D**, in setting out to print a pedestrian steel bridge in Amsterdam, chose a high-profile project that others in Engineering and Construction could immediately relate to and wanted to be part of. In fact, one of the key ingredients of MX3D's success is its collaboration with prominent companies across traditional industry boundaries, such as ABB, AirLiquide, ArcelorMittal, Autodesk and Heijmans. They contributed their respective expertise (in robotics, welding gases, metals, design software and Engineering and Construction) to MX3D's development of robotic autonomous 3D-printing software. In addition, MX3D's core team brings together experts of very diverse backgrounds in design, 3D printing, and metallurgy.

It's one thing for a team to generate great ideas; it's another to implement them. In this regard, a very helpful approach is to create innovation accelerators to drive innovation. The **@one Alliance**, for instance, invites its employees to submit ideas for improving its products and processes. Once an idea is considered promising, on the basis of its potential business impact, it is piloted as a "pathfinder project". Successful pathfinder projects can be quickly rolled out to the entire organization. The teams submitting the ideas are responsible for driving the pathfinder project and get full support from the leadership.

3. Take a customer-centric approach to devising innovations, starting from the pain points of construction clients and asset end-users

Unlike other industries, the construction industry suffers from an inherent disconnect between its main sets of stakeholders – project developers, investors, architects, designers and contractors on one side and the end-users and external stakeholders on the other. The first side is often disconnected internally as well. Successful innovators opt for a customer-centric approach to innovations: they take user needs and pain points as the starting point for design and engineering. Consider the case of **The Edge** again. The new office building was going to accommodate a professional services firm, so the design team observed the employees in their previous buildings and interviewed them about their preferences and pain points. This end-user orientation was maintained during all project phases; the constant aim was to enhance the user experience. The end-user-centric approach is now manifested in a building app on everyone's smartphone or tablet, enabling one-stop personalized control of temperature and lighting levels, room bookings, parking reservations, and so on. Not surprisingly, user satisfaction with the building is extremely high.

Two further examples highlight the importance of understanding client and end-user pain points. **Aditazz** faced initial resistance to its automated design solution, but architecture and design firms came to accept the solution when the Aditazz team showed them how it simplified the traditional tedious proposal process (which typically involves a lot of non-billable hours). A similar concern

for client pain points is evident in **Uptake**: from a careful analysis of the pain points, the company creates tailored solutions and develops new data-driven revenue streams for its clients.

Another aspect of user orientation is illustrated by **Moladi Construction Systems**, which provides low-tech affordable buildings in developing countries. The company knows how crucial it is to develop solutions in tune with local market requirements and conditions. All too often, local communities dislike affordable building projects, particularly if the system is imported from abroad. Moladi has made a point of conscientiously using local suppliers and labour and addressing user preferences. When people knock on the building walls, as they tend to do, they hear a reassuring solid sound similar to that of traditional bricks-and-mortar construction. Rival affordable solutions, involving hollow panel structures and wood, are often rejected as being unstable or vulnerable to the weather. Moladi has gained wide acceptance of its innovations and it has now applied its formwork and in-situ cast-building technology in 20 countries in Africa, South America and Asia.

4. Establish product platforms rather than taking an individual-project perspective to create the business case for innovation

Anglian Water's @one Alliance shows the value of embracing a longer-term product perspective instead of a project one. The Alliance operates within the framework of Anglian Water's five-year investment programme to enable a longer-term perspective and planning certainty. By looking at a *series* of projects, the Alliance was able to identify repeatable tasks and project elements that would benefit from product standardization. For instance, it developed a space-optimized and solar-powered water-sampling kiosk, manufactured off-site, which substantially reduced construction and operating costs relative to traditionally built kiosks.

Another way to scale benefits from innovation is to develop platforms that allow easy customization of products to individual project requirements. **BSB**, to facilitate its high-rise construction, has developed a technology platform based on prefabricated steel-frame floor plates and structural columns. By tailoring the desired building design through a simple menu online, clients can customize the building they commission.

In information technology, the concept of platforms is very common. **Uptake** has taken this approach: its predictive-analytics solution is deliberately technology- and industry-agnostic. The platform has a single code base and is highly scalable: lessons derived in one vertical can be quickly applied to other verticals. For example, insights from machine and engine properties have been taken from the railway sector and applied to construction machinery. Similarly, **Aditazz** has invested heavily in recent years to build up its automated design and engineering platform. Although aimed primarily at the healthcare sector, to showcase its power in designing complex buildings, the solution is readily applicable to other building types.

The concept of product platforms is also widespread in the automotive and other manufacturing industries. By taking a longer-term product-platform perspective, companies can more easily make a business case for innovation. The **@one Alliance** developed its standard products only after a careful business-case analysis, taking into account the long-term investment horizon of Anglian Water and its willingness to invest upfront. In the future, the Alliance plans to enhance product “optioneering”: assessing and developing different options and applications based on the same product and platform.

The eternal challenge for innovators is to find seed funding, whether from within the organization or from external sources. Unfortunately, the Engineering and Construction industry is very risk-averse, so sourcing of innovation financing is limited. One important lesson from the Lighthouse innovation cases, therefore, is to systematically assess and consider alternative sources of financing, such as venture capital funds. **MX3D**, for example, required only \$1.5 million to launch its venture into autonomous robotic 3D printing, yet it struggled to raise this seed capital in the construction sector. Similarly, the multi-year research-and-development of **Aditazz’s** design automation platform was made possible only thanks to the strong backing of a venture capital fund. In the case of the **New Karolinska Hospital**, the main contractor, Skanska, decided to invest heavily upfront in developing a comprehensive lifecycle BIM model – going far beyond the contractually mandated BIM usage – as the company is operating within the framework of a 25-year PPP contract and thus receives the payback from optimized operations and maintenance over the lifecycle.

5. Develop pilot projects and prototypes to demonstrate the potential and provide proof of value

One imperative for innovators – to attract not only potential investors but also customers – is to make the innovation tangible as early as possible. Almost all successful innovators in our analysis went out of their way to create early pilots and prototypes to claim market space and prove the value of the innovation. For example, the prefabrication specialist **BSB** quickly developed a minimum viable product to demonstrate the power of its technology for high-rise construction. This rapid prototyping has featured prominently in BSB’s guerrilla-marketing strategy (YouTube time-lapse videos of its projects), aimed at creating global awareness of its technology. In the case of **Moladi**, when its innovative approach to affordable construction was met with scepticism, the company built prototype houses for public inspection: people could knock on the walls to conform their solidity. This strategy helped to create social acceptance and client demand for the project, including arousing the interest of Tanzania’s government. When the company built several courthouses in pilot projects, the government was so impressed that it agreed to roll out the affordable building solution across the entire country.

Another example is the Chinese 3D-printing company **Winsun**, which invests heavily in printing prototypes to overcome scepticism shown by project developers, owners and end-users. In keeping with the theme, “If you don’t believe it’s possible, we print it”, the company takes designs from independent or in-house designers and makes them a reality by printing them on its giant 3D printer. Outside its main factory in Suzhou, clients can enter, touch and feel a real 3D-printed mansion or a multistorey building. These prototypes have not only proved to be a very effective marketing vehicle but have also enabled further development of its technology.

Continuously improving the minimum-viable product, via project experience and client feedback, is another key success factor for many innovators. Consider the case of **BSB**: by systematically refining its production processes and optimizing the materials used, the company continues to expand its horizons and creates new generations of its buildings. What’s more, the company is now developing a new honeycomb steel that will increase stability and building life by addressing steel corrosion. Or consider the predictive-analytics start-up **Uptake**: since initially developing a basic analytics platform, with a restricted client data set, to attract its first clients and prove its value, the company has engaged tirelessly in enhancing the platform. It keeps refining the machine-learning algorithms and applying them to new data sets and continuously applies construction-industry know-how that it has acquired through its strategic partnerships to refine its platform.

6. Nurture the broader ecosystem necessary for implementing the innovation by developing the (local) supply chain and partnerships

Engineering and Construction companies operate in a project-based and fragmented industry and have to collaborate with many partners – a reality that complicates long-term optimization of products and processes and hinders the widespread adoption of innovations. Companies should, therefore, shift the emphasis and strive to establish long-term partnerships with key suppliers and other partners. The **@one Alliance** model adopted by Anglian Water, involving a select group of contractors and long-term contracts, creates the right contractual framework and incentives for open collaboration between companies (members of the Alliance receive bonus payments for joint improvements).

Another important lesson can be learned from **The Edge**. Its developer, OVG Real Estate, realized that many technology suppliers are a valuable source of innovation but lack the right business model to market their innovative products. OVG worked closely with some of these suppliers (for instance, connecting suppliers of different sensors with Philips to develop its Ethernet-connected LED lighting panels) and also with various start-ups (to develop the building app, for example), and in that way succeeded in integrating these innovations into the building without increasing costs.

The construction team behind the **Burj Khalifa** took a similar approach in working closely with its suppliers. Most of the project's innovations – notably the concrete-mix design and pumping, the GPS-controlled jump formwork and the prefabricated window panels – were developed by suppliers. Yet, it required close collaboration between contractors and suppliers to test and implement the innovations in Dubai's challenging physical environment. In many cases, the expertise of the various partners was invoked as early as the planning phase to enable pre-emptive modifications and avert costly reworks.

The need to nurture an enabling environment for innovations is not confined to high-tech solutions. The **Moladi** affordable buildings system has benefited greatly by expanding the local supply chains for its innovatively *low-tech* supplies, skills and processes.

A different approach to establishing long-term partnerships was taken by **MX3D**. When it undertook "The Bridge" project – an ambitious and well-defined challenge – it publicized it conspicuously and tempted several key industry participants into collaborating by holding out the prospect of advancing the technology and accumulating knowledge. These partners duly contributed their complementary competencies to the venture and have continued to do so beyond the project.

The experience of **Uptake** provides another key lesson: form strategic alliances with key clients to advance the innovation and lend credibility. By entering into strategic alliances with established companies such as Caterpillar, Uptake has succeeded in overcoming market resistance and in further developing its technological and data solutions. What's more, the prestige of these client partners has boosted Uptake's reputation and credibility and its efficacy in educating the market.

Rather than limiting their collaborative efforts to clients or upstream suppliers, innovative companies should strive to collaborate along the entire value chain and educate others on how best to use and incorporate the innovation. The **New Karolinska Hospital** is an excellent example in this regard. The main contractor, Skanska, was able to use BIM technology to great effect (to keep track of materials, facilitate handover and improve facility management), but concluded that BIM's potential could be fully realized only if subcontractors and suppliers also worked with the BIM model. Accordingly, Skanska put considerable effort into persuading them of the value of BIM, discussing their concerns openly and helping them with relevant financing and training where necessary.

7. Embrace business-model innovation alongside technological innovation in Engineering and Construction

For many disruptive technologies, gaining market acceptance is a serious challenge. Lighthouse innovation companies have some useful lessons to share on how to meet that challenge. One is to adapt the existing business model and go-to market strategy to the market realities and to a deficient value chain. Consider **Moladi** once again.

At origin, it is a provider of affordable building technology (plastic formworks and its patented concrete additives), with a focus on optimizing the products. And that is how it would like to remain. However, owing to the persistent resistance and scepticism of local developers and builders in South Africa, the company has decided to adapt and to offer turnkey solutions as well.

Sometimes it might even be necessary to create a new business model to exploit the full potential of innovation. **Aditazz** is a case in point. It has created a hybrid business model of software products plus professional services. Thus, it not only can provide the design and automation tool but also has in-house project-delivery capabilities – a necessary add-on, as the market is not yet capable and/or willing to use the platform independently but requires an integrated solution. What's more, its software-as-a-service design-automation platform contravenes the common practice of billing designs by the hour – challenging the current procurement model.

Being traditionally slow to change, the market often appears unwelcoming to innovations or ill-prepared for them. Successful innovators will strive to educate and shape the market. One example is that of **BSB**. To raise awareness and increase acceptance of its disruptive prefab technology, the company is partnering with several design institutes to engage and train designers and architects – key agents in promoting the technology. And in response to resistance from construction workers, the company plans to roll out a local joint-venture system, which will make the prefab technology platform available to local franchisees and thereby benefit the local economy.

Another example from China: 3D-printer company **Winsun** – facing widespread scepticism among designers, developers and clients – has energetically set out to educate the market and demonstrate the viability of its technology. Moreover, the company liaises with architects and designers to train them and instil the 3D-printing approach into their design thinking.

8. Advocate new ways of contracting to enable and incentivize effective collaboration with project owners from day one

Among the major barriers to innovation, according to industry experts, are traditional contracting and procurement models that only focus on initial capital expenditure and the lowest bidder wins the contract. Innovators should, therefore, advocate other forms of contracting, with a longer-term and performance-based approach.

Anglian Water's @one Alliance has taken a longer-term, performance-based approach. The Alliance closely collaborates with suppliers from the very start of a project (during the planning stage), to overcome the issues of traditional procurement models in which suppliers begin their involvement much later. The Alliance has found that its framework contracts, aimed at forging long-term relationships, help to intensify and sustain collaboration,

and also generate appropriate incentives to improve performance and share best practices within the Alliance.

Whether an innovation can be successfully implemented in a project environment often depends on the role of the project owner. Therefore, it is crucial for innovators to collaborate closely with project owners regarding client demands, planning and approvals. In the case of **MX3D's** Bridge project, for instance, the company got the Amsterdam city government engaged at an early stage, which facilitated approval negotiations (using a performance-based approach in load-testing the 3D-printed bridge) and created a sense of trust and shared ownership of the project. The project duly received the official go-ahead and both company and city will benefit from the global media attention.

9. Shape the regulatory environment proactively to enable and promote adoption of the innovation

Just as traditional contracting and procurement models can hold back innovations and reinforce the status quo, so, too, can traditional regulation and building codes. The initial strategy of innovators has to be one of working *flexibly* within the existing regulations. In the case of **The Edge** office building, the Amsterdam municipality was invited to participate in the central project meetings; pragmatic solutions were developed jointly that enabled some ambitious innovations to go ahead – for example, Philips' Ethernet-connected LED lighting panels, which allow customized lighting (via the building app) even at levels lower than the normally specified minimum level for workspaces.

Early engagement and close collaboration with regulatory authorities is even more important for delivering highly visible and heavily scrutinized construction projects. Aiming to construct Dubai's new urban landmark, the project team constructing the **Burj Khalifa** felt the pressure to get started (and complete) as soon as possible. Being experienced in constructing super-high-rise buildings, the team knew the importance of early engagement with regulators and other enablers, and how best to go about it. They promptly approached and negotiated with the relevant Dubai government agencies and utilities providers to expedite the official go-ahead for pouring its special concrete mixture and placing transformers on different floors throughout the building to avoid voltage drops.

Successful innovators also engage with regulators to set new standards. An active push for new standards is particularly relevant for disruptive technologies such as 3D printing: as in the case of **Winsun**, which is actively shaping the regulatory environment, working closely with construction departments and regulators on the regional and national level in China to adapt building codes.

Another example is **Uptake**, which is pressing for the regulatory setting of data standards and facilitating the integration of different data sources and client systems. And **BSB** is working with Chinese government institutes to upgrade its guidelines on prefabrication into regulations.

Innovative companies should also consider the positive aspects of regulation and certification – notably, the help they provide in overcoming client resistance. Leading innovators strive for certification that lends credibility to their innovation. When countering deeply ingrained scepticism, innovators can validate their innovations by obtaining official certification. Official authorization also has the effect of facilitating publicly procured projects, as the example of **Moladi** shows. However, the example of **MX3D** shows that certification is not always necessary before commercializing and marketing a minimum viable product but can be pursued in parallel. While refining this product, the company is at the same time pushing for the certification and regulation of the technology; and it is also digitally collecting and storing information that can be used later for certification and quality control.

Incorporating these nine key success factors in an organization is not easy, but it is certainly worth pursuing. The case studies both from large-scale projects as well as from start-ups and pilot projects show that it is possible to implement new technologies. Any company or project in the Engineering and Construction ecosystem will need to consider these success factors if they want to form part of the innovation leaders (and not laggards) and reap the associated productivity benefits.

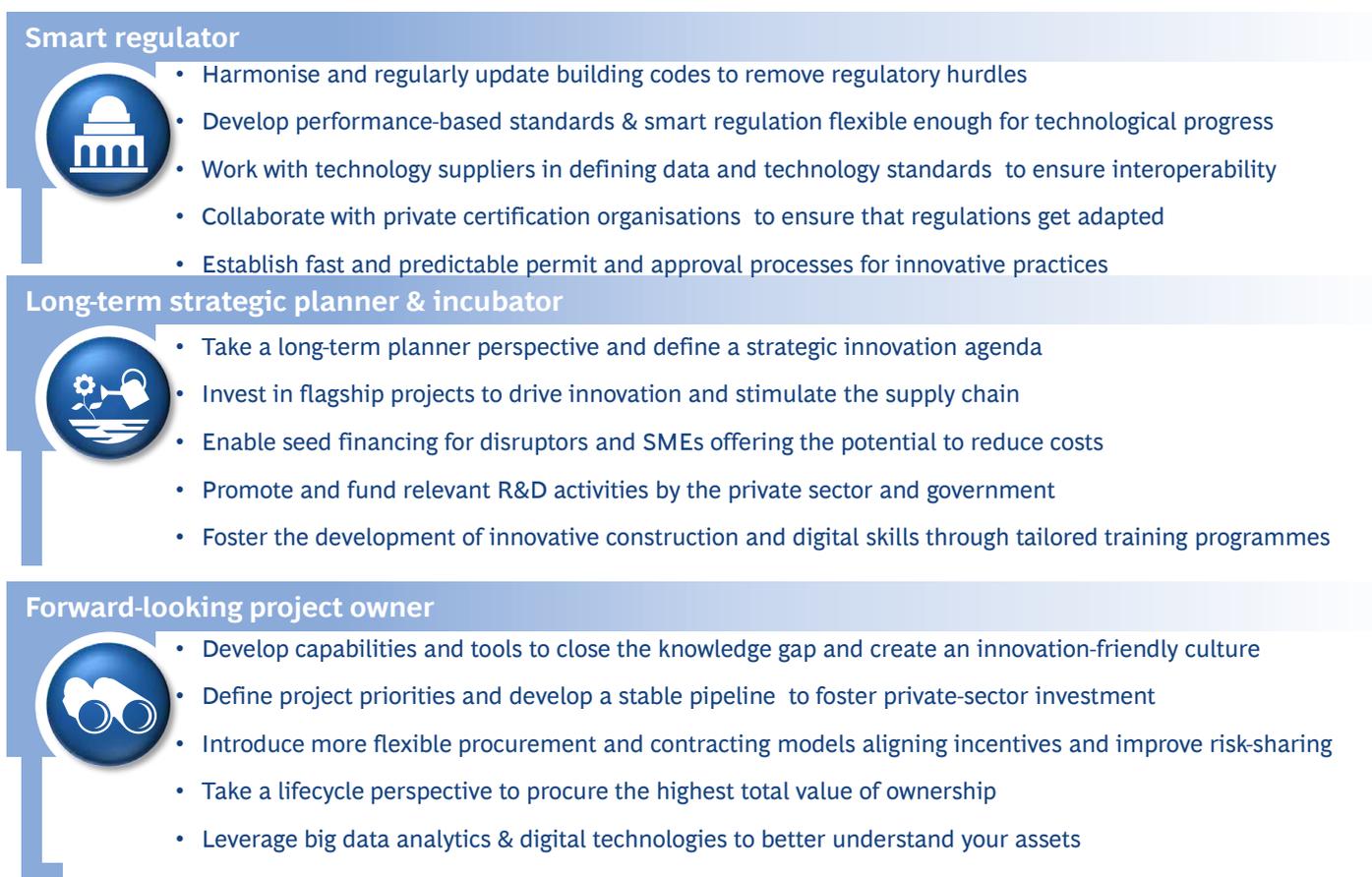
The above success factors describe what companies can do to accelerate innovation. However, the case studies also underpin the important role governments play in devising policies conducive to the adoption of innovation. The next section describes these policy recommendations.

Policy Recommendations

Engineering and Construction companies can and must spearhead the digital transformation of the industry. To do so, however, they rely on the help of governments: policy-makers need to set the right conditions and create an innovation-friendly environment that fosters the broad adoption of new technologies, processes and business models. From the case studies, and from the discussions

with representatives from the industry, government and civil society, three key roles for governments emerge: they have to act as *smart regulator*; as *long-term strategic planner and incubator*; and as *forward-looking project owner*.

Figure 5: Three Roles for Governments to Foster the Adoption of Innovation in the Construction Ecosystem



Source: The World Economic Forum; The Boston Consulting Group

Government as smart regulator

Regulation is necessary for ensuring the health and safety of construction workers and tenants, and for protecting the environment. On the other hand, regulation is often cited as one of the key impediments to technological progress in the construction industry and is regarded as perpetuating outmoded ways of doing business. Accordingly, what's needed is smart regulation – regulation that ensures that the necessary standards are met efficiently and effectively, and that provides a framework flexible enough to allow for rapid technological progress. Here are some key recommendations, together with real-life examples:

- **Harmonize and regularly update building codes** to remove regulatory hurdles and reflect technological change
Example: Most building codes make no provision for 3D printing as an aspect of construction technology but remain focused on classic bricks and mortar or pouring of walls. Therefore, the Chinese 3D-printing company **Winsun**, to comply with existing regulations, is obliged to combine its printed hollow walls with traditional structural elements. According to reports, however, the Chinese government is now developing specific regulations to nurture the adoption of 3D-printing technology in construction.
- **Develop performance-based standards and smart regulation** flexible enough to accommodate rapid technological progress
Example: Prescriptive and proprietary specifications still represent a serious barrier to innovation, as they reinforce the status quo and fail to reflect new technological developments. The Amsterdam City government could have invoked these old conservative standards when considering a daunting proposal presented by the start-up **MX3D** – to 3D-print and install a pedestrian bridge that contravened traditional calculation methods and construction practice. Instead, however, the civic authorities worked with the innovators to find a pragmatic solution and eventually agreed to take a performance-based approach and load-test the bridge.
- **Collaborate with private certification organizations** to ensure that regulations get adapted to already certified innovations
Example: The case of **MX3D** also exemplifies the way that companies and start-ups are actively seeking private-sector certification to fill the regulation void. Governments should reach out to and collaborate with these certifying bodies – Lloyd's Register, for instance – to ensure that the latest technological developments are reflected appropriately by regulation and, if necessary, incorporated into regulation.
- **Work with technology suppliers in defining data and technology standards** to ensure interoperability
Example: With the advance and even mandated use of new technologies such as BIM, interoperability of systems is crucial. Without such interoperability, contractors risk investing in redundant and incompatible systems, training their employees on different systems and wasting time trying to harmonize

different input files into one system. The absence of interoperability is particularly acute in large-scale projects such as the **New Karolinska Hospital**, where more than 400 design consultants used a range of systems and trade contractors had to be trained in the use of BIM. Governments should work with the industry to align on a common standard, based on the various competing standards that exist today.

- **Establish fast and predictable permit and approval processes** for innovative practices; engage with project developers to discuss actual barriers in these processes
Example: During the planning and construction phases of **The Edge**, the Amsterdam municipal government attended regular project meetings with the developers to discuss potential issues as they arose. It was thanks to this methodical engagement that a pragmatic solution was quickly found for the building's adjustable Ethernet-connected lighting system, for instance: the default configuration of 300 Lux got the go-ahead, even though it is well below the regulation minimum of 500 Lux, since users can easily increase the lighting, to their own comfort level, on their smartphones via the building app.

Government as long-term strategic planner and incubator

The construction industry accounts for about 6% of GDP globally, and forms the backbone of other industries, almost all of which rely on buildings and infrastructure for value creation. What's more, the sector is a major consumer of raw materials and is responsible for about a third of global CO₂ emissions. Accordingly, governments should take a strategic approach to planning the development of the industry and helping it achieve greater productivity, enhanced affordability and improved sustainability and disaster resilience.

- **Take a long-term planner perspective and define a strategic innovation agenda** for the industry, and establish a public-private initiative that drives that agenda and fosters cross-industry collaboration and knowledge exchange
Example: By setting clear and ambitious targets for BIM usage, the United Kingdom has become one of the international leaders in BIM and its construction companies now have a strong competitive edge in international projects. It is no surprise, therefore, to learn that the BIM field appliance used for facilitating handover in the **New Karolinska Hospital** had previously been applied by the handover manager in the UK and that the project relied on personnel from the UK for an effective knowledge transfer. On a different note, Dubai, too, is taking the long view, this time in regard to 3D printing. It has set the ambitious target of printing 25% of buildings by 2030 – in 2016 it opened the first 3D-printed office building (produced by Winsun).

- **Invest in flagship projects** to drive innovation and stimulate the supply chain required for scaling up
Example: London’s Crossrail project serves as a model for strategically developing new technologies such as BIM in publicly procured projects. Driven by a four-person innovation team and governed by a comprehensive innovation strategy, Crossrail pushed the boundaries in advancing BIM and related digital innovations, deployed them throughout all project phases, and provided appropriate training courses and education for suppliers and other rail-industry stakeholders. Another key element was the collaborative approach – collecting ideas from all areas of Crossrail via an online portal – as well as integrating and incentivizing its suppliers into the joint innovation effort.
- **Enable and provide seed financing** for start-ups and small and medium enterprises (SMEs) that have the potential to reduce engineering, construction and operations and maintenance costs
Example: The case of **MX3D** shows the importance of seed financing to start-ups. Without such funding, innovative ideas risk being abandoned before they can prove their potential. Fortunately, the MX3D founders were able to secure funding from equipment manufacturers. Another start-up, the design-automation company **Aditazz**, owes its success partly to the long-term oriented venture capital fund that gave it the freedom to continually enhance its platform. Due to the high fragmentation of the industry and long lifecycle of projects, such patient and long-term oriented venture capital investors are essential.
- **Promote and fund relevant research and development activities** by the private sector and government research institutions, and support demonstration projects to foster the adoption of innovations
Example: The French Ministry of the Environment financed the first pilot of a 1km “solar road” in Western France. The road was inaugurated in December 2016 and is expected to produce enough energy to power the streetlights in a nearby town of 5,000 people. The “Wattway” technology was developed by the National Institute for Solar Energy and the construction company Colas.¹
- **Foster the development of innovative construction and digital skills** through tailored job-training programmes and effective curricula in technical colleges, apprenticeship schemes or universities
Example: Singapore’s Building and Construction Authority supports the acquisition of construction skills through the “SkillsFuture Study Award for Built Environment Sector” – a grant of \$5,000 for workers in the construction sector that can be used for a variety of construction-related courses, including courses on BIM, design for manufacturing and assembly or lean construction.²

Government as forward-looking project owner

Finally, governments are major owners of construction projects, whether physical infrastructure assets such as dams, ports, highways and bridges, or social infrastructure assets, including hospitals, schools, universities, courtrooms and recreational facilities. A large proportion of construction is contracted by the public sector (about a quarter of the total, in the case of both the US and the UK, for instance), so governments and taxpayers stand to benefit greatly by helping the construction industry to boost its productivity through innovation. And as major clients, governments – local, regional and federal alike – can strongly shape the industry, they set de facto standards for technologies, processes and tools for their own projects and those standards then oftentimes spill over into private construction projects as well.

- **Develop owner capabilities and tools to close the knowledge gap relative to the private sector** and create an innovation-friendly culture that is open to new methods and technologies
Example: Industry leaders stress how important it is for project owners to develop an innovation-friendly culture on the client side. The **Burj Khalifa** in Dubai exemplifies vividly the impact of such a culture, in combination with a clear vision and effective public-private collaboration. In striving to create an urban landmark and the world’s tallest building, the owners, together with its contractors and suppliers, enabled many record-breaking innovations – for example, in concrete pumping, building design, facade installation and lift technology.
- **Define project priorities clearly**, and develop a stable pipeline with reliable funding to foster private-sector investment in innovation and capabilities
Example: By publishing its five-year investment plans, the water utility **Anglian Water** enabled long-term planning that stimulated standardization and project-based thinking in the @one Alliance. Suppliers were now able to identify repeatable tasks and expected production volumes and, therefore, to invest confidently in new capabilities and production capacities.
- **Introduce more flexible procurement and contracting models** that align incentives and improve risk-sharing, and enable earlier and longer-term collaboration between owners, contractors and operators
Example: **Anglian Water** is again a case in point here. The company opted for an alliance model with key contractors, with a view to collaborating on a more continuous and longer-term basis. Previously, using traditional procurement models, the company had struggled to involve the contractors early in the planning and design phase and eventually had to “drag” them in for delivery.

Example: For the **New Karolinska Hospital**, the city authorities adopted a 24-year PPP model, awarding a single integrated contract for design, construction, financing and operations and maintenance. As a result, the consortium – consisting of a facility manager and a main contractor – collaborated very effectively. It was able to achieve long-term cost reductions, for instance, by investing upfront in a comprehensive lifecycle BIM system and co-investing in an optimized IT landscape.

- **Take a lifecycle perspective to procure the highest total value of ownership**, taking into account all costs and benefits across the whole lifecycle and flexibility for potential repurposing of assets

Example: Viewed simply in terms of its construction costs, **The Edge** office building in Amsterdam was the most expensive building in the Netherlands that its main tenant, Deloitte, could have chosen. However, per employee and across the lifecycle, it is very inexpensive thanks to its flexible set-up and technology-enabled hot-desking. It is also energy-positive, thanks to its aquifer heating system and solar panels. What's more, its flexible design, including a second entrance, provides for quick and easy repurposing if and when the need arises – for instance, to house the neighbouring university, or even to be converted into residential units.

- **Leverage big data analytics and digital technologies** to better understand your assets and to maximize the assets' lifespan and utilization

Example: More than 700 dams and 75 hydropower facilities are owned and operated by the US Army Corps of Engineers. About 95% of the dams are over 30 years old and 52%³ have exceeded the 50-year service life they were designed for.⁴ Huge benefits will accrue by optimizing the operations and maintenance of these assets and extending their lifespan. Such optimization is now in prospect because embedded sensors and digital asset-management tools can provide the engineers with a real-time view of each asset.

The above recommendations and examples should help policy-makers to support and accelerate the transformation of the industry. The recommendations should be viewed in the broader context of previous joint World Economic Forum and Boston Consulting Group reports on strategic infrastructure.⁵

Implementing these policy recommendations and key success factors will help to accelerate innovation in the construction ecosystem. The case studies demonstrate the large potential the industry stands to gain from adopting innovation more broadly. Read their inspiring stories on the following pages.



Lighthouse Innovation Cases

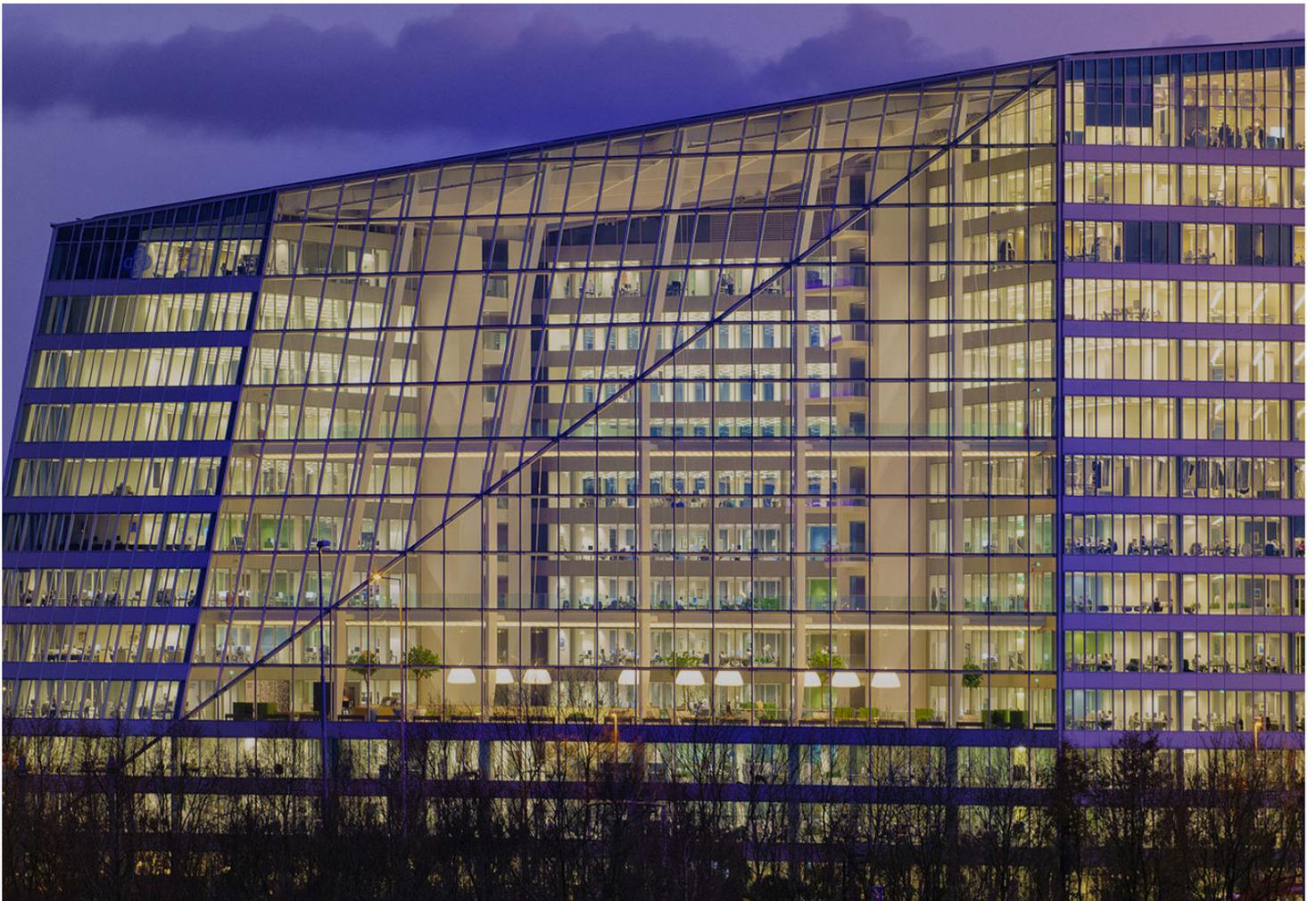
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The Edge

Creating the world's most sustainable and most connected office building by integrating smart technologies and collaborating closely with suppliers



The challenge

Modern office buildings require considerable flexibility to accommodate new uses and working patterns, and also need to meet high standards of sustainability.

When Deloitte Netherlands began envisaging their new Amsterdam office, they not only considered the working environment, but also the natural environment. That is to say, the building should have a double emphasis on productivity and sustainability. Moreover, the office would be extremely energy efficient with a strong emphasis on workplace efficiency.

The new building is planned to house the company's 1,700 local employees (previously spread over several buildings) in one modern space, creating a visible symbol of the company's digital approach and contemporary outlook.

Working in the digital age differs from traditional office life – it is much more flexible, decentralized and collaborative. In the digital age, employees are no longer desk-bound, or even office-bound; they might choose to work from home (at least a couple of days a week) and will go to the office mainly for meetings and social interaction with their colleagues. As such, it is not uncommon that 50% of desks in a conventional office are unoccupied at any one time during office hours – a waste of urban space, and a rallying call for a radically different building design and configuration of rooms.

This trend towards greater flexibility affects other types of construction too, of course. Transport infrastructure, for example, has to adjust to the growing numbers and changing tastes of travellers. Heathrow Terminal 5 in London was specifically designed as an adaptable building that can be easily transformed internally to cater for different demands.

As for the other dimension, sustainability, it is no longer a mere optional add-on offered by property developers, but a key feature of new buildings, actively promoted by developers and demanded by owners, tenants and end-users. The sustainable design is not just to comply with regulatory requirements, such as energy-efficiency specifications or renewable-energy policies, but also out of genuine environmental concern.

It is not uncommon that 50% of desks in a conventional office today are unoccupied at any one time during office hours – a waste of urban space, and a rallying call for a radically different building design and configuration of rooms.

The idea

Combine smart building design and innovative technologies to improve sustainability, workforce interaction and end-user experience.

Developed by OVG Real Estate and designed by PLP Architecture, The Edge was completed in November 2014. In its 40,000 square metres of floor space, it sets new standards in sustainability, technology, flexibility and user experience, and shows how smart building design can reduce energy demands. The most prominent architectural feature is the multi-storey, north-facing glass atrium, which admits abundant daylight while on the south façade concrete walls absorb heat (and shield the interior from sunlight), and solar panels on that façade and on the roof convert that sunlight into energy.

Perhaps the most innovative element of The Edge is the way that the many different elements of the building are interconnected, pushing the boundary of the Internet of Things. Every technical system in the building is controlled within a single network, enabling a live view of the building and modulated for maximum efficiency: the lift, the lighting and cooling systems, the robot that cruises around the building at night as a security guard, even the coffee machines and towel dispensers.

By working closely with suppliers, the developer introduced 21 innovations that had never been applied before, such as Philips' Ethernet-connected lighting and a safe plastic for cable insulations that is non-toxic in the event of fire. These and other solutions, according to Erik Ubels, Chief Technology Officer at OVG, are "integrated on the silicon level, instead of just gluing technologies together".

Consider the 6,000 low-energy LED luminaires, on which the lighting system is based: they contain multiple sensors for measuring temperature and light, and even for detecting movement. These sensors – and a further 28,000 positioned throughout the building – are linked to the building network and integrated into a data analytics platform enabling smart facility management. This helps, for example, guide cleaning staff to heavily used areas, or refilling the towel dispenser before it runs out, and allows predictive maintenance of the LED lights by monitoring their usage.



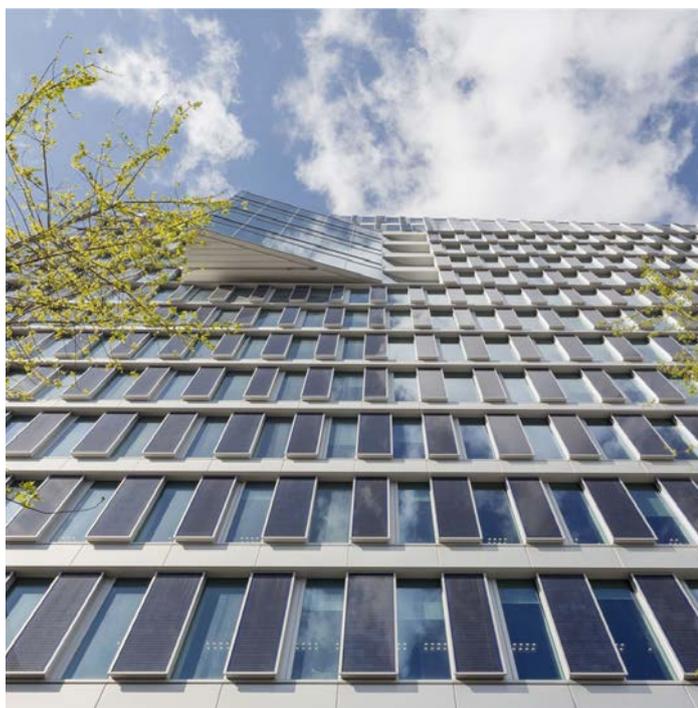
Further design features – from the layout of the central cafeteria to the positioning of the quiet zones – aim to enhance the user experience, and are based on interviews with users themselves and an analysis of their work patterns. One novelty is the building app, which employees can operate on their smartphones or tablets. The app allows employees to instantaneously adjust the lighting and heating at each workspace to their personal preference, reserve meeting rooms or parking places, track their progress in the on-site gym (treadmills are connected to the building's electricity grid, too), or locate their colleagues within the building.

The impact

The project has set new standards for sustainability and flexible working, while keeping O&M costs to a minimum.

The Edge is aptly named. It is at the very forefront of office-building accomplishment, maximizing the productivity of its occupants, minimizing the running costs and the environmental impact.

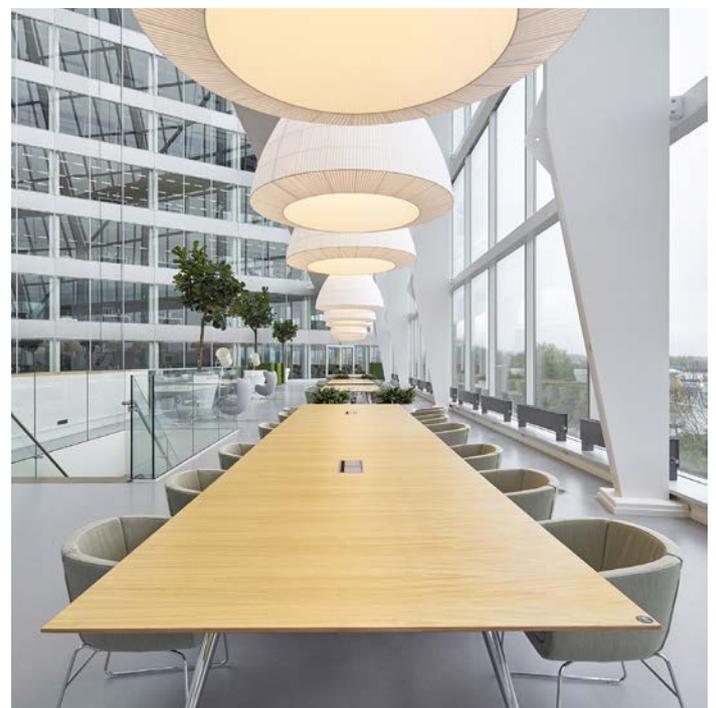
The office space's environmental impact is remarkably light. With a BREEAM rating (Building Research Establishment Environmental Assessment Method) of 98.36%, The Edge is widely considered the most sustainable office building in the world. Thanks to its solar panels (including some on rented roof space nearby), its aquifer thermal energy storage system (ATES), and, most importantly, demand reduction through such factors as efficient lighting and smart building design, the building's energy consumption is net negative – an estimated -0.3 kWh/m²/year versus +40.7 for a traditional office building. That translates into an estimated saving of 42 million kilograms of CO₂ in a decade. Another environmental feature is rainwater collected from the roof and balconies, and used for flushing the toilets and irrigating garden areas.



Office buildings are notoriously expensive to operate and maintain, but dramatic cost reductions are now possible thanks to technological advances and smart facility management. In the case of The Edge, the ventilation is to a large extent natural, effected by convection flows within the atrium, while heating and cooling are provided cost effectively via the ATES. The LED Ethernet-connected lighting system yields modest energy savings relative to conventional fluorescent-tube lighting systems, but an impressive savings on materials (notably, on cables) and repairs. The Edge's customized building analytics system reduces maintenance costs by remote monitoring of the actual use of the building and equipment. Cleaners and repair workers, for example, are directed promptly to the location where they are needed.

As for the productivity of the building's occupants, finally, and the user experience in general, The Edge offers many advantages. The layout might initially seem wasteful – the atrium and communication areas account for 25% of the building space, compared with just 10% in conventional office buildings, but it encourages productive interaction and dialogue between colleagues (and does not create extra cost as it does not need to be specifically conditioned). It is actually economical per employee: the flexible set-up, together with the smart data system and the building app, allows for accurate hot-desking, so much so that the building's 1,100 workspaces now serve more than 2,500 employees, even though originally intended for 1,700.

Coming as a surprise for the developer and the architect Ron Bakker, the atrium and cafeteria are actually one of the most popular work areas of the entire building, despite lacking specific sound insulation, and temperature, lighting as well as air movement are not



as controlled as required for typical workspaces.

User satisfaction is high. Many of the traditional frustrations of office life – paper jams, non-functioning equipment, double-booked meeting rooms – are now pre-empted by The Edge’s sensors and analytics. Employees can recharge their electric cars and bicycles for free in the garage, using the building’s self-generated excess power supply. And they can facilitate their work and personalize their workspace in numerous ways by deploying the building app. As it happens, many employees make little use of the app, but far from being regarded as a disappointment, this shortfall is interpreted favourably, as evidence that the building has now learned to respond unprompted to employees’ needs – for instance, by automatically regulating the lighting and heating to their preferred levels.

OVG has relocated its own headquarters to The Edge – appropriately enough, as the building serves as the company’s showcase project, generating global interest and positioning the company as an acknowledged leader of smart and sustainable building development. For Deloitte, the building has become part of its identity – an asset not just in branding and marketing its services, but also in recruiting; 62% of candidates specifically mention in their application that one of the factors attracting them to Deloitte is the prospect of working in The Edge.

The barriers to innovation, and the solutions

Financing, traditionalism, regulation – all presented challenges to the stakeholders, who responded boldly in collaboration with one another and with suppliers, and often made a virtue of necessity.

Planning for The Edge began in 2006. Just two years later, a serious challenge emerged, precipitated by the global financial crisis – a cut in available financing, coupled with a change in Deloitte’s specifications. Deloitte reduced its floor space requirement by 25%, or 10,000 square metres – meaning that it would no longer be the only tenant of the building. The team of developers and architects responded methodically to the challenge. First, they adjusted the design, adding

extra flexibility to accommodate additional tenants. This was done by subdividing the core office space, for example, and making provision for a second entrance. In fact, the building could today be radically repurposed at little cost and inconvenience to house a university, for instance. Second, the team achieved cost savings through value engineering, for example, by pre-fabricating parts of the building’s concrete southern façade.

Having initially envisioned a BREEAM rating of “excellent”, the team set themselves the challenge of going one better and achieving the highest rating, and finally to claim for The Edge the status of “greenest” office building in the world. The sustainability challenge here might appear to be at odds with the financial challenge: the additional solar panels, for instance, had not been budgeted for. The main investor ABN Amro had a strong interest in sustainability, and agreed to continue financing the project in 2010. In fact, in early October 2016, ABN Amro and OVG announced a further collaboration in smart retrofitting of old buildings, and the creation of the bank’s first green real estate loan.

The financial barriers facing any highly innovative project are never the only barriers. Almost inevitably, there will be technological barriers, and often resistance from potential partners and clients (especially in such a conservative industry as the construction industry) and regulatory barriers, too.

By taking a holistic view of the building in all its phases, and using the BREEAM rating system as a practical guide, team members were able to assess every relevant aspect and identify areas for improvement. They then initiated a continuous product-development process with their suppliers, prompting numerous refinements and innovations. One of the challenges in this regard was that many of the new technologies were untested, and the risk-averse engineering and construction industry was therefore reluctant to adopt them.

Sometimes even the technology suppliers seemed unwilling to move away from the status quo. Philips’ Ethernet-connected lighting system, according to one OVG executive, was something that initially Philips itself was wary of investing in. To overcome resistance of this kind, OVG worked closely with suppliers on developing the business case and proving the joint benefits. In the case of Ethernet-connected lighting, the three companies involved – Philips, OVG and Deloitte – eventually agreed to co-invest in the new system when the building was already nine storeys (with Philips taking the technology risk). Innovation-friendly had overcome risk-averse, and been vindicated. Today, Ethernet-connected lighting is a standard product in the Philips portfolio, having gained a competitive boost through being implemented in The Edge.

As for the various technological and sustainability challenges, the stakeholders addressed these by bringing together many different areas of expertise, from renewable energy to app design and Big Data. Client, developer, architect and contractor formed a multi-disciplinary core team, with a culture of open discussion, and an enthusiasm for innovation and boundary-pushing. One crucial factor was that the design team remained engaged



long after the initial design phase, contributing ideas throughout the construction process, and collaborating with suppliers – for instance, on developing that safe plastic for cable insulations. Another factor certainly was that Deloitte – particularly Erik Ubels, at the time still Chief Information Officer at Deloitte – was actively demanding innovation and willing to invest as long as the payback period was less than eight years.

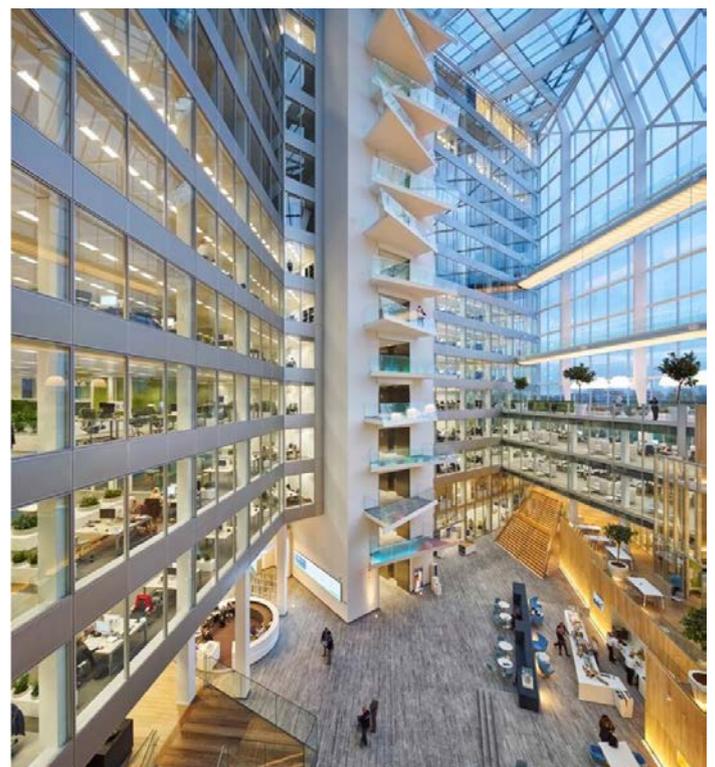
Regarding regulatory barriers, some of the innovations fell afoul of the existing building codes. Whereas regulation prescribes a minimum lighting level of 500 Lux for workspaces, The Edge's energy-efficient lighting allows employees the choice of working at a mere 300 Lux. The team resolved the matter by initiating an early dialogue with the municipal regulatory authorities, and securing their agreement. Of course, this pragmatic and solution-oriented approach, so characteristic of the consensual Dutch society, is an approach that many countries might be slower to adopt.

Needless to say, a few of the desired innovations could not be implemented. However, with digital technologies evolving so fast, some previously unaffordable (or even unimagined) innovations have meanwhile become available. One example is that of iBeacons, now successfully installed in OVG's office space, and soon to be installed throughout the building. The Edge is about to become The Edge 2.0, with iBeacons and additional sensors enhancing both building performance and user experience. The data system will be able to track the location of each individual, create more accurate heatmaps of usage, and thereby analyse and model the actual behaviour patterns within the building, and help its users become even more productive and fulfilled – making even the scanning of a QR or RFID tag redundant when checking into meeting rooms.



Lessons learned

- **Take user needs and wishes as the starting point for design and engineering.**
With the help of user studies and interviews, the architects gained an early and accurate understanding of the client's needs and preferences; combining open spaces with focus rooms and quiet zones to allow for different usages during a typical working day – phone conferences, informal meetings and tasks requiring high-focus.
- **Create a project team that is multi-functional and highly motivated.**
The central team driving the project contained representatives from the developer, designer, contractor and client; they brought their varied talents together in a highly creative way, aided by their common enthusiasm for innovation and their shared commitment to an open discussion culture.
- **Collaborate with suppliers to help them market their innovations.**
OVG quickly realized that technology suppliers are often a valuable source of innovation, but often lack the right business model to market their innovative products. By working closely with these suppliers and startups (e.g., for the building app), OVG was able to integrate these innovations into the building without increasing costs while minimizing technology risks.
- **Involve the regulator early on in the process.**
The municipality was invited to participate in the central project meetings; pragmatic solutions to work within the pre-existing regulations were then developed jointly that incorporated ambitious innovations.





New Karolinska Hospital

Leveraging lifecycle building information modelling (BIM) to optimize the construction, handover, and operations and maintenance of the largest-ever public-private partnership for a hospital



The challenge

The hospital public-private partnership faces difficult circumstances, including a tight timeline, intense public scrutiny and the ongoing operations of the old hospital, and needs to be flexible enough to accommodate future trends in healthcare.

The New Karolinska Solna (NKS) Hospital project is considered the world's largest public-private partnerships, involving an overall investment of \$3.0 billion (including \$1.6 billion for construction). Construction started in 2010 and is expected to be completed as well as to 2017. When completed, the hospital – which will cover 320,000 square metres – will have over 12,000 rooms, 35 operating theatres and 17 magnetic resonance imaging (MRI) units.

In addition to the core hospital building, the project includes a parking garage, research building, technology building (to handle the energy supply and deliveries for the hospital), cancer treatment (radiation building), as well as new roads connecting the buildings and an entrance to a new subway station. Located in the north of Stockholm, Sweden, the integrated hospital and research complex will contribute crucially to the development of the new Hagastaden neighbourhood.

To complicate matters, construction has to take place without disrupting the normal operations of the old Karolinska University Hospital and the research-focused Karolinska Institute, which are located nearby. Meeting the relevant noise, dust and traffic level requirements was no easy task.

Moreover, given the significant public investment and the institution's global reputation, the project is under close scrutiny from the media and the general public, and is highly political. As a result, all parties involved are under considerable pressure to complete the project on time and on budget.

The construction of the NKS hospital should be viewed in the wider healthcare context. Several trends are relevant here. Populations in urban areas – Stockholm is no exception – and an ageing population are raising and changing the demand for hospital services; older patients account for about half of hospital-bed occupation globally. Advances in medical equipment and healthcare delivery are producing a shift towards outpatient care. The shortage and discontent of healthcare staff obliges hospitals to improve working conditions. Over the lifetime of the new hospital, these trends will play out further.

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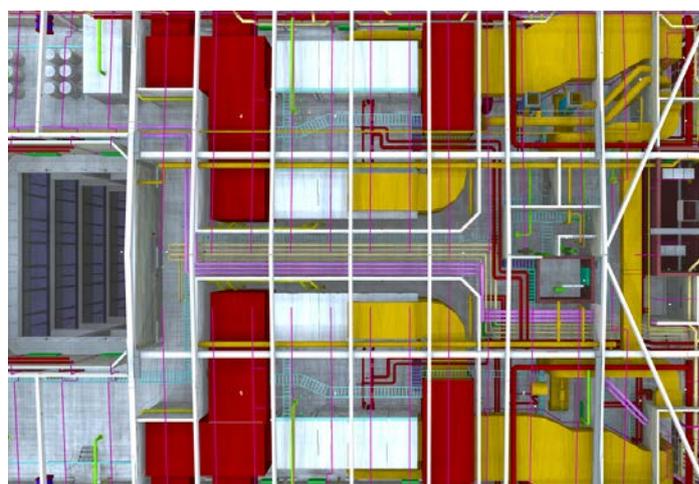
The idea

Leverage building information modelling across the entire lifecycle to enhance design, construction, operations and maintenance, and patient care, and reduce the environmental impact by means of methodical planning and the optimal use of prefabrication and green technologies.

NKS aims to set new standards in patient care, integration of healthcare and research, adaptability to future needs and sustainability. The planners benchmarked leading hospitals to identify optimal care procedures, workflows and working conditions. The project incorporates many innovations in the construction process and in operations and maintenance (O&M), and now itself serves as the benchmark for large and complex healthcare projects.

NKS is being delivered as a turnkey project under a public-private partnership scheme in which the Stockholm City Council signed an agreement with the dedicated project company Swedish Hospital Partners – a joint venture of Skanska Infrastructure Development and the UK pension fund Innisfree – for designing and building the hospital and operating it until 2040 (possibly even extending the contract until 2055). Swedish Hospital Partners in turn contracted Skanska Healthcare for the building contract and Coor Service Management for the facility management. The actual patient care – and everything directly related to it, such as procuring medical equipment – is the responsibility of the Stockholm City Council.

The contract mandated the use of building information modelling (BIM). Mindful of the project's vast size, complexity and tight deadline, Skanska adopted an advanced BIM model across the entire lifecycle, creating a single data platform on which designers, contractors and eventually facility managers could collaborate (BIM Level 2). Starting with entering the design specifications and performance requirements, the architects and designers create 3D designs; every object is then digitally stored in the model, with its key attributes and exact location. Once completed, the object list will contain about one million items.



The list and the model can be accessed from anywhere via a Sharepoint System, enabling construction workers, project managers, auditors, project owner or O&M staff to access all information on their smartphones or tablets – to inspect building plans, for instance, or check on the progress of a specific construction task via BIM 360 Field software also plays a key role in preparing handover, by providing for “digital snagging” – identifying potential issues and communicating them in the form of a virtual punch list by referencing the BIM model (i.e. linking issues and location) – and allowing digital quality control and virtual handovers. The BIM model is also linked to an environmental library, with all relevant information about all materials used in the building; it expedited environmental certification, and it can track materials for future replacement.

The comprehensive BIM model, populated during design and construction, will then enhance O&M, making that phase as efficient as well as operator and patient-friendly as possible. By providing quick access to all relevant data about objects – installation date, exact location, actual usage – the BIM model will enable predictive maintenance. By providing access to repair manuals as well as identifying spare parts and indicating remedial procedures, it enables faster and more effective responses to typical failures. And by providing a digital 3D representation of the building, it enables better planning and quality control of daily operations, e.g. cleaning.

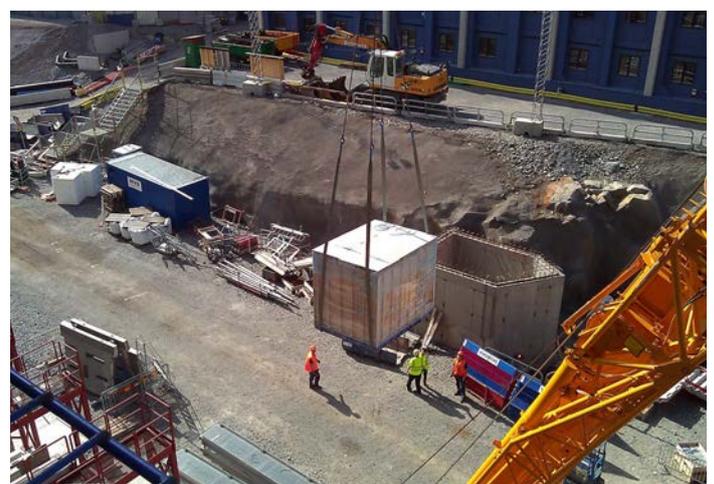
The project includes 29 automated guided vehicles (widely used in the automotive industry), which will autonomously conduct logistics within the hospital and between the different buildings – for instance, delivering medical supplies or transporting laundry. To minimize on-site traffic, the vehicles will use separate underground tunnels wherever possible. There is a central drop-off point for deliveries. Staff will be informed of deliveries via their mobile devices. For this purpose, the BIM model’s object list serves as an address book.



The Stockholm County Council takes environmental protection seriously and has made sustainability a priority for this project, both in construction and O&M. The site is classified as a Skanska Green Site with sustainable solutions at all stages, and the construction process was carefully planned to minimize the environmental impact: an on-site concrete plant pre-empted 20,000 truck trips during the first three years, and an on-site crushing plant reduced off-site transport activity as well as landfill quantities. Where required, hybrid and lower-emission trucks were used, and deliveries are scheduled to minimize interference with local traffic patterns. Construction waste is systematically analysed with the aim to reduce it to zero (in 2010, only 5% went to landfill). The work cabins are “environmental cabins”, minimizing energy consumption through heat pumps, and there is a recycling facility on-site.

Once completed, NKS will be climate-neutral, thanks to its energy-efficient insulation, a geothermal energy plant (with more than 160 bore holes, many of them 230 metres deep), the collection of food waste for biogas, and energy-saving lifts. Inside the building, emissions from chemical substances and compounds will be reduced, and the entire building will be moisture-proofed to create a healthy environment for staff, patients and visitors. All waste will be separated and transported to an on-site recycling facility through an underground piping system.

To avoid disrupting normal operations at the current Karolinska University Hospital and the Karolinska Institute, and to speed up the construction process and exploit scale effects, the planners strove to identify building components that were standard and if possible prefabricated. The new hospital’s over 12,000 rooms consist of about 650 different standardized room types. Or consider the 740 bathrooms pods, completely prefabricated and pre-fitted by a supplier in northern Sweden, which were transported in sealed containers to the local storage facility and delivered on site “just in time”, and lifted and pushed into position; all that remained was for the workers to connect the pre-fitted cables and wiring to the rest of the building (bathroom modules of this kind are standard practice in



hotel construction, but had never before been used in hospital construction). Prefabrication has been applied to other components too, and helps to reduce manual labour and avoid the need for scaffolding; prefabricated mechanical and electric modules, for example, are simply lifted to ceiling level and welded together in situ, and prefabricated structural concrete elements and façade modules are simply lowered into place by cranes.

The impact

The project has shown how the BIM model and prefabrication can boost the speed and quality of construction and commissioning, and has taken a certified leading role in sustainability.

The use of BIM was contractually mandated, and the business case for it has not yet been formally proven here, but all project stakeholders agree that it has been indispensable to the success of such a complex project. Without it, the documentation and the building work could never have reached the same quality. Evaluating the business case for BIM can be compared to evaluating the business case of using mobile phone: the benefits are numerous, diverse and obvious, yet hard to quantify exactly. Both costs and benefits are distributed among participants and increase with the number of users (network effects).

On a project involving over 12,000 rooms and a tight schedule, the snagging and smooth handover would be almost impossible, were it not for a cloud-based and mobile-accessible BIM solution. Thanks to BIM 360 Field, project managers and sub-contractors can communicate and collaborate easily and productively, trade contractors can digitally report completed works, and project managers can pinpoint potential issues before handover. Skanska (as main contractor) and the specialized trade contractors can access up-to-date information and jointly resolve issues very fast, coordination is much smoother and speedier, and there are far fewer costly errors and omissions, re-works and delays in commissioning. In addition, auditors can access from anywhere and at any time a detailed progress report of each task and object, so handover of nearly finished rooms and floors (95%

completed) can proceed accurately and efficiently. Note that the BIM model confers its complete range of benefits, and repays the investment fully, only over the full lifecycle of the building: it reduces O&M costs, boosts the quality of healthcare provision through preventive maintenance and effective repairs, and reduces operations costs by enabling the use of automated guided vehicles.

The prefabrication strategy too has had a strong positive impact on construction: it has reduced costs, facilitated logistics, accelerated installation, improved the quality of the building, and enhanced the health and safety of the workforce. The prefabricated bathroom modules illustrate these advantages. Traditionally, finishing a bathroom requires a number of different trade inputs and components – floor slabs, tiles, handrails, towel hooks, washbasins and shower units – to be applied in a very small room, resulting very frequently in delays and quality issues.

In regard to sustainability, Skanska is not only meeting the terms of Sweden's Green Building Council certification (Miljöbyggnad) as required by the Stockholm City Council, but actually going beyond them, in line with its ambition of becoming the world's greenest construction company. With parts of the main hospital building already completed, NKS has achieved the accolade not only of a preliminary Miljöbyggnad Gold rating, but also of a LEED Gold rating (for the first part of the hospital, pending verification after completion of the entire building) – one of the first hospital buildings in Europe to do so.

In its normal operations, the building will be climate-neutral with a heat-recovery system and its geothermal plant (meeting 65% of the hospital's heating and cooling demand), as well as green roofs that will provide insulation and retain surface water. The hospital's energy consumption will be 110 kWh/m² requiring 40% less energy than a comparable building constructed according to current building norms. The purchased energy will come from renewable energy sources. Note that the Miljöbyggnad certification is based not just on environmental protection, but also on a healthy indoor environment – admitting sufficient daylight, for instance, and cutting hazardous pollutants. Guided by the Swedish Schedule 19 certificate and Byggvarubedömningen (as part of the contract requirements – a building materials assessment – the project team closely collaborated with suppliers to eliminate controversial materials. For example, they managed to secure PVC-free flooring, and placing a large order stimulated the production of different colours.



BIM model confers its complete range of benefits, and repays the investment fully, only over the full lifecycle of the building.

The barriers to innovation, and the solutions

When a hugely complex and demanding project relies heavily on technological innovations, the successful implementation of those innovations depends in turn on effective knowledge exchange between the key stakeholders, early and pragmatic collaboration between project partners, and skills-building among suppliers.

The capital project is of very long duration – from the tender process in 2008 and financial closing in 2010, through to completion of construction in 2017 (and O&M until 2040) – so the project team has had to be amenable and flexible, particularly in regard to integrating new technologies. Consider again the BIM solution outlined above. Thanks to technical advances and declining costs, staff can now readily use mobile devices to access the BIM model on-site. The BIM 360 Field solution was actually introduced at NKS only in mid-2015, shortly before the handover of the first part of the main hospital building. The technology now enables project managers to inspect and sign off 250 rooms per week – a remarkable pace that was almost unimaginable eight years ago.

The driving force behind the introduction of the software was Clive Howard, Skanska Completion Manager, who had gained experience of cloud-based mobile snagging solutions on previous projects, and realized that the technology would help enormously to prepare and handle the commissioning of such a complex project. This transfer of personal experience from earlier projects has emerged as a key theme of the NKS project, and has been deliberately orchestrated by Skanska.

The building contract was awarded to Skanska Healthcare – a joint venture between Skanska Sweden and Skanska UK, which would exploit their experience of UK hospital projects. Ulf Norehn was selected as managing director for the project company Swedish Hospital Partners, specifically because of his prior experience in delivering public-private partnerships for hospital projects in the UK. More broadly, Skanska staff members from several countries (notably the UK, the US, Norway, Poland) have brought to the NKS project their experience of working on BIM projects elsewhere, and will no doubt effect a reversed knowledge transfer in due course, contributing their NKS experience to other Skanska projects in future.



Within the NKS project, systematic learning takes place, by transferring personnel from phase to phase. In particular, lessons derived from work on the first part of the main hospital building (Phase 4) are now being applied in Phase 5 and are facilitating all the remaining building work – even before Phase 4 itself is actually completed. A simple example: Fire safety consultants are now being engaged in the very first general audits in order to identify potential issues early on (eliminating a major source of delays in the previous phases).

One key challenge for the roll-out of BIM in the project (and in the industry as a whole) is the diversity of the subcontractor landscape. Many smaller (trade) contractors and suppliers lack the skill-sets and financial resources to invest in basic BIM, let alone to handle competing BIM systems with their rival standards and data formats. To get sub-contractors and suppliers to adopt BIM, therefore, Skanska had to put much effort into persuading them of its benefits and providing training courses in its usage. In the future, BIM competence will be a criterion for selection of sub-contractors and suppliers, and will be included explicitly in their contracts.

Much effort has also gone into encouraging open communication and increasing transparency about risks and errors – not to assign blame, but to identify issues and to jointly address them before they become critical and more costly. Sub-contractors and suppliers have duly become more open and collaborative, and can appreciate the benefits; for instance, by adding photos of the finished works and digitally signing off, they can cite later on-site damage (a common problem) as the source of a problem.

A major challenge in the construction industry as a whole is to reduce the lifecycle costs of assets. Normally, a contractor's responsibility ends when the construction phase ends. At NKS, the long-term public-private partnership contract – valid until 2040 – intensified the need for a longer-term perspective. One helpful step was to secure the early and active involvement of the facility manager, Coor Service Management. Facility managers are often presented with a fait accompli, whereas Coor was able to contribute operator expertise far sooner, during the project's design phase. And the company will be able to commence the O&M phase with the backing of a comprehensive BIM model – something unprecedented in the hospital sector.

One example of longer-term cost-reduction through the effective collaboration is the change in the IT landscape. The original plan specified different physical servers (one for each building control system), but the revised plan specifies a common platform with standardized virtual servers complemented by a common storage and backup solution. This consolidation will reduce IT costs during operations, but it was not budgeted for, so Coor Service Management and Skanska agreed to cover the additional costs jointly.

A recurring challenge for all BIM projects is the lack of standardized data formats and systems. At NKS, about 400 design consultants were involved, all

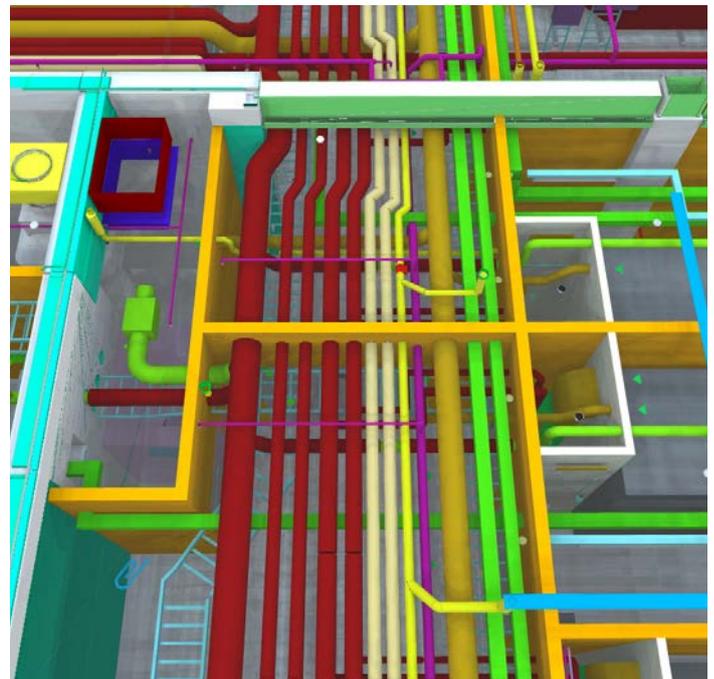
working on their own preferred system. The input from these disparate systems had to be integrated into one model. The BIM model, with its single data standard, enabled a smooth transition from the construction phase to the O&M phase, but if the original design consultants are required to adjust design aspects in future, they might struggle with the different format.

The recent transformative changes in the engineering and construction sector is even outpaced by the rapid changes affecting the healthcare sector, particularly the ongoing changes in healthcare equipment, processes and client demand. Various corresponding challenges have arisen for the NKS project; for example, the Stockholm City Council has several times required the relocation of heavy medical equipment. In anticipation of such shifts, the building was designed for flexibility, and can readily accommodate changes in usage. Some examples: vertical load-bearing columns are placed at both ends of the building, so the room layout can be adjusted fairly easily; parts of the façade can be removed fairly easily if large equipment has to be moved into or out of the building; slabs are sufficiently reinforced throughout the building in case heavy medical machinery needs repositioning at short notice (a MRI scanner can weigh more than 10 tonnes); and the piping and wiring have a built-in overcapacity of 20% to allow for extra demand or innovative uses in the future.



Lessons learned

- **Involve the facility manager or operator early on in the process in order to improve lifecycle performance**
Selecting and promptly engaging the facility manager Coor Service Management has helped the planners to take a holistic, full-lifecycle perspective of the project, and to ease the transition between phases, especially between construction and O&M.
- **Rotate personnel across countries, projects and project phases to enhance knowledge transfer**
Innovation works best when those leading and implementing it keep increasing their own expertise and sharing it with others. By seconding staff that have BIM experience on similar projects elsewhere, the NKS project has fostered knowledge exchange and optimized its own implementation of the new technologies.
- **Deploy BIM across the project's entire lifecycle and its stakeholders to maximize the benefits**
Every BIM model requires upfront investment, and the benefits are spread over the lifecycle of the project. BIM can speed up and enhance the handover and commissioning. It is important that contractors and facility managers should co-invest in the model, and planners need to find the right funding mechanism for that purpose.
- **Educate suppliers and sub-contractors on the benefits of BIM, and provide training courses to enable them to use it effectively**
The project has shown how powerful a tool such as BIM can be, especially when it is also used by sub-contractors and suppliers. It is worth putting considerable effort into persuading them of the benefits of the BIM model, discussing their concerns openly, and helping them with relevant financing and training if necessary.



Moladi Construction System: The Courthouse Project in Tanzania

A low-tech, scalable and affordable building solution
to improve and expand social infrastructure



The challenge

As with many developing countries, Tanzania needs to upgrade its social infrastructure and provide affordable housing for those at the bottom of the income pyramid.

Tanzania has witnessed strong economic growth, above 7% per year, over the last decade. However, similar to many of its African neighbours, the country lags behind in providing access to public services such as the justice system. According to the Ministry of Justice, the country faces a shortage of 3,115 courtrooms. Many rural areas have never had court buildings and some buildings have had to close due to poor quality. With the support of the World Bank, the government is now aiming to expand access to judicial services. Plans are underway, accordingly, to build hundreds of new courthouses and test mobile courts. Given the budget constraints and tight timelines, the government is seeking cost-effective solutions to constructing these additional assets. Of course, the courthouse shortage is hardly the only social infrastructure issue that Tanzania is facing. More importantly, the country has a huge housing deficit – 3 million units, the 2012 census suggests – especially for people in the lowest income bracket.

Globally, the need for affordable housing is driven by several megatrends: strong population growth in many developing and emerging countries, large numbers of people living in substandard or informal urban dwellings (“slums”), continuous urbanization, with an estimated 40,000 people moving into cities in Africa every day.

In industrialized countries, a common approach to affordable housing is to prefabricate building components. In many developing countries, however, bad road conditions tend to make that option impracticable and even causes problems for standard brick-and-mortar construction. The bricks may get damaged during transportation from the factory to the construction site. Hence, the need for new, customized solutions that are suitable for developing countries – solutions that are low-cost and adapted to local supply chains.

“
Train the unemployed to build for the homeless.

”
Hennie Botes, Founder and CEO

The idea

Devise and implement a scalable, low-tech and affordable construction solution for social-infrastructure buildings and housing – a solution that relies on local materials and labour, thereby boosting the local economy.

Moladi was founded by South African entrepreneur, Hennie Botes in 1986, with the aim of replacing brick-and-mortar construction with an easier and more affordable approach to housing. Botes was not trained as a builder or construction engineer and hence, unrestrained by conventional wisdom: he could see for himself how cumbersome the traditional bricklaying process was, and could not accept that there were no alternatives. Describing himself as a social entrepreneur, he sees Moladi as part of a larger endeavor namely, to find a comprehensive way of providing shelter for those at the bottom of the income pyramid and more broadly, to uplift communities by using local unskilled labour.

Moladi’s Construction System involves the use of lightweight plastic formwork, which is filled with an aerated mortar (fast-setting thanks to the patented MoladiChem additive) to cast entire houses on-site. The formwork itself is assembled by clipping together a set of injection-moulded, 30 x 10-20 cm plastic panels that are removable, reusable and recyclable. Once the foundation is in place (Moladi favours a floating raft kind), a building can be constructed in as little as two days. On the first day, the formwork panels are assembled. Window frames and door frames, as well as piping and wiring are positioned within the wall cavity. Additional reinforcing bars can be added to comply with local building codes and finally, the mould is filled with the special mortar. The speed is remarkable. To build a house measuring 40 square metres, it takes a team of 18 workmen barely two hours to erect the formwork and another two hours to pour the mortar. On the second day, the formwork is removed for future use, the walls are painted with a cementitious water-based paint, lighting and sanitary equipment are installed and other finishing touches added. The building process can be monitored by just one Moladi supervisor who provides on-site training and assistance to local workmen with no prior construction experience or special construction skills.

Moladi’s system is generally associated with small affordable housing units, but it can be applied to a wide variety of infrastructure assets, including schools, hospitals or courthouses, for example, as well as multi-storey buildings. The small plastic panels used in the formwork allow for great versatility and workers are able to adapt the formwork easily to the specific needs of the project.



In Tanzania, extensive market research (conducted by Ardhi University) confirmed that the Moladi system offered the most cost-effective solution to the courthouse shortage. Moladi was duly invited to construct prototypes that can be tested under different site conditions, including single- and double-courtroom buildings, two- and three-bedroom houses for the judges and court staff as well as primary-court buildings. The first Moladi courthouse (covering about 1,200 square metres) has recently opened in Kibaha, in a ceremony attended by Tanzania's Prime Minister. Based on this success, Moladi Tanzania received the go-ahead to build 11 additional district courthouses throughout the country. Over the next five years, the government plans to build a total of 120 district courthouses. Moladi is well-positioned to win the tender process, in view of its competitive pricing, social acceptance, positive impact on the local economy and employment and last, its trusted relationship with the World Bank.

Here are some details of the Kibaha courthouse project. Following the laying of a traditional raft-and-strip foundation, the construction was carried out by a group of 25 people hired locally – many of them were women and previously unemployed. The group was trained by a two-person team from Moladi Tanzania and five university students, who, very quickly, succeeded in mastering Moladi's standard building techniques, e.g. assembling the formwork panels and erecting the completed formwork; positioning window and door frames; inserting the wiring and steel structures; pouring the mortar. The formwork panels and MoladiChem were sourced from the Moladi factory in South Africa and the floor tiles from another South African supplier. All other building materials and components were sourced locally – windows and doors, the steel structures, roofing, cement and sand for the mortar. The trained workers will now in turn provide training for new workers on other projects, so that the reservoir of trained Moladi workers grows steadily and the need for supervision diminishes.

Following the initial success of the courthouse prototypes, Moladi Tanzania was commissioned to build staff houses for the magistrates, additional public-servant houses and police stations and the associated police housing – all in keeping with Moladi's core objectives of developing the local area and helping communities to uplift themselves.



The impact

Sure enough, these buildings are high quality and are being constructed at impressively high speed, low cost, low environmental impact and are contributing to local economic development.

The main advantages of the Moladi Construction System are the speed and ease of production, the lower costs and reduced environmental impact, the quality of the end product and the localized supply chain that benefits the local communities.

Regarding costs, by employing local labour, using local materials and reusing the formwork, Moladi keeps overall project costs at a very modest level. Costs are further reduced and changes avoided thanks to the Moladi wall-construction process, which incorporates plumbing and electrical installations within the mould and makes walling surface finish unnecessary. The 1,200 square metres Kibaha courthouse was built for a total cost of about \$300,000 (including 18% VAT) or \$250 per square metres – roughly half the cost of conventional methods and competing bids. Costs should decline even further once local production of the plastic formwork panels begins. These ultra-low costs are crucial to help people with very low incomes. Another major advantage of the Moladi Construction System is its cost transparency. The use of plastic formwork means that it is very easy to calculate beforehand the quantity of materials and the working hours required.

Regarding speed, the Kibaha courthouse might have taken three years to complete via conventional construction methods. It took just six months using the Moladi methods. In fact, things would have moved even faster, were it not for the initial testing and training needed and teething troubles such as duties on formwork imports from South Africa. The second courthouse took a mere four months from start to finish thanks to the reusable assembled formwork, which is made of lightweight plastic and is easy to transport. Also, the project benefited from the workmen and women's previous experience. In future, comparable buildings are expected to take less than three months. By the end of 2016, it is planned to complete a total of six courthouses .

In terms of quality, the rapid and cost-effective construction process does not require a compromise in quality. Moladi buildings are built to last. The company's earliest buildings, dating back 30 years, remain resilient and serviceable. The cast walls have a strength of between seven to 15 newton/mm² – considerably stronger than traditional brick-and-mortar structures. The technology has undergone extensive testing and received certification from several national building authorities, including the South African Bureau of Standards and the Tanzania Bureau of Standards. The structures are also reported to be very earthquake-resistant, on the basis of tests conducted by the University of Panama.

Regarding the environmental impact, the Moladi system keeps the environmental impact to a minimum by sourcing local materials, optimizing thermal properties and adopting reusable moulds. Moladi buildings generate

about 50% less CO₂ than traditional brick-and-mortar buildings of a similar size (due to the CO₂-intensive brick production). The lightweight formwork can be reused up to 50 times on nearby projects, thereby reducing the CO₂ emissions as well as costs associated with transport and manufacturing (between sites the assembled formwork can be transported very easily). The plastic panels can even be recycled, typically into toilet seats.

And last, regarding the effect on the local economy, in contrast to other affordable housing solutions, which use prefabrication and precast concrete to reduce manual and on-site labour, the Moladi system is specifically designed to be labour-intensive and low-tech, in order to provide local employment opportunities. Instead of using machine casting, Moladi requires the mortar to be poured manually – however, mechanical casting can be applied. Moladi also strives to build up local supply chains and assembly lines for building components such as doors and windows. Concrete tiles and pavers can be cast on-site for use in villages. Labour can be readily recruited and trained locally given the lightweight panels and the avoidance of heavy lifting, many of the workers are women (women have proved to be more reliable than men). For the Kibaha courthouse, 25 local workers completed all the formwork and walling, before local subcontractors took over to complete the roofing.

Moladi's solution involves a building system rather than a turnkey model and therefore, is scalable. The system has been applied to build several thousand units in 20 countries in Africa (e.g. South Africa, Nigeria, Tanzania), South Asia (Sri Lanka) and Latin America (Mexico, for two-storey buildings and Panama). Moladi is now preparing for expansion into the United Kingdom and other industrialized countries that have a shortage of affordable housing. One of the virtues of the Moladi system is that it can be adapted easily to local building codes and conditions, by integrating the required reinforcing structures into the cast. Currently, the system is limited to single- or two-storey buildings, but Moladi is working with engineers to upgrade its construction processes and mortar, with a view to qualifying for multi-storey buildings.



The barriers to innovation – and the solutions

The resistance shown by the established building industry and the scepticism shown by local communities can be countered by building demonstration units; supply shortages and design challenges can be resolved by enhancing local supply chains and integrating Moladi building technology from the outset.

Scaling up the Moladi solution will not be easy. There is scepticism on the part of developers and clients towards the new building technology; and there is resistance from the traditional building and masonry industry, which is keen to protect its vested interests by lobbying government, for instance. One response of Moladi's is to set up demonstration units to explain the advantages of its technologies and convince clients. Once the Moladi philosophy gains traction, the company aims to work together with local people as distributors. In the case of Tanzania, social entrepreneur Abeid Zagar was won over when visiting Moladi's South African factory in Port Elizabeth, thereby becoming an advocate of the technology. He invested in a demonstration unit as early as 2010, and was instrumental in getting Moladi selected for the courthouse projects.

To sidestep resistance from developers, however, Moladi has had to make some adjustments to its business model. In South Africa, Moladi is now adopting a turnkey model to develop buildings, including financing. Such a move is only possible when the supply chain is a mature one and easily accessible, as in South Africa.

Another barrier to innovative construction processes is the regulatory one. Moladi has actively sought and quickly gained approval by regulatory authorities in many countries. As mentioned, its technology is now certified by the Bureau of Standards in South Africa and in Tanzania. The company is registered as an official contractor by Tanzania's National Housing Institutions and it has a partnership with the country's Transnational Bank, which provides credit to Moladi and accepts the buildings as collateral.

From the point of view of government, one particularly strong selling point for Moladi is that it serves as a one-stop shop. Its Champion Teams bring together a range of experts – engineers, urban planners, architects and renewable-energy specialists – to offer a holistic vision and solution for rural development.

A further barrier for Moladi is social acceptance. It is a barrier encountered by any affordable housing solution, especially if the solution is imported from abroad. In Tanzania and many other African countries, the population will often take a very sceptical view of prefabrication measures: gypsum-board walls, for instance, are regarded as less strong and weather-proof and building site visitors tend to knock on the walls to check for solidity. Moladi's cast structures, however, always gain immediate approval because they provide the same reassuring, solid sound as traditional brick-and-mortar walls. In fact, most people are so happy with the finishing of the cast walls, they do not even request skimming or painting.

Moladi has gained further social acceptance by maximizing the benefits for local communities. Its

projects source all materials locally (apart from the formwork), and employ local workers. As mentioned, the building process is specifically designed to be labour-intensive, and can provide employment to local communities without requiring special skills or technologies. Moreover, Moladi's hiring strategy is designed to avoid conflict with the local population. During training, observers identify those trainees that are most motivated and skillful. The latter are subsequently appointed foremen who, once confirmed, may pick their own teams, without any further involvement by Moladi.

The workers are contracted on a project basis, but their prospects for further employment are good. Their initial training equips them to work on other sites and they are often specifically assigned to new projects to train workers there. And there seems to be no shortage of new sites, given Moladi's rate of expansion. Indeed, one interesting outcome of Moladi's economic boost to local communities is that the demand for Moladi housing is rising. Another beneficial outcome is that each local community has a sense of integration with the project and a sense of ownership, which reduces the incidence of building site theft.

A further challenge facing Moladi in countries like Tanzania is the local supply chain. In South Africa at least, the company has managed to develop a complete supply chain, including production of the plastic formwork, window frames, door frames and roof tiles. In other countries, however, local production capacity has to be built up. Importing the materials from South Africa is not only more costly, but also likely to cause serious delays in construction. (The Kibaha courthouse encountered import duty problems and eventually had to resort to alternative materials.) In Tanzania, negotiations are now underway for a new factory that will produce the formwork locally and Moladi is establishing alliances with local suppliers for windows, doors, floor tiles and cement, e.g. considering a collaboration with Dangote Cement. By bypassing distributors and other middlemen, Moladi will be able to reduce costs even further.

Finally, the design challenge: the Moladi system relies on standardized plastic formwork panels (30 x 10/20 cm) that impose limits on new designs and can sometimes, clash with existing designs. In the case of the Tanzanian courthouse prototypes, for instance, some general designs had already been proposed and they now had to be adjusted to comply with allowable wall heights (multiples of 30 cm) and wall lengths (multiples of 10 cm). Wall heights are also constrained by the relative slenderness of Moladi walls vis-à-vis conventional construction. These minor



changes in building design will in turn affect the sizing of windows and doors. Accordingly, Moladi takes care to integrate all phases of a project, starting with the planning phase, to gain fullest advantage of the Moladi system and avoid costly reworks or last-minute supply changes.

Lessons learned

- **Adapt the solution to local conditions and develop a service offering in tune with market requirements**
The best solution can sometimes be low-tech (involving much manual labour) and locally sourced. Such a solution is truly scalable as Moladi's experience has shown.
- **Create tangible prototypes to demonstrate the look and feel of the solution as well as the technology's potential**
Any innovative approach to affordable construction is likely to provoke scepticism. By building prototypes that people can actually see and touch, Moladi won them over and created social acceptance.
- **Work closely with regulators and government to gain official approval and backing**
In the face of traditionalist resistance and scepticism, companies can validate their new technology by obtaining certification from the government and regulators. This formal endorsement then paves the way for publicly procured projects.
- **Build a broader ecosystem, notably a dedicated supply chain, to make the solution work**
Approaches that break the status quo typically require different supplies, skills and processes. Developing an efficient local supply chain is key to implementing innovation successfully, even for a low-skill and low-tech solution such as Moladi's.
- **To overcome resistance by established companies, it may be necessary to adjust currently accepted business models**
Moladi's original and overarching mission is to provide affordable building technology (notably plastic formworks and MoladiChem), continually refine its system and optimize the product. In South Africa, however, in the face of concerted resistance and scepticism by local developers, Moladi opted to forward-integrate along the construction value chain by offering turnkey solutions as well.
- **Think holistically about the problem to be addressed and seek a comprehensive solution**
As a social entrepreneur, Hennie Botes has always thought of his construction solution as part of a broader endeavor – community advancement. The projects should not only provide shelter but also improve the lives of local communities via social infrastructure and employment opportunities. This requires a holistic solution that serves as a one-stop shop for governments by incorporating the planning of entire villages, including housing and social-infrastructure assets (schools, hospitals, courthouses), as well as measures to integrate renewable energy.



Burj Khalifa

Constructing the world's tallest building and an iconic landmark leveraging innovation in building materials and techniques



The challenge

A record-breaking skyscraper, in keeping with the concept of a vertical city – the vision is one thing, but realizing that vision is another and requires both persistence and ingenuity.

When Emaar Properties acquired a site of abandoned military barracks to develop the 500-acre mega-project that is now Downtown Dubai, the vision was to “create one of the world’s leading urban destinations”, according to Robert Booth, Chief Executive Officer of Emaar Dubai Real Estate, at the time. The development as envisaged would take about 20 years of work, concluding in 2025, at an estimated cost of \$20 billion. It was to have iconic architecture that would attract great admiration and boost real-estate value. And its centrepiece was to be a breathtaking super-high-rise building, the tallest skyscraper in the world.

The new building, as imagined by Mohamed Alabbar, the Founder and Chairman of Emaar Properties, would overtake the 449-metre record that was held by Taipei 101 in Taiwan. Alabbar’s masterplan was for a mixed-use super-high-rise, incorporating hotel accommodation, private residential apartments and varied commercial premises – in short, an integrated vertical city, which would mark a new approach to the worldwide challenge of mass urbanization and megacities. And what a challenge that is: the outlook is that, by 2030, the world will have 41 megacities, each with more than 10 million inhabitants; and, by 2050, two thirds of the global population will live in cities. Urban centres are going to have to build high – even higher than today – to accommodate their workforce and residents. According to its advocates, the concept of vertical cities will become a widespread reality: vertical cities reduce traffic and urban sprawl, by combining different usages – living, working and leisure – within a single location.



The idea

Bring together an experienced team, work closely with suppliers, and engage government early on to build at top quality and dizzying heights.

When planning of the Burj Dubai tower (later renamed Burj Khalifa) began in 2002, it was already clear that many innovations would be needed in the design, construction and building technologies. The initial design brief was for a building of 550 metres. When the planned height subsequently increased to 750 metres, the innovation imperative became even clearer. And more so still when the main contract was awarded in 2004: the target height at that stage had surged again – with the encouragement of the visionary Sheikh Mohammed Bin Rashid al Maktoum, Vice-President and Prime Minister of the United Arab Emirates and Ruler of Dubai – and necessitated static recalculations of the foundations.

Three major themes characterized this flagship project: first, a highly experienced international team, allowing effective knowledge transfer, diligent front-loaded planning and optimized logistics; second, close and proactive collaboration with innovative suppliers; and third, early engagement with government and other major stakeholders.

The team

Regarding the first theme, the developer Emaar Properties put great effort into assembling a project team from across the world, with both experience and expertise in super-high-rise construction. The design was led by the Chicago-based design firm Skidmore, Owings & Merrill. The construction-management team from Turner International was brought onboard in 2003, very early in the planning process. Turner’s main construction manager, David Bradford, had already been involved in the construction of Taipei 101, so was ideally positioned to plan and oversee the highly complex construction logistics of Burj Khalifa.

At the time, in the early 2000s, Building Information Modelling (BIM) was not in wide use and the Turner team leaders focused on an analysis of the project to avert the bottlenecks and obstacles they had encountered when working on Taipei 101 and similar projects. Their high-rise experience also helped them to split up the Burj Khalifa project into work packages that could be executed in parallel, to speed things up. Construction of the first levels, for example, began as early as 2004, while the design of the upper levels was still in progress.

Another key ingredient of the project’s success was the detailed attention paid to the selection of consultants, contractors and suppliers. Turner managed all contracts centrally and included very detailed specifications and performance incentives, including penalties for delays. In total, more than 40 speciality consultants – experts in fire and safety, concrete-mix design, or lighting, for example – were hired early on to liaise with the relevant external stakeholders, in particular the suppliers and government authorities. Samsung, with its rich experience in superstructures, was selected as the main contractor and headed a group of contractors that included BeSix from Belgium and Arabtec from the UAE.

The project team also paid particular attention to logistics – a crucial emphasis, given that about 12,000 workers could be active at peak times. Prefabrication and lean construction methods were exploited to the full to keep on-site tasks to a minimum. Consider two contrasting examples. First, the approach to windows: in total, 26,000 panels were needed, involving 120 standard designs. The window panes would vary according to their destined position in the building, to suit the different wind speeds. The window panels were prefabricated and assembled off-site, then put in containers and transported to the site, lifted by cranes and slotted into place. Second, the workers' canteens: during the later phases, they were located temporarily on higher floors of the building to avoid the long travel times that a central ground-level canteen would require.

Collaboration

Close collaboration with innovative suppliers, the second theme, played a central role in the implementation of the various state-of-the-art innovations. The suppliers of building materials and technologies were invited very early on to provide their expert opinions. Even before the main contract was put out to tender, two leading formwork specialists – Doka and Peri – were consulted and their feedback prompted changes both to the architectural design and to the construction process. For instance, the project team decided to use poured concrete for the walls of the lift shaft to speed things along. Fortunately, the project team was experienced and flexible enough to accept suggestions from collaborators and to feel comfortable with ambitious innovations. Such a tall building would probably have been unrealizable without pioneering some of the very latest technologies. The GPS-controlled jump formwork is a case in point: to control for verticality as the building rose, conventional optical laser-based methods could no longer be relied on, so a new military-precision GPS system was adopted (and has now become standard practice in high-rise construction). Other innovative technologies included Favco's diesel-powered self-climbing cranes, which avoid the voltage drops plaguing normal electric cranes at such heights, and the special concrete pumps, which set new records in pumping concrete.



In fact, some expert observers consider the concrete technology to be the most innovative feature of the entire project. The concrete supplier, Unimix, contracted the German concrete-pumping specialist Putzmeister to develop, test, supply and install high-pressure pumps – able to reach a height of about 600 metres and withstand the required 200-bar pressure. The composition of the concrete mix was fine-tuned in extensive tests to guarantee fluidity and ultra-high strength, and to cater for different applications in the building's floors and concrete core. Construction often took place in extreme temperatures of more than 40°C, so the concrete mix would sometimes be cooled with ice rather than water, and the quality of each concrete batch would be rigorously tested.

Engagement

The third theme – close and early engagement with the government authorities and other key stakeholders – would prove a great help in converting the vision into a reality. Almost from the start, negotiations with the local authorities got under way. Local consultants, specially hired for the purpose, liaised with the Dubai municipality for building approvals, with Dubai Civil Defence for fire, life and safety protection, and with the local utility company for electricity.

The benefits of such prompt engagement can be seen vividly in two cases: the regulations regarding concrete and the electricity supply. The existing policy on concrete meant that each pouring of a concrete slab would have to be approved individually after an inspection on-site – hardly practicable in the context of a skyscraper with 200 levels, 160 of them habitable, and an ambitious timeline. The project team negotiated a solution with the municipal authorities: a specialist and properly certified consultant, jointly agreed on, would supervise the pouring of concrete and report to the municipality. As for the electricity supply, the conventional approach was again impracticable. Normally, transformers would be placed in the base of the building, but in the case of Burj Khalifa, the consequent voltage drops would be too severe, and daily operations would be jeopardized. The obvious solution was to locate transformers on floors throughout the building though the local utility company was uneasy about defying standard practice and feared complications if the transformers broke down. Both sides were committed to the collaboration, however, and eventually found a satisfactory compromise: transformers were placed on different floors and the design was adjusted to provide for a special lift large enough to transport a transformer up and down if it needed repairing or replacing.



The impact

Burj Khalifa has broken several world records for buildings, has indeed become an iconic urban landmark, and has tested and vindicated many innovations on the way.

Burj Khalifa is a project of superlatives and has broken numerous world records. At 828 metres, it is the world's tallest building and tallest man-made structure. It took less than four years from the first excavation works to reach level 141 and overtake Taipei 101 as tallest building, and just three years more to reach completion and be formally inaugurated, in January 2010. The building also has the world's highest aluminium and glass facade and holds the record for vertical pumping of concrete – 605 metres!

These and all the other records would have remained pipe dreams had it not been for a series of innovations in building materials, technology and techniques. The remarkable speed of construction was made possible by careful logistics planning, effective collaboration with specialist suppliers and experts, and up-to-the-minute technological advances. Thanks to the prefabricated and packaged window panels, for example, the site engineers managed to increase the installation rate from an initial 20-30 window panels per day to an impressive 175 panels per day. And thanks to a combination of innovative technologies and optimized planning, the concrete cycle of an entire floor could be completed in a mere three days.

Burj Khalifa has become an architectural icon of the modern world, attracting thousands of visitors every day and making Downtown Dubai a favourite urban destination. According to an Instagram analysis, Burj Khalifa now ranks third in the world on the ultimate edifice metric – selfie popularity – beaten only by the Eiffel Tower in Paris and World Disney World in Florida, but ahead of New York's Empire State Building and Big Ben in London.¹

Tourists flock to the observation decks on levels 124, 125 and 148, travelling in one of the world's fastest lifts. Their enthusiasm is shared by the building's occupants, commercial and residential alike, and those of surrounding buildings: "view-premium" owners pay handsomely for an unobstructed view of the tower. As Emaar Properties had reckoned, real-estate value has indeed risen and the company's decision to invest only in top quality (\$1.5 billion of investment, for Burj Khalifa specifically) has indeed paid off.

¹ The National (2015). "Dubai's Burj Khalifa one of top selfie hot spots in the world". 2 November 2015. Retrieved 14 February 2017, from <http://www.thenational.ae/uae/tourism/dubais-burj-khalifa-one-of-top-selfie-hot-spots-in-the-world>.

The barriers to innovation – and the solutions

Scepticism in the construction industry can be overcome and unforeseen setbacks can be turned to advantage when offset by a clear and resolute vision, precise planning, and effective collaboration.

It comes as no surprise that the proposal to build this unprecedented structure was met with scepticism from planners, government officials and potential investors. Alabbar was undaunted and retained his vision – supported by the far-sighted ruler of Dubai, Sheikh Mohammed – not just of building Burj Khalifa but also of developing the entire site, however many years it would take. Strongly convinced that quality pays off in the long term, Alabbar resolved to invest upfront in world-class contractors and technology to turn his vision into a reality. He vetted many of the detailed decisions himself, including the design, the selection of artworks throughout the building, decor for the lobby, and furnishings in the apartments. Pre-selling 80% of the apartments helped to fund the project, with several down-payments linked to construction progress.

For Sheikh Mohammed and Alabbar, the sky was the limit (almost literally). When construction was already well under way, they pushed the team of designers and construction managers to increase the building's height. Fortunately, the design team from Skidmore, Owings & Merrill had incorporated a contingency buffer into their structural calculations, and, for instance, allowed for a giant damper at the top to absorb the movements of the building. It turned out, however, that such extra stabilization was not required, thanks to the wind-breaking properties of the building's Y-shaped cross-section, so the height of the building could be increased without too much trouble – by almost 200 metres beyond the initial brief. The unutilized space for the damper at the top was eventually converted into a private mosque – breaking another world record.



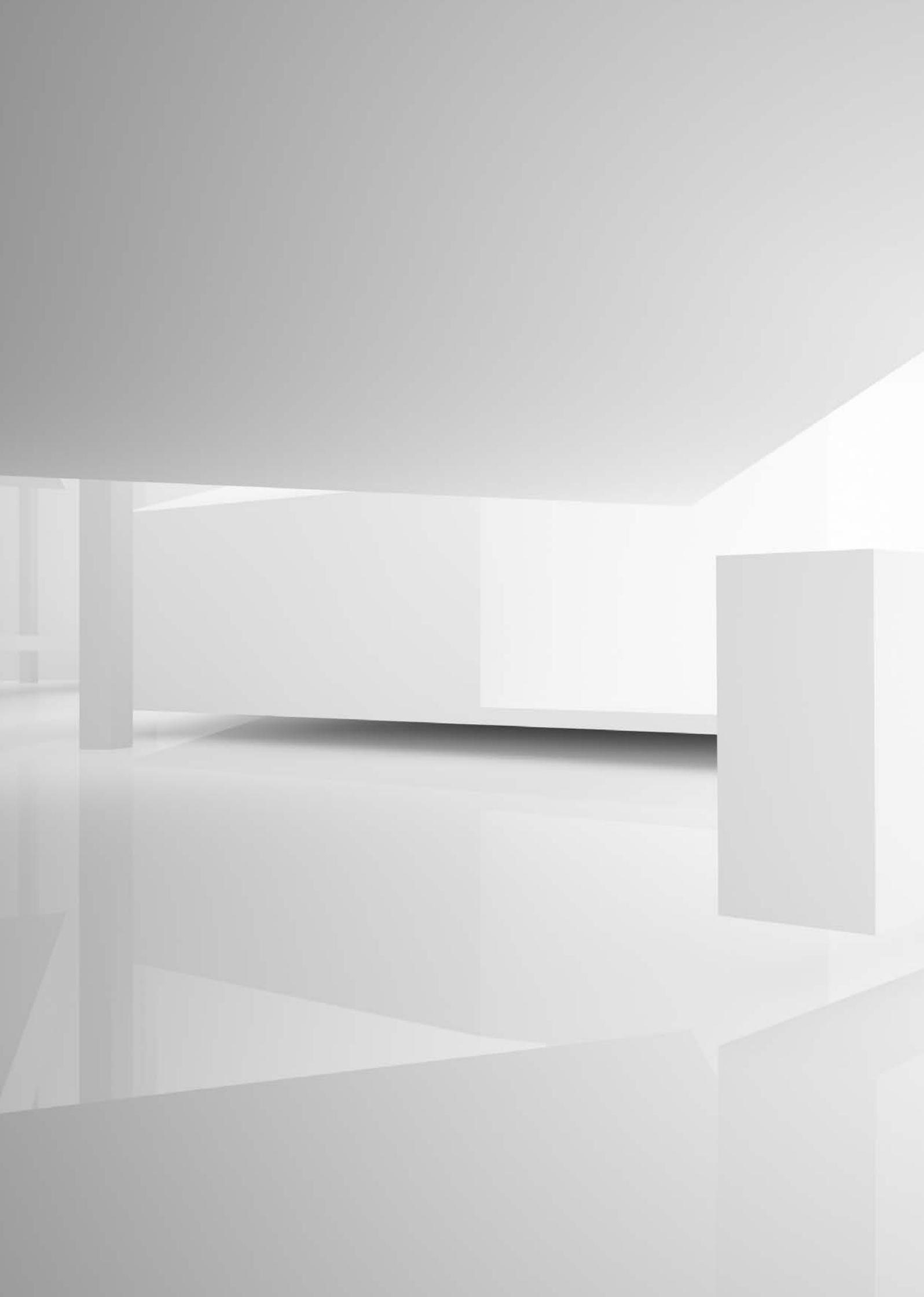
The most challenging moment for the project was when Schmidlin, the Swiss supplier of the window panes, declared bankruptcy in 2006, just nine months after it signed the contract. Schmidlin's joint-venture partner Arabian Aluminium would have to find a replacement supplier very quickly if it was to keep to the schedule. With the help of the project team and its international network, a high-quality supplier was soon identified, the Hong Kong-based Far East Aluminium. Initial testing confirmed the quality of the panes and quality control thereafter continued to validate their high standard: of the 26,000 panels delivered to the site during the construction phase, only 30 were rejected.

So Burj Khalifa's exterior cladding is the result of a cross-border supply chain and international collaboration. The glass panes were manufactured by Far East Aluminium and final assembly took place in the UAE, where the window panels were put in containers for delivery to the construction site. There the containers were picked up by cranes, dropped at loading areas on to the right floor, pushed on wheels by workers to the right location inside the building and lifted into place by a chain-hoist system. The actual installation was conducted by a team of international professionals, as the correct placement of the panels required considerable experience.



Lessons learned

- **Develop and maintain a vision to motivate everybody and to reject the status quo**
By being personally involved in the project, proudly and prominently, Dubai's ruler Sheikh Mohammed and Emaar Properties chairman Mohamed Alabbar provided the requisite driving force behind the development of Downtown Dubai and the construction of Burj Khalifa. Their unwavering vision inspired the project team to go beyond the known limits – increasing the building's height and implementing still-unproven processes and technologies.
- **Assemble an experienced, best-in-class team to drive innovation**
Alabbar had a long-term investment horizon as well as a long-term vision, and a determination not to compromise on excellence – a threefold motivation to assemble an expert team that had deep experience of super-high-rise structures. The formation of this team had the effect of maximizing knowledge transfer, enabling excellent upfront planning, optimizing logistics management, exploiting prefabrication to the full, reducing risks and facilitating collaboration with the technology providers and innovators.
- **Collaborate closely with suppliers to develop, test and implement innovations**
Most of the project's innovations – notably, the concrete-mix design and pumping, the GPS-controlled jump formwork and the prefabricated window panels – were developed by suppliers, though it required close collaboration between contractors and suppliers to test and implement the innovations in Dubai's challenging physical environment. In many cases, the expertise of the various partners was invoked as early as the planning phase, to enable pre-emptive modifications and avert costly reworks. A striking example is Doka's recommendation to use poured concrete for the elevator shaft.
- **Engage regulatory authorities early on to speed up the approval process**
For high-visibility projects, there is pressure to get things started (and completed) as soon as possible. All the more so in the case of Burj Khalifa – one of Dubai's flagship projects. The project team, being so experienced, knew the importance of early engagement with regulators and other enablers, and how best to go about it. The team promptly approached and negotiated with the relevant Dubai government agencies and utilities providers to expedite the official go-ahead and overcome any subsequent obstacles that might arise.



Anglian Water @one Alliance

Improving the construction and performance of infrastructure assets by forming an alliance of contractors and suppliers, and by taking a broad programme approach that enables standardized products



The challenge

Infrastructure for water and wastewater services has room for improvement and has to respond to the sector's key challenges – reliability, sustainability, affordability, and workforce health and safety.

In developed and developing countries, the water sector has to deal perpetually with a set of broad challenges: enhancing the infrastructure assets, while keeping their construction costs and lifecycle costs to a minimum; ensuring health and safety at sites; and minimizing any harmful environmental impact. At the same time, the water sector – in common with other grid-based, monopolistic infrastructure services – is tightly regulated in regard to both pricing and service levels. Against this background, companies have to make considerable efficiency improvements if they are to generate sustainable returns.

Anglian Water is the largest water and wastewater company in England and Wales (by geographic area). It serves about six million customers in the East of England, and has about 4,200 employees. In striving for ever greater reliability, affordability and sustainability, the company responds to customer requirements and to regulatory Outcome Delivery Incentives (ODIs), including its performance on service and pollution. For the current regulatory period of 2015-2020, the company aims to increase efficiency in infrastructure delivery (i.e. reduce capital costs) by over 15% relative to the 2015 baseline, to halve the time spent on-site relative to the 2009 baseline, and to lower embodied carbon (CO2 emissions related to the construction phase, including the transport and installation of materials) by 60% and operational carbon (CO2 emissions generated by the assets during the operations phase) by 27% relative to the 2009 baseline.

Viewed at the global level, the water challenge is obviously of a different order. Society is heavily dependent on the water sector for providing drinking water and irrigation in agriculture, and for enabling many industrial processes. In developed countries, the existing infrastructure often dates back to the early 20th century – the average age of water infrastructure assets in the UK is estimated at 70 years – necessitating ongoing investment in repair and upgrading. In developing countries, basic infrastructure is still missing in many regions: worldwide, over 660 million people lack ready access to drinking water, 2.4 billion people lack access to basic sanitation services, and more than 80% of wastewater resulting from human activities is discharged into rivers or the sea without any prior treatment.



The idea

Adopt an Alliance model based on effective collaboration in integrated teams, and take a broad programme approach that encourages product standardization and digitally enabled product lifecycle management.

To improve the quality, efficiency and sustainability of its infrastructure assets, Anglian Water realized that it could benefit by more effectively drawing on a great deal of supply chain expertise. To that end, it adopted an innovative collaboration model. Launched in 2005, the @one Alliance formally links Anglian Water Asset Delivery (Anglian Water's team responsible for the capital delivery process) with six key contractors – Balfour Beatty, Barhale, MMB (Mott MacDonald Bentley), Grontmij (Sweco), MWH and Skanska – and the wider supply chain through framework agreements. During each five-year regulatory period, the Alliance designs and builds the majority of Anglian Water's projects, numbering about 800 and costing about £1.2 billion (\$1.5 billion) in total.

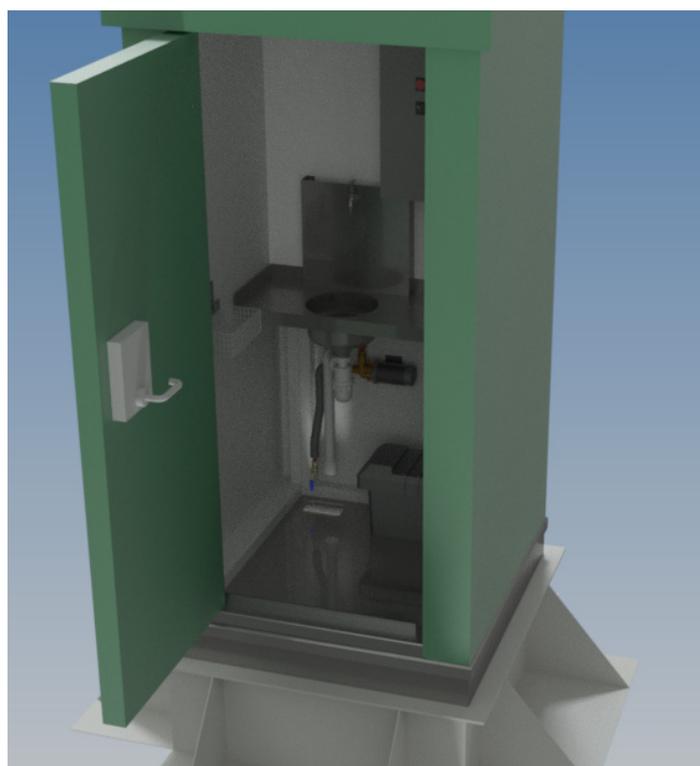
The @one Alliance was developed by analysing and benchmarking supply-chain models from different sectors (retail, manufacturing, etc.), and six key elements were identified as characterizing these models: alignment, incentives, collaboration, integrated teams, visible programmes and minimizing of waste. Anglian Water then conducted a selection process among relevant contractors (with preferred bidder status), assigning much weight to their collaborative ethos, and the Alliance was duly formed as a virtual joint venture. Each partner sends secondees to the integrated Alliance, contributes to the overall organization in proportion to its individual share and receives a proportional share of the joint profits. Every five years, Anglian Water and the Alliance Leadership team evaluate each partner's contribution. Based on this assessment, partners are renewed, replaced or supplemented.

One defining element of the @one Alliance is the emphasis on collaboration in pursuit of a common goal. The six partners are aligned with Anglian Water through a set of common objectives linked directly to customer outcomes. These are cascaded through the Alliance and the supply chain with an emphasis on improving performance and generating value. The Alliance is able to take a holistic and longer-term view, rather than just focusing on individual projects. This broader outlook is in keeping with Anglian Water's five-year investment programme – which is shared with the Alliance as a prioritized list of both maintenance works and quality improvements. The work within the programme is allocated to the various partners on a "best for task" basis. Performance of the Alliance is measured against a defined cost base, with each alliance partner receiving a share of the combined efficiency based on their respective shares in the alliance. The alliance model is contrary to the industry's usual approach – the classic bidding process, which is based on the belief that only competition can ensure cost-efficient solutions.

The collaborative model extends to suppliers. For the wider supply chain, the alliance sets up long-term framework agreements. These agreements mean that 80% of the Alliance is now covered by framework contracts or partnerships.

The culture of open collaboration contributes significantly to the Alliance's success. All partners assign staff to the alliance, who then form integrated teams. Through this integration and constructive relationships, a highly productive exchange of information and experience takes place – often more effectively than happens within each individual company. Each project begins by creating a high-performance integrated team with inputs drawn from all partners based on this best for task approach. This approach frequently leads to valuable new ideas and innovations. While every partner in the project will benefit in various ways, any intellectual property emerging from it is retained by Anglian Water.

Another key enabler of the @one Alliance's innovations and success is the longer-term perspective implicit in its programme of projects. Instead of tackling each project individually, the partners are able to identify repeatable tasks and standard products, and apply them inexpensively on a wide array of projects – taking advantage of off-site prefabrication for production. Following a comprehensive analysis, almost 200 standard products have subsequently been identified and developed in partnership with suppliers. Product-based delivery is now a cornerstone of the Alliance's work. Based on the Alliance programme, workflows are revisited and value engineering is applied to develop new products before the demand from specific projects arises. All products are integrated into 3D product libraries for design, process calculations, and piping and instrumentation drawings (P&IDs), greatly facilitating the work of designers, project managers and process engineers.



This approach to product-based delivery can be illustrated by looking at a number of simple examples. First, there are the “sampling kiosks” used for checking the water quality at reservoirs. Traditionally, each kiosk was individually built on site on a large concrete base, and required a large lead time. Faced with the challenge of refurbishing or replacing about 50 kiosks in a short timeframe, the Alliance developed a new standard product – a space-optimized solar-powered booth manufactured off-site, which can be stored at Anglian Water's sites and installed at short notice – and on a quickly-constructed metal base rather than on a concrete foundation.

The second example is that of “trickling filters” – biological wastewater treatment systems that use a biofilm to remove impurities from the water trickling through a bed of media. The new standard product is far quicker and cheaper to construct; it also dispenses with the traditional concrete base, with the side walls using low-carbon recycled plastic sheets, which are pre-fabricated and assembled on site into rectangular or hexagonal tanks.

Another great example is the Air Valve (AV) Standard Product (for clean water). Traditionally, Anglian Water used large ductile iron AVs that were difficult to maintain and often inefficient. Challenging its suppliers to reduce embodied carbon, a new reinforced nylon product was developed.

Finally, the product team is currently working with suppliers of kiosks and motor control centres for a Motor Control Centre (MCC) Kiosk & Trench standard product to harmonize sizing and avoid extensive civil works for concrete structures. To this end, the team visited the factories of its suppliers to better understand the manufacturing process and identify optimization potential.



The Alliance intends to enhance its standard-products strategy in the future by means of product optioneering (i.e., assessing different options) and by improving plug-and-play assembly. It will also simplify procurement by linking its product catalogue directly to suppliers – just like in online shopping. All that the project team then has to do is “add products to a basket and check out” – greatly facilitating budget calculation and automating procurement schedules. The outlook is that by 2020, 67% of capital spending will be on standard products, and 90% of projects will include at least one standard product. The Alliance is also working with other water companies to develop joint standard products, exchange best practices and work towards an industry-wide product catalogue that would enable further cost savings.

One final distinctive feature of the Alliance is its adoption of product lifecycle management (PLM). Used mainly in complex manufacturing industries, such as aerospace design, PLM leverages digital technologies to enable digital development and operations of assets and thereby reduce costs. Digital data are collected and integrated throughout a product’s lifecycle – from the design phase to operation and maintenance (O&M) and eventually to the dismantling stage – so it is now possible, for instance, to automatically

create a maintenance manual before the asset is actually constructed. The PLM process outdoes even building information modelling (BIM) in its emphasis on the customer and the operating environment. It starts by modelling customer or operator requirements, and then creates appropriate instrumentation diagram/drawing (P&IDs), integrates them into BIM 3D models and enables early collaboration across all teams, establishing integrated plans for Alliance partners and suppliers.



The BIM model can be reviewed virtually by the delivery team – including sub-contractors, suppliers, and health and safety specialists – and by the operating team in a digital rehearsal room using immersive technology (augmented reality) before construction even begins. (The safe-to-operate and safe-to-maintain reviews are likewise conducted virtually.) The design is then optimized virtually. Modular and off-site construction can then progress, with the help of integrated module-based procurement and pre-planned logistics. During the O&M phase, maintenance and service teams can access information remotely. This digital process has been successfully piloted on several projects now, and full roll-out across the programme is underway: the digital rehearsal room now serves as a gatekeeper for every new project.

The impact

The Alliance’s approach has reduced costs, carbon emissions and accidents substantially, and continues to boost customer value.

Ultimately, the Alliance’s performance is measured by Anglian Water’s success, in respect of customer outcomes and generally increasing value for clients. However, the Alliance has also set its own targets relating to project delivery, including workers’ welfare. Broadly, the organization has three key objectives: efficiency, sustainability, and health and safety.

Efficiency has increased impressively. Thanks to effective collaboration of partners and suppliers, the conscientious use of standard products (and hence off-site construction) and PLM, the Alliance achieved annual savings of 2 to 3% while increasing quality of service delivery to its customers over the last 10 years, considerably outperforming the sector.



Sustainability has improved substantially too, mainly through the Alliance's Sustainability in Design initiative. Embodied carbon (CO₂ emissions related to the construction phase, including the transport and installation of materials) was reduced by 54% from 2010-2015, against a 50% target; and operational carbon (CO₂ emissions generated by the assets during the operations phase) was reduced by 41%, against a 20% target. These figures serve as a benchmark for the entire infrastructure sector.

Regarding health and safety, the Alliance's performance improved from being at industry average in 2005 to being an industry leader today. The @one Alliance partners work collaboratively to exchange best practice with one another and with suppliers. Overall, the accident frequency rate rate of more than 7 days has plummeted from about an accident every 300,000 hours worked to one every million hours worked.

These improvements can be attributed largely to the standard products strategy. Taking the product examples again: the sampling kiosks are today produced and installed at a cost of just 77% relative to the 2005 cost, embodied carbon has declined by 11%, and operational carbon is now zero, thanks to the use of solar power. As for the trickling filters, they cost just 70% relative to the traditional solutions, and involve only 45% of the embodied carbon. Finally, the new reinforced nylon air valves constitute a step change compared with the previous metal-made components: they only weigh 1kg instead of 25kg, increase ease and safety of installation, save 90% on embodied carbon and 36% on costs, and have a longer design life thanks to their corrosion resistance.

The barriers to innovation, and the solutions

Success depends on changing the traditional mindset, culture and procurement models, and on pursuing effective collaboration, long-term partnerships and a continuous improvement philosophy.

The immediate obstacle facing the Alliance was the old-fashioned culture and mindset of the engineering and construction, and utilities sectors. First, the leadership team had to convince senior executives at all partner companies, including Anglian Water, that collaboration was indeed the best approach; that effective collaboration would lead to better outcomes than project-level competition (the latter being the norm in such a project-based industry). Second, the team had to adapt everyone to product-based thinking instead of approaching each project individually. The focus is now on product development – once a product is developed design engineers have to become product optimization and integration engineers. Some experienced professionals can struggle with the idea of choosing from a product catalogue rather than designing and planning from scratch. Recent graduates find it much easier, of course, and this cultural adaptability is reinforced in the training sessions for new hires.

The new digital technologies (forged by the PLM), being so unfamiliar to most employees, and the rapid pace of change, have obviously presented challenges of their own. The Alliance team continues to drive that change by nurturing an open and innovation-friendly environment, in which employees can test and develop new ideas. Recent examples include individuals developing digital apps for the optimization of installed treatment processes. The role of the Alliance itself is changing as a result of the digital technologies: it is becoming more and more an integrator of different technologies in an open system. As such, PLM is designed as a very open system, able to integrate different software solutions and thereby avoid becoming dependent on any one provider.

A related challenge was to create a continuous-improvement organization, much more closely resembling a manufacturing company. Previously, the view had been that any efficiency would be limited by diminishing returns, and that initial progress after its set-up was just the Alliance benefitting from low-hanging fruit. The Alliance leadership, having learned from the continuous improvement approach of other sectors, including from some of the world's top manufacturing companies, has tried to instil the new approach into the organization. Improvement initiatives now constitute a core component of the business plan. As part of the continuous improvement efforts, project teams are encouraged to suggest ideas for improving products or processes. If an idea is considered promising, it might be tested by a "pathfinder project", for which the team gets full client and leadership support. If the pathfinder is successful, the solution is quickly rolled out to the entire organization.

Another potential barrier was the old standard procurement procedure, which excludes suppliers and contractors from the early planning and design phases. The Alliance overcame that barrier by adopting a long-term relationship model – on the one hand, the shareholder principle of the core partners, and on the other, framework agreements with the wider supplier network. This model allows the contractors and suppliers to participate in developing the designs, rather than being "dragged in" at a later stage to work on the delivery.

The long-term relationship model has several interesting features to avoid typical shortcomings of traditional procurement practice. On the contractor side, alliance partners, after studying the White Book initiative plan, decide if they can generate a return and participate in the Alliance. If so, they are set performance-based minimum requirements instead of traditional detailed engineering specifications – a huge step for a utility company, and are expected to work in a very collaborative way, and only use standard products as far as possible.

The team had to adapt everyone to product-based thinking instead of approaching each project individually. [...] Design engineers have to become product optimization and integration engineers.

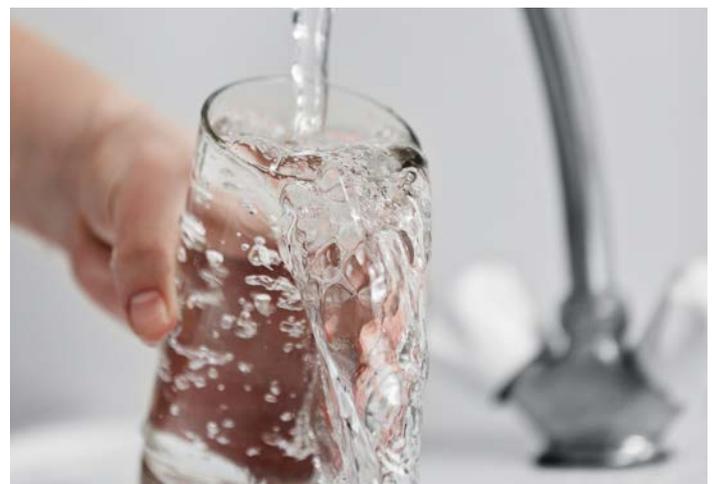
On the supplier side, the Alliance welcomes new suppliers that want to enter into a framework agreements, allowing a constant inflow of new ideas and avoiding complacency among the incumbents. Specifically, the Alliance engages with suppliers and screens their proposals by means of the open Water Innovation Network, a free membership network for suppliers in the water industry to develop innovative solutions. Anglian Water poses specific challenges for optimizing its products and everybody is encouraged to submit their business case – often the best ideas come from outside the water industry.

Lessons learned

- **Collaborate to the maximum, and share best practices with your partners**
The success of the @one Alliance proves the value of open collaboration and best-practice sharing in the E&C industry, both within a company and between companies. So much depends on breaking down silos and siloed thinking – allowing for integration and collaboration across all project teams, departments and companies as a whole.
- **Take a programme approach and strive to develop standardized products**
By taking a longer-term and more holistic approach to capital projects, organizations can identify repeatable tasks and potential synergies between similar projects. That was the basis on which the Alliance was able to define standardized products and move from traditional design and construction to assembly and integration. The Alliance could guarantee suppliers an order for a fixed quantity of units over a five-year period, and the suppliers could then confidently invest in production capacity. The use of standard products allowed for off-site prefabrication and improved quality control, and thereby led to large efficiency gains.
- **Adopt a continuous-optimization mindset**
From other manufacturing industries, the Alliance has learned the value – and the methods – of becoming a continuous improvement organization, rather than just focusing on the delivery of individual projects. Two crucial aspects are: working closely with suppliers; and creating a conducive environment for employees to develop new ideas.



- **Adapt procurement models that foster collaboration**
The Alliance favours close collaboration from the very start of a project, during the planning stage. That attitude is incompatible with traditional procurement models, in which suppliers begin their involvement much later, during the bidding process. The Alliance has found that framework contracts, aimed at forging long-term relationships, help to intensify and sustain collaboration, and also generate appropriate incentives to improve performance.
- **Leverage digital technologies across the entire product lifecycle**
The Alliance's PLM approach shows the potential of fully leveraging digital technologies throughout the entire lifecycle; virtually testing and operating assets with the help of augmented reality before construction allows to optimize design before construction is initiated. In addition, quality and effectiveness of operations and maintenance can be enhanced substantially through a fully integrated BIM model.
- **Foster cultural change to embrace new mindset of continuous improvement and product-based delivery**
Success of the Alliance is reliant on the change in mindset required on the side of Anglian Water as well as the Alliance partners and suppliers. Being conscious about this challenge and leading it through dedicated initiatives (e.g. improvement initiatives) and providing training for new hires and especially for experienced professionals were key to instil the new way of thinking.



BROAD Sustainable Building

Bringing manufacturing principles to the construction of high-rise buildings



The challenge

The engineering and construction sector is glaringly lagging behind other industries in process optimization, knowledge transfer and lean principles.

Construction projects today are conducted in a very similar way to those of several decades ago: the bulk of work is still done on-site, with little automation and process optimization. The sector has not fully entered the third industrial revolution, let alone the fourth.

One of the problems is inherent: the construction site. Although it does allow lean principles to be applied to some degree, it is not really conducive to them. The full potential of lean principles in the construction process, transport and logistics is difficult to realize outside a factory setting.

A quite different problem is the industry's inattention to knowledge transfer. True enough, each construction project tends to be an individual, unique, one-off project, but that is no reason for companies to approach it as an individual challenge. It will obviously share many characteristics with earlier projects and would benefit greatly from any lessons yielded by those projects. Yet few companies have a systematic knowledge-transfer policy. As a result, the construction industry – unlike almost all other industries – has barely raised its productivity level in generations and has a poor track record for on-budget budget delivery.

This downbeat assessment is even bleaker in the developing and emerging countries where construction projects remain heavily reliant on low-skilled labour and use less machinery and equipment. The construction process is, therefore, generally less efficient and the built assets are of lower quality.

One final shortcoming of the industry: inadequate environmental and resource protection, especially in developing countries. Construction remains the largest consumer of raw materials, and buildings are responsible for about 30% of greenhouse gas emissions.

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The E&C industry is not even in the Third Industrial Revolution, let alone in the Fourth; a step change is required.
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Future of Construction Session in Davos 2016

The idea

Prefabricate buildings off-site to increase the speed and quality of construction.

The origins and emphasis of Chinese BROAD Group were in manufacturing – producing (non-electric) air-conditioning systems for commercial buildings, such as Dubai Mall or Qualcomm HQ, or for civil infrastructure facilities, such as Madrid Airport. And things might have stayed that way if it hadn't been for a parallel preoccupation on the part of the group's chief executive and chairman, Zhang Yue. He had grown increasingly frustrated with the building industry – not only with its often suboptimal quality standards but also with the prevalent disregard for environmental protection.

Backed by his abundant manufacturing experience, Zhang Yue resolved to revolutionize the construction of buildings by applying manufacturing industry processes and principles: factory-made components, quality-management strategies, and energy-efficiency techniques. In 2009, he duly founded BROAD Sustainable Building Co. Ltd (BSB) – a BROAD Group subsidiary specializing in the prefabrication and assembly of high-rise buildings.

Central to its technology are two massive components that are prefabricated in large production lines. The first is the standardized floor plate, a steel frame structure measuring and measuring about 16 x 4 metres (about 64 square metres). Each giant plate is pre-fitted with pipes and wires, and with flooring (such as tiles or laminate). The second centrepiece is the structural steel column, to bear the load. The plates and columns are loaded on to trucks, together with the appropriate tools and equipment (such as bolts), and transported to the construction site for assembly.





During assembly, the prefabricated columns are erected and the floor plates are simply fitted into position, making the construction process “as easy as playing with Lego”. The role of the on-site workers is mainly just to connect the steel columns, bolts and wall panels, and to link up the pre-installed wiring and piping between the plates.

Prefabrication is used for other components too – exterior walls, for instance, complete with four-pane windows and integrated solar shading. Once delivered to the building site, these walls are lifted into position by cranes. In total, 90% of the building is prefabricated in the factory, which maintains efficient production and enables rigorous quality control.

While most buildings are delivered as turnkey products, clients can place orders to their own specifications. They might require only the building shell, for instance, or only the structural components for use in their projects.

BSB has invested more than USD 650 million into R&D and production capacities. Its Xiangyin factory spans 230,000 square metres, and can now produce 5 million square meters of BSB components per year.

In keeping with his vision of environmental responsibility, Zhang Yue favours the trend in which people both live and work in the same building, thereby reducing land use and commute. Accordingly, BSB concentrates on high-rise construction. However, its technology can be applied to other building types, too. It is particularly well-suited to the hospital sector, for instance, since hospitals have such high operating and maintenance costs and could greatly benefit from the energy efficiency that BSB buildings allow.



The impact

BSB's technology proves how steel-frame prefabrication reduces the speed and cost of construction and at the same time increases quality and energy efficiency.

BSB's prefabrication strategy has many advantages over traditional construction techniques, in respect of time, cost, environmental impact, and overall quality.

Time: BSB's speed of construction is especially impressive. Famously, a 57-storey building was completed in just 19 days, having risen each day by three storeys typically. Contrast the 3-10-day cycle (for pouring concrete and allowing it to cure) involved in each individual storey in traditional high-rise construction. Note, too, that BSB's avoidance of concrete, except in the foundations, reduces the building's weight to a mere third or even a fifth of its traditional counterpart.

Cost: Shifting the bulk of work to the factory enables a huge boost in efficiency, thanks to scale effects and lean principles. On-site work is transformed; assembling the building involves little more than a series of short, straightforward, standardized tasks. Factory production also reduces transport and logistics costs, as building materials can be stored and handled in large quantities off-site.

In combination, the efficient manufacturing, assembly and logistics will reduce the costs of a new building by 20%-40% relative to traditional in-situ construction methods. That amounts to a reduction of at least \$1,000 per square metre from the average conventional cost (in Europe, North America and Australia) of about \$3,000 per square metre.

Environmental impact: BSB buildings typically have thermally insulated walls 15cm-30cm thick, triple- or quadruple-glazed windows, fresh-air heat-recovery machines, external solar shading, and (unsurprisingly, given the company's background) up-to-the-minute air-conditioning and ventilation. The result is impressive: five times the energy efficiency of conventional Chinese buildings and 1% the level of air impurities – a particularly attractive combination for hospitals, of course.

BSB buildings have further environmental benefits. Construction waste is less than 1% (as opposed to 5%-10% for conventional buildings), and the buildings can be dismantled easily, offering the prospect of reuse and recycling of steel. As for emissions during the construction process, they are now virtually eliminated as negligible air and noise pollution is produced when the cranes lift the prefabricated modules to their final position.

Quality: BSB buildings excel in many dimensions of quality. Their light-weight and ductile yet stiff steel structure enhances earthquake resistance, for example. That resistance is rigorously tested and BSB buildings are certified to withstand magnitude 9.0 earthquakes. In the devastating 2008 earthquake in Sichuan, thousands of deaths might have been avoided

if the housing had been of higher quality. Protecting people against earthquakes was one of Zhang Yue's initial motivations in establishing BSB in 2009.

In emerging and developing countries, part of the reason for low-quality construction, as mentioned earlier, is its heavy reliance on unskilled labour. By replacing that traditional approach with a standardized, quality-controlled manufacturing process, BSB boosts the quality and safety of new buildings and greatly reduces the need for costly rework.

Since its foundation, BSB has completed more than 30 pilot and commercial projects, almost all of them in China. The most celebrated of these pioneering projects is Mini Sky City (J57), the 57-storey building erected in only 19 days, as described above. Its construction was captured in a time-lapse video that made international headlines and received millions of clicks on YouTube. BSB also constructed the 30-storey T30 building in 15 days and the 15-storey Newark Hotel in a mere six days.

BSB won the Council on Tall Buildings and Urban Habitat (CTUBH) Innovation Award in 2013 – the first Chinese construction company to do so. The presenters paid tribute to the company's technology and its "innovative way of fundamentally rethinking tall building construction". BSB has also received much attention from the media and academia around the world (including Reuters, the BBC and the Harvard Business Review) and was praised by UN General-Secretary Ban Ki-moon for its exemplary sustainable buildings. In 2011, the United Nations Environment Programme honoured Chairman Zhang as its Champion of the Earth for his entrepreneurial and environmental vision.



The barriers to innovation, and the solutions

Scepticism from architects, engineering and construction firms and end-users is far from insuperable. BSB collaborates with design institutes, builds showcase projects and sets industry standards for quality to introduce its innovations into the engineering and construction ecosystem.

Given its clear advantages, why is BSB-style prefabrication technology not more widespread? The main impediment seems to be that of scepticism from architects and designers, whose education would have concentrated on classical construction methods and who tend to associate prefabrication with low quality. To overcome this scepticism, BSB has partnered with several design institutes for the design work and has successfully obtained approval from the national experts committee on construction and the government for the planned 838-metre world's highest building, "Sky City". BSB has launched a joint venture with a design institute in Wuhan not only for planning and designing BSB buildings but also for educating designers. One aim is to show that the floor-plate structure, although standardized, is still amenable to innovative and creative design.

Mistrust of prefabrication is not limited to architects and designers but extends to potential clients as well. BSB's strategy in this regard is to publicize its processes conspicuously. The now-famous internet videos have not only educated the market but also have promoted the BSB brand. And the company has validated its image by rigorously implementing its production-quality principles, in much the same way that Toyota did in the automotive industry. And then there is the sensational prospect of the 220-storey edifice, the Sky City building. Even if the plan is never realized, the vision itself has captured the interest of industry stakeholders around the world. Regulators and property developers alike are becoming more receptive to and impressed by BSB's technological capabilities, and that should facilitate the company's forthcoming endeavour to expand its sphere of operation and to co-invest in flagship construction projects in core markets such as New York or Guangzhou.

Another obstacle that BSB encounters is the lack of environmental awareness on the part of potential clients. In China and other developing countries, many project owners and developers still do not care about the advantages of energy-efficient buildings. That said, the construction ecosystem in China is showing signs of change, with a growing concern for the sustainability and lifecycle performance of buildings. Part of the impetus is no doubt due to government commitments on greenhouse gas emissions. And BSB's showcasing of prefabricated and high-rise buildings conveys a reassuring message to developers: that an environmentally responsible approach generates considerable savings – on the land needed, on materials, and on operations and maintenance.

One other broad obstacle is worth mentioning: the system of third-party supervision that dominates the Chinese construction sector (and is a source of corruption within it). BSB has always been challenging this system – implicitly, by setting quality standards and pressing for more certification; and explicitly, by working with government institutes to promote their *guidelines* on prefabrication into *regulations*. Happily, things are changing. Although prefabrication accounts for less than 1% of construction today, the Chinese government aims to increase that share to 30% by 2026, with a special emphasis on steel structures. Hunan province, with BSB in support, is taking a leading role in this regard. In a similar vein, BSB is seeking to secure its international expansion by getting its technology properly appreciated and accepted in other countries, and is working with international partners to acquire formal certification and building permission.

BSB moved quickly to make its presence felt in the market and demonstrate the power of its innovative technology. As soon as it was equipped to create a minimum viable product, it did so but was hardly going to rest content with that. The company is constantly refining the manufacturing process and striving to optimize the characteristics of the materials. One weak point of steel structures generally is their susceptibility to loss of integrity due to fire and the potential corrosion that will affect them during the lengthy lifetime of the buildings. In response to this challenge, BSB developed the *stainless-steel honeycomb structure*, which improves stability as well as extends the building's life and avoids rework due to corrosion. This form of steel imitates the natural structure of honeycombs and combines strength, thinness, high-temperature resistance, anti-corrosion and sound isolation – and all at an even lower weight and thus higher specific strength than standard steel components. What's more, the honeycomb structure completely avoids concrete – nothing short of a revolution in the construction industry.



Previously, such honeycomb steel, being very costly to produce, was limited mainly to aerospace design, but BSB succeeded in bringing down the cost dramatically by inventing automatic copper-brazing streamline production. The company also uses the innovative steel for columns, crossbeams, floor slabs, walls and roofs.

The stainless-steel honeycomb component will be produced in panels of standard size – 12x2 metres and 15cm thick. That will facilitate BSB's expansion into overseas markets, as the panels will fit into a 40ft container for remote low-cost transport. To rapidly promote BSB technology globally, BSB plans to establish local joint-venture factories and hire local workers for mass production. Through a network of local factories with local supply chains, BSB can not only avoid tariff payments, technical and labour barriers but also contribute to an equitable development of the global economy.

One final possible barrier – again, mainly in developing countries, with their labour-intensive construction processes – is resistance by local stakeholders of traditional buildings, in particular from workers as well as architects and designers who fear losing their jobs. BSB's planned franchise system should address that challenge to some extent – by sharing the benefits locally, BSB would increase buy-in. Two key elements of this strategy are a strict selection process for partners, and in-house training courses provided by BSB to guarantee quality. Candidate partners would need to have experience in manufacturing, government support and sufficient funding to pay the technology licensing fee (about \$50 million). They would then have a production line that produces 2 million square metres of BSB components per year and can receive any subsequent technology updates for free.

BSB's mid-term objective is – within five years – to reach a market share of 10% of all new buildings.

Lessons learned

- **Apply winning principles from other leading industries in construction**

With its background in manufacturing, BSB brought a fresh perspective to the design and construction of high-rise buildings, using the techniques, quality standards and lean principles of the manufacturing industry to enhance both efficiency and quality.

- **Combine a standardized platform with easy customization**

BSB presents its standardized technology platform (a platform based on floor plates) as an opportunity rather than a limitation. Clients are able to customize the building according to their needs via a simple menu – an approach familiar to the automotive industry but a novelty in the engineering and construction sector.

- **Provide training and information to designers and architects to overcome their resistance and to create multipliers**

To raise awareness and increase acceptance of its disruptive technology, BSB will partner with several design institutes to engage and train designers and architects – key agents in promoting the technology. As for resistance from construction workers, that should ease once the local joint venture system is rolled out and brings benefits to the local economy.

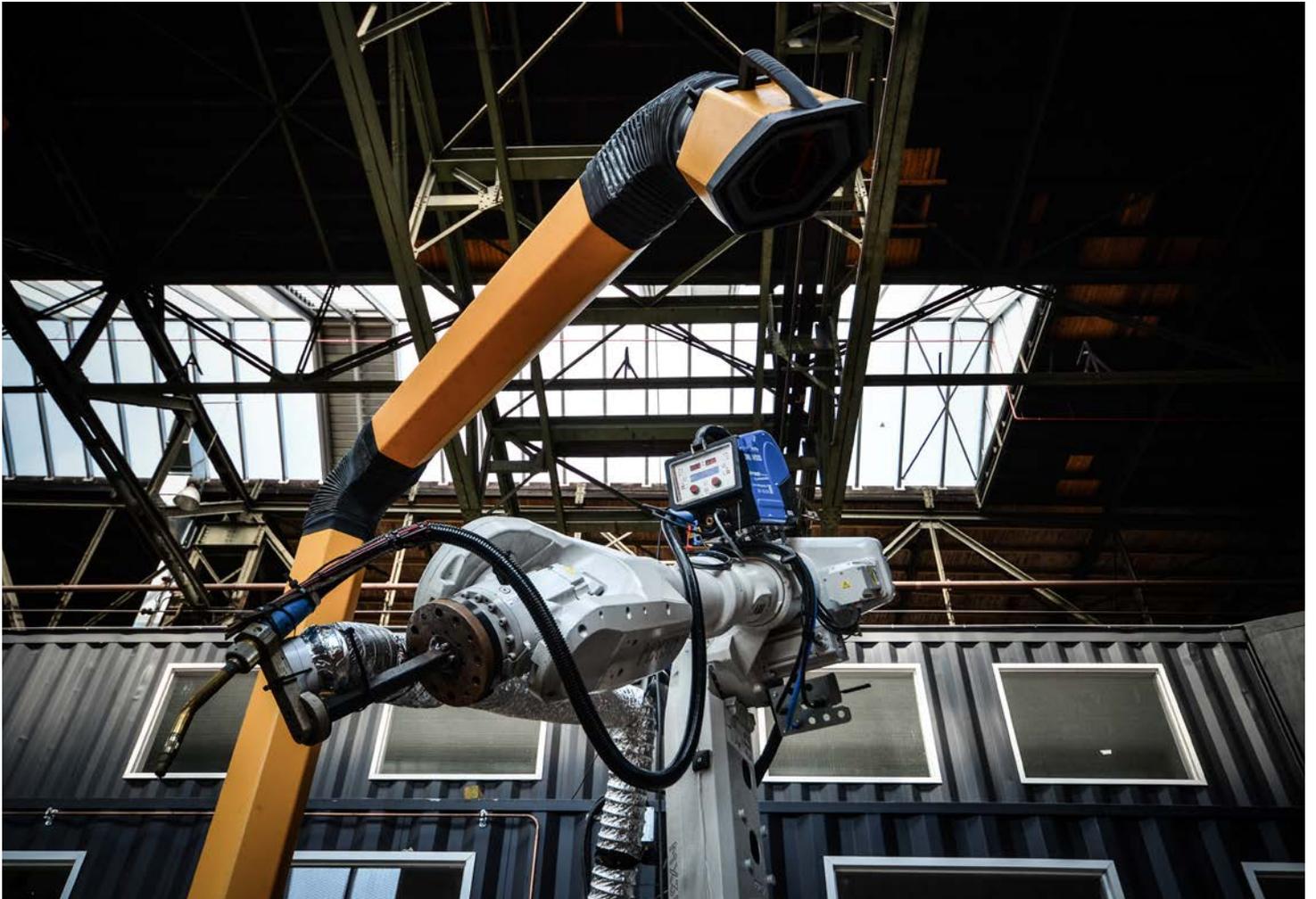
- **Develop a minimally viable product to showcase an innovative approach and, from that basis, continue making incremental improvements**

BSB quickly developed a basic viable product to demonstrate the power of its technology. By systematically refining its production processes and optimizing the materials used, the company has constantly expanded its horizons, releasing new generations of buildings and developing the innovative honeycomb structure component. This rapid prototyping has featured prominently in BSB's guerilla-marketing strategy (YouTube time-lapse videos) to create global awareness of its technology.



MX3D

Collaborating with key industry partners to advance on-site fully autonomous robotic 3D printing in the E&C sector



The challenge

While other industries have been eagerly embracing automation and the automation of equipment, the engineering and construction (E&C) sector has been hesitant.

Over the past 50 years, the productivity of most industries has surged but it has virtually been at a standstill in construction. One of the main reasons for this is the difference in degree of automation. Manufacturing industries are currently experiencing the Fourth Industrial Revolution, with the automation of production and smart factories. Even the fragmented agricultural industry has adopted autonomous equipment (by leveraging geographic information systems (GIS) data). The construction industry has been very slow to follow the trend but is at last beginning to catch up. Companies are now making use of autonomous bulldozers or welder robots. However, apart from these dirty, dull and dangerous applications, the construction process remains heavily reliant on low-skilled workers, especially in developing and emerging countries.

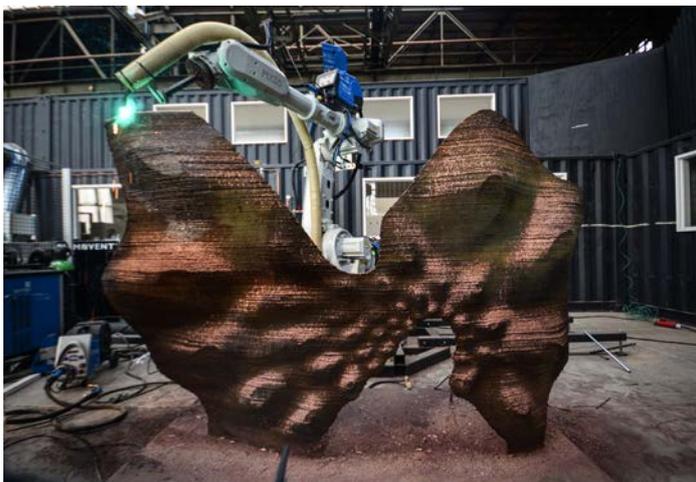
The idea

Apply robotic 3D metal printing to the construction process.

MX3D is a technology start-up that is developing an easy-to-use “plug & print” robotic additive manufacturing software platform to transform standard industrial robots (six-axis robotic arms) into a large-scale, mobile, 3D printer for construction.

MX3D’s particular interest is metals, and the company specializes in wire-arc additive manufacturing (WAAM) technology, which uses standard welding wire and is faster, cheaper and easier to scale than rival additive

Transform standard industrial robots into a large-scale, mobile, 3D printer for construction.



manufacturing technologies, such as selective laser melting or powder-bed printing. In principle, however, the MX3D software can be applied to other materials as well, such as concrete, plastics and resins.

MX3D was founded by four innovation entrepreneurs as a spin-off start-up of the Amsterdam design studio Joris Laarman Lab. In 2004, the lab started experimenting with new technologies such as 3D printing for complex artworks (their works are featured in leading museums such as MoMa, the Pompidou Centre and the Rijksmuseum in Amsterdam).

MX3D was set up in 2014 and turned its full attention to venturing into large-size robotic additive manufacturing. Its flagship project, The Bridge – printing a steel pedestrian bridge in Amsterdam – will demonstrate the technology’s viability and power, as well as attracting the attention of potential customers and suppliers. In addition, the aim is to develop a supply chain strong enough to fulfil large orders for steel wire, specialized welding gases, software and other essential input factors. The bridge is scheduled to be printed by the end of 2017 and installed at the beginning of 2018.

The project has brought MX3D into a creative collaboration with some major industry players, enhancing the technology with their complementary competencies. These partners include the industrial-robot specialist ABB, the design- and engineering-software provider Autodesk, the Dutch E&C company Heijmans, the specialist gas supplier Air Liquide, and the steel producer ArcelorMittal. Other stakeholders in the project include the Amsterdam City Government and Delft University of Technology (with the aid of AMS, the Amsterdam Institute for Advanced Metropolitan Solutions).

The vision for the future is to develop and market the software for fully autonomous robotic 3D printers – printers that can move freely, for example, on construction sites and shipyards, to create printed structures by adding layers from below, from above, or from the side, and can supplement the workforce by completing tasks during off-hours.



The impact

The construction industry can at last enjoy the freedom of design that 3D printing affords.

The main advantage of 3D printing technology is that it allows freedom of design to be a practical option at last. E&C companies can now utilize algorithm-based or “generative” software to optimize the design of buildings and to design special lightweight beams and other components – in short, to “build what we could not build before”. By no means do E&C companies try to replace standard parts but instead they leverage 3D printing for very complex components that can be combined with traditional construction methods – that is, to “add to the tools that the E&C industry already has”. In fact, if the entire building design takes account of it from the outset, the technology has even far greater potential.

Traditionally, 3D printing technology has been used only for complex, high-value, low-volume products. And indeed, that is how MX3D technology generates its highest value currently – by significantly reducing lead times and costs for casting complex structures that would otherwise take up to several months. But MX3D is also becoming increasingly competitive

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Using technology “to build what we could not build before”

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Gijs van der Velden, Co-Founder and Chief Operating Officer

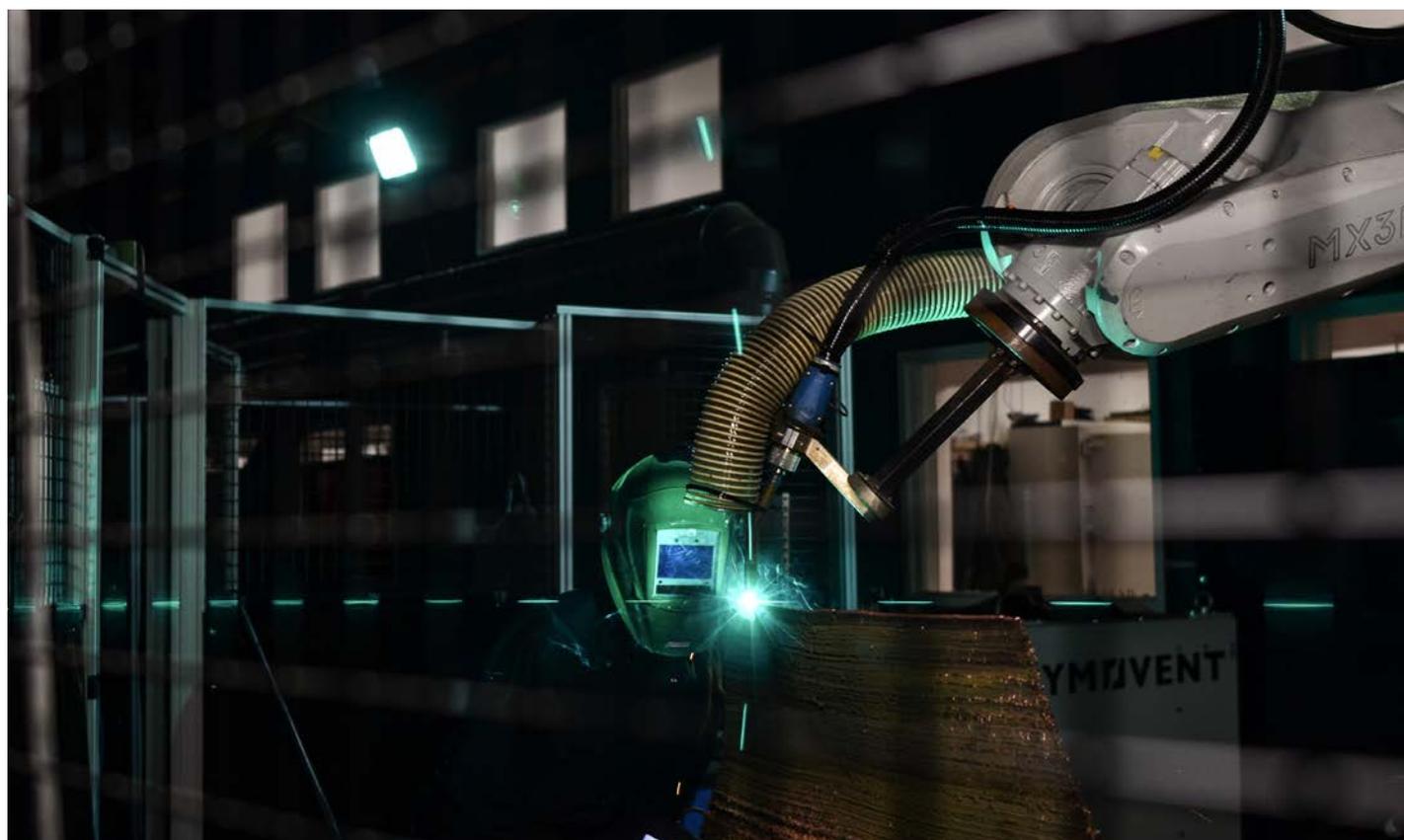
at making or installing standard parts, thanks to its technology that transforms standard industrial welder robots into 3D printers – with large cost savings.

MX3D’s 3D printing technology offers environmental benefits, too. Being fully integrated into digital construction models and tools, it provides a very accurate method of producing structures, with zero waste and minimal, and costly rework. What’s more, by allowing material savings through optimized shapes (if the weight reduction is at least 7%), 3D printing technology emerges as the most eco-friendly technology in a Lifecycle Analysis by the TU Delft.¹

The technology has now moved beyond the prototype stage. MX3D has just signed its first deal for a museum pavilion in the United States, where its proposed solution was judged the best and cheapest for realizing the architect’s distinctive vision. This success bodes well for the company’s strategy of initially targeting unique architecture projects to accumulate experience and then expanding into large-scale construction projects.

MX3D was fortunate in having as a springboard the reputation of Joris Laarman Lab, so it quickly attracted global media attention (from *Time*, *The Economist* and *FastCompany*, among others) and was able to establish its brand as a leader in autonomous metal printing.

¹ Bekker, A.C.M. (2016). *Intermediate results of the sustainability comparison between WAAM, Green-sand casting, and CNC milling, by means of an LCA*. TU Delft (forthcoming).



The barriers to innovation, and the solutions

The persistent conservatism of the E&C sector creates difficulties for new technologies in regards to fundraising, regulation and attracting clientele. Rather than trying to meet these challenges by going it alone, MX3D has engaged in various imaginative and rewarding collaborations.

One of the main barriers that the fledgling MX3D encountered was the difficulty in securing seed-financing for its innovation venture. Seed capital in the construction sector is rare: *technology venture capital firms* tend to avoid the E&C sector because it is large and slow-moving. *General venture capital firms* tend to avoid it because they lack industry know-how. And construction companies themselves are hesitant to invest in any emerging technology. Traditionally conservative and risk-averse, they prefer to wait for a technology to prove itself before adopting it. They see little appeal in the strategy of developing a minimum viable product for later scale-up, since industry is heavily regulated for reliability and safety, and it tends to think in large-scale rather than small-scale owing to the generally low margins.

Mindful of these barriers, MX3D decided to seek its initial financing (a modest \$1.5 million) not from construction companies but from equipment specialists and technology providers – funding sources that are known to be more innovation-friendly.

The construction industry conservatism was alien to MX3D's founders, who have a background in technology, arts and design. They “were lucky not to have too many builders in the group” and brought together an interdisciplinary team of experts in metal printing and 3D design, capable of creative thinking and revolutionizing aspects of the industry.

In keeping with the more open culture of arts and design, and lacking the expertise and skills anyway to develop its solution solely in-house, the MX3D team opted to design and market The Bridge as an open innovation challenge – a specific and tangible project that others in the E&C space could immediately relate to. Sure enough,

companies approached MX3D to participate in the project, to advance their R&D on 3D printing and accumulate knowledge jointly with MX3D and with one another. MX3D's collaboration with some high-profile industry names has given the project considerable credibility.

The collaborators help to resource the project, through cash or in kind, but their most important contribution is complementary expertise: ABB enables MX3D to realize the full potential of its robots; Autodesk develops the underlying generative design and optimization software; ArcelorMittal provides its metallurgical expertise; Heijmans supplies building expertise; Air Liquide contributes its welding experience; and the University of Delft, as a research partner, is conducting several scientific research projects, such as developing an independent lifecycle analysis of the technology and a methodology for mechanical property testing of complicated shapes.

The project has a core team of seven to eight people, mainly innovation managers or R&D specialists. Although the intellectual property is owned and will remain with MX3D, the collaborative approach enables the partner companies, jointly and individually, to extend their knowledge, and to explore and develop new solutions. MX3D serves as a hub, organizing regular informal meetings. But the partner companies are now also collaborating on other projects beyond The Bridge and, by publicizing these joint projects, have generated interest and demand from their respective customers. Additionally, the open-innovation approach is prompting creative challenges in other industries. For instance, MX3D's technology raises the possibility of quick-print spare parts for propellers or rudders in the (sub-)marine industry, thereby reducing the vessels' downtime, or repairing dredging equipment on-site, thereby requiring a smaller stock of spare parts and inventory cost and potential downtime.

Another barrier to the realization of the The Bridge project – and, more generally, to the advance of 3D printing in construction – is the absence of authorization and clear regulation. In response, MX3D decided to involve the Amsterdam City Government early on and thereby enhance the dialogue and smooth the review process. The city government has come to regard The Bridge as a prestige project, which helps to define



Amsterdam as a hub for innovation. As MX3D's co-founder and chief operation officer Gijs van der Velden says: "The first step was to make everybody want this project." The result is that the city government is open to discuss the conditions for such a permit and does this only under strict supervision of Heijmans – taking a performance-based standards approach that guarantees safety. Despite the lack of certification and the difficulty of modelling the 3D-designed structure with traditional engineering software, the completed bridge will be load-tested in a controlled environment before its final set-up.

More broadly, MX3D is shaping the regulatory environment, working closely with Lloyd's Register to certify the process. In the absence of official public regulation, Lloyd's will offer a private form of guarantee (based on the engineers' and in situ testing of the first bridge) based on existing WAAM regulations and on lessons from other additive manufacturing processes. As a further step, Lloyd's is working with the ASTM/ISO² joint working group to advance industry standards (towards ASTM F-42 on Additive Manufacturing and ISO Technical Committee 261 on AM).

One related challenge is this: although the 3D printing process can be certified, the demands for each industry vary; in terms of materials and applications the outputs are always unique and, therefore, cannot be certified in a similar way. To move forward, MX3D has designed a base method that facilitates different certification processes and its technology as a minimum viable product which stores the entire process digitally, enabling later certification and quality control. Accordingly, the innovation and certification processes are conducted in parallel.

The field of application of MX3D's technology is very diverse, going beyond vertical and horizontal construction to include other engineering industries such as shipbuilding. To secure maximum benefit from these opportunities, and to scale up the technology, requires very specific expertise. MX3D plans to form strategic partnerships with key clients from relevant industries to integrate WAAM tools into their workflow and to improve the software continuously. As a software and technology provider, MX3D can concentrate on R&D to refine its products, while its strategic partners can focus on ways of exploiting those products, given their specific industry challenges. The actual use of the products should present few problems to clients, as the software itself is deliberately designed for ease of use – so friendly that it can be mastered within a day.

Lessons learned

- **Seek alternative sources of financing**
A serious impediment to MX3D's efforts to develop its innovations was the shortage of seed financing in the construction industry. Venture capital is wary of getting involved and incumbents obviously have little incentive to fund their potential disruptors. Determined not to forfeit their products' potential, MX3D turned instead to technology and equipment companies for funding.
- **Leverage open innovation to foster industry collaboration**
By setting an ambitious and well-defined challenge and publicizing it broadly, MX3D tempted several key industry participants into collaborating to advance the technology and accumulate knowledge. These partners have brought complementary competencies and fostered cooperation, not just on The Bridge project but beyond.
- **Collaborate closely with government regarding approvals and regulation, starting in the design phase**
By engaging with the Amsterdam City Government at an early stage, MX3D facilitated approval negotiations and created a sense of trust and shared ownership of the project. The project duly got the official go-ahead, and both company and the city will benefit from the global media attention.
- **Pursue innovation in parallel with the certification process**
MX3D has developed a minimum viable product that is already being commercialized and marketed. And while refining this product, the company is at the same time pushing for the certification and regulation of the technology. The company is also digitally collecting and storing information that can be used later for certification and quality control.
- **Create multi-disciplinary teams to allow creative thinking**
With its origins in art and design, and by bringing together experts in robotics, 3D printing and metallurgy, MX3D was not bound by the conservatism and risk aversion in the E&C industry.



² American Society for Testing and Materials (ASTM) and International Standards Organization (ISO)



Aditazz

Transforming Engineering & Construction
by applying design-automation principles
from the semiconductor industry



The challenge

The Engineering & Construction (E&C) industry's current design approach is less than optimal for overall life cycle performance.

To date, designing buildings has been tradition-bound. Recently, however, industry has made great progress by moving from 2D CAD drawings to 3D designs in Building Information Modelling (BIM). Yet, the way these designs originate has remained fundamentally the same: human designers painstakingly draw the floor plans and vertical plans line-by-line.

One issue with this approach is that the impact of the design on operations cannot always be accurately predicted and as a result, it is not possible to evaluate a building's *performance* early on, in the design phase. The designers cannot confidently anticipate user "wait-and-walk" times, occupancy levels or energy consumption and maintenance costs. It is only when construction is completed that the building's real performance becomes apparent and can be evaluated by users or other experts. This experience is useful and in the end, designers are able to improve their plans, but the lessons are learned painfully and expensively.

The traditional design approach has another inherent flaw as it requires many iterations between the architects, engineers, builders, suppliers and owners to become aligned. Such iterations are time-consuming, drain resources and are notoriously error-prone. If such errors, omissions and inconsistencies persist, further rework on the construction site may be required, thereby generating additional costs.

Therefore, the E&C industry could benefit greatly from revising its approach to design, the building block of any project. From construction through operations to maintenance and even decommissioning, design is a major determinant of an asset's life cycle costs and performance.

The idea

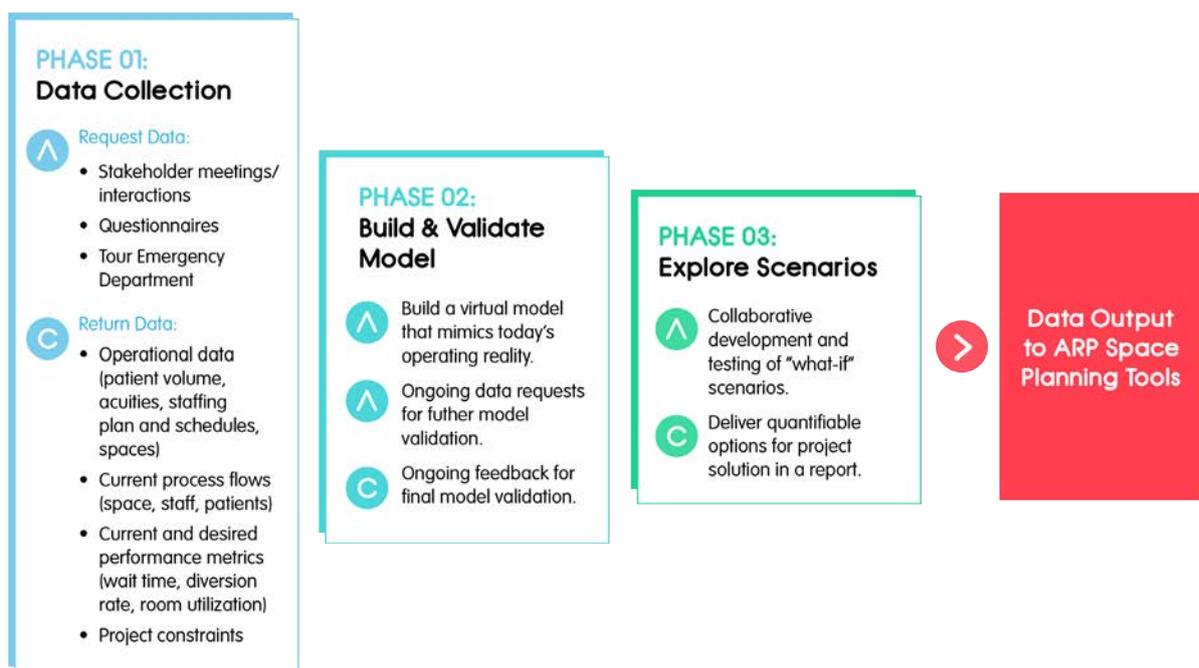
E&C could adopt design-automation principles from the semiconductor industry.

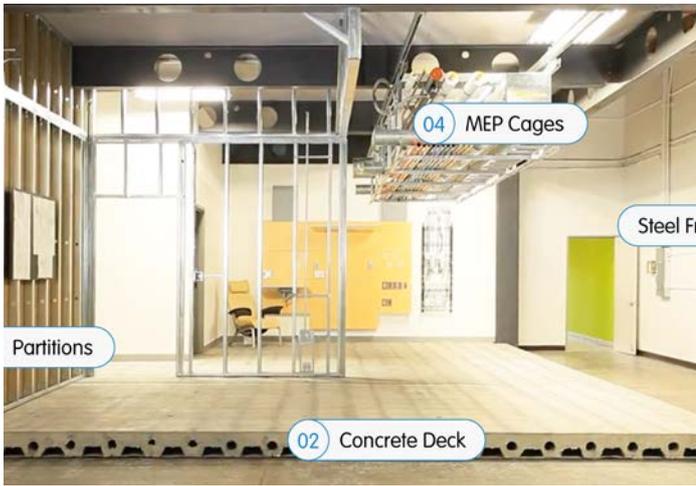
Aditazz Inc., founded in 2011 in Silicon Valley, aims to revolutionize the way buildings are designed. BIM is not enough. Although it propels design methods into the 3D digital world and facilitates coordination in later phases, the methods themselves are outdated. Aditazz has introduced a new way of designing buildings through design automation, an approach borrowed from the semiconductor industry.

The Aditazz platform assists owners, architects and engineers in the development of building design with the help of software algorithms. The initial input is a set of design rules based on client requirements, constraints, building codes and workflows. An example might be a nurse who needs to reach a patient's bedside in 60 seconds or less. Further input is added from a library of predefined objects, e.g. a standard-size office. The technology then automatically generates a variety of different designs that incorporate all of these inputs, allowing for significant improvement of an otherwise challenging and inefficient phase of building design.

This is just the first step. There are hundreds of design options which, if appropriate, will undergo simulation and virtual operation. The platform subjects them to realistic operation environments according to client specifications and tests the performance of the different design options to identify the most robust and suitable one.

The final output is not only a BIM model that can be further processed and modified with standard software, but also a set of metrics for the building, including likely capital expenditure (capex) and operational expenditure (opex), required quantities of building materials and operational performance.





The Aditazz platform solution can also be applied to existing facilities to optimize layout and workflows, e.g. hospital emergency departments. However, it is most powerful and impressive when applied to new-build projects.

Note that Aditazz is able to link its design software to modularized and prefabricated components such as flooring panels, walls and frames all of which can further improve the efficiency of the construction process. Finally, although the company focuses on planning and design automation software, it also has a robust professional services division and thus, is able to assist customers in delivering projects efficiently on site.

The impact

Lifecycle performance is enhanced thanks to greater design speed and sophistication.

Aditazz' key asset is its ability to optimize space and overall lifecycle performance, beginning in the design phase. This translates into cost savings: smarter and denser layout, lower construction costs, fewer building materials and greater energy efficiency.

By automating complicated, often mundane tasks and eliminating errors and omissions in real-world projects, Aditazz has shown it can improve design-and-construction productivity by approximately 30%, cut up-front costs by approximately 10% and save a further 10% on the whole-life cost of ownership. The company also believes that the buildings will be more customer- and staff-centric and cites its first rank its success in the Kaiser Permanente International Design Competition.

Aditazz software has already been used in many design and operational optimization projects around the world. It is currently working on several large medical centers that are still in the design phase, including the King Abdullah Financial District Medical Center and Health Network, a University Cancer Hospital in China, the University Medical Center in Hong Kong, and facilities for several health systems in California.

A particularly informative case is a greenfield project for the University Cancer Hospital in China, with a catchment of more than 20 million people. The brief was to minimize construction costs and maximize patient capacity. The charitable foundation commissioning the project needed to evaluate the tradeoffs between capex and opex in light of budgets and priorities. Aditazz succeeded in making capex savings of about \$10 million thanks to a 40% reduction in the required floor space, achieved by improving operational efficiency and building layout in the surgery and radiation oncology departments. The optimal solution was automatically drawn from among hundreds of option generated by the platform. The number of beds was reduced from 900 to 540, linear accelerators from 12 to 6 and operating theatres from 12 to 10. Once operational, opex savings too, will be obtained by improving IT tools, equipment, staff training and by extending operating-theatre hours.

However, the full potential of the Aditazz platform cannot yet be realized on a broad scale. For that to happen, the E&C ecosystem has to change: architecture-design-and-engineering (ADE) firms need to boost their digital skills, refine their work processes and business models. Owners need to get into the habit of requesting that ADE firms utilize design automation to improve efficiency.

The barriers to innovation, and the solutions

The traditional E&C marketplace requires a digital disruption.

Aditazz's initial challenge was to develop its powerful design platform. The key success factor was the deployment of a multi-disciplinary, cross-functional team comprising co-founder Deepak Aatresh, with his vision of applying semiconductor design principles to E&C; veteran designers, engineers and construction experts to provide the industry perspective and skills and finally, mathematicians and software engineers to develop the code. A massive investment in R&D was needed over several years, which required venture capital funding, a resource that was and still is fairly unusual in the E&C industry.

Now that platform development has been successfully completed, Aditazz faces a different kind of hurdle, namely getting its product to the E&C market. E&C has its traditional ways of working and remains attached to them. The industry seems to be not quite ready for digital innovation. ADE firms are hesitant to buy Aditazz software and fear it could seriously disrupt their business model. Could they really switch from 100% human-produced design, charged for by the hour, to design that has major, technical sections generated almost instantly by algorithms? Aditazz software would also require investment in new digital skills and training, as well as different ways of working.

ADE firms might welcome the automated process, while keeping the more creative work as the preserve of human designers

Since any ADE firm would have difficulty adopting the Aditazz platform as a whole, Aditazz has tried an alternative strategy, addressing their pain points and offering smaller-scale targeted solutions for them. Consider the proposal process, for example: for ADE firms, it involves a lot of tedious and non-billable work. Aditazz software, however, could increase process efficiency and minimizing inconvenience. Or, the less creative aspects of a design project such as designing functional rooms: ADE firms might welcome the automation of such aspects, while keeping the more creative work as the preserve of human designers.

One further reason for ADE firms' reluctance to adopt the Aditazz platform is fear of losing Intellectual Property (IP) protection and their competitive advantage. To address this, the Aditazz platform separates customer IP from the product and ensures that a customer's data cannot be seen by users outside their firm unless it has been specifically shared by the customer. In this way, the ADE firm retains ownership and control of its IP and can protect it even when exposing it to the world of digitization.

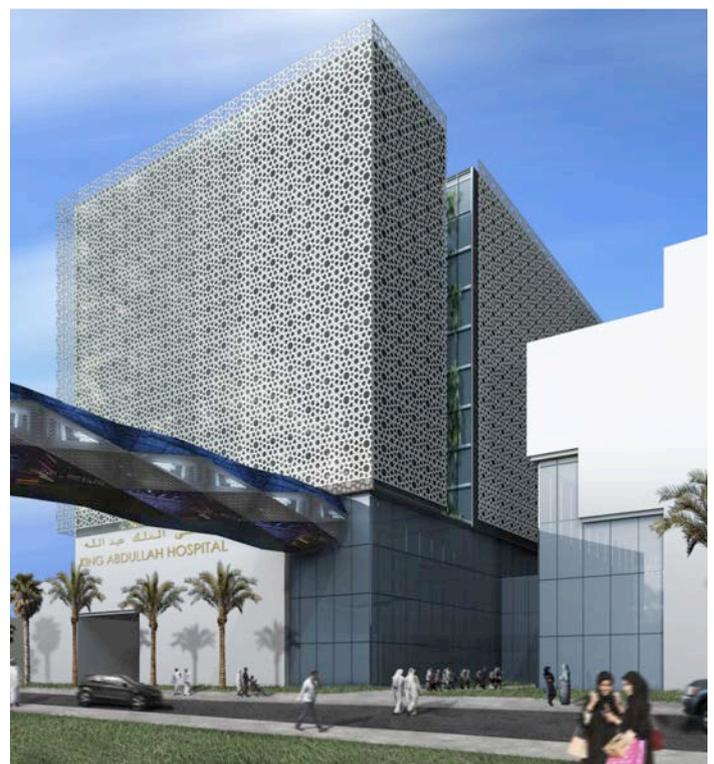
Given the above challenges in the E&C industry, Aditazz is pursuing a parallel strategy too: integrating professional services that can assist or subcontract with ADE firms as well as providing services and expertise to selected project owners directly.

Even though the company prefers a horizontal solution for the E&C industry and does not want to compete with ADE firms, it has the ability to provide design and technical services to smooth out and assist in project delivery. In effect, this means that Aditazz has become a highly-specialized, new kind of design firm with its own in-house project-delivery resources which can be deployed for external ADE firms and project owners. With the additional new business capability, technology delivery and design services, it has to focus on one vertical and bring in domain-specific design skills. Its choice was hospitals, which not only demonstrated how powerful the solution is for a complex building, but also attracted the best Silicon Valley talent, eager to crack tough problems, to join the company. The company also managed to recruit internationally renowned experts in healthcare design and architecture for its management and advisory board. In addition, the new integrated business model gives Aditazz the opportunity to experiment, learn and refine the platform.

The parallel strategy has had difficulties of its own. Project owners, much like ADE companies, are tradition-minded and are often skeptical of the value and functionality of the Aditazz platform. To overcome this resistance, the company can now engage project-owner CEOs directly

when pitching its value-based proposition, in conjunction with an ADE firm or on its own. Under this scheme, clients pay a flat fee to use the platform for a specified period of time, with unlimited design iterations, in contrast to the conventional scheme, which is hour-based and offers no incentive for design efficiency. Yet, even when the project-owner CEOs buy into the idea, they might be held back by the procurement department and by compliance issues. There are template contracts that are based on man-hour billing and cannot easily accommodate the Aditazz approach. So, Aditazz is now actively promoting new forms of contracting, including based on performance.

In dealing with project owners, Aditazz has encountered a further challenge. The Aditazz solution relies heavily on *data*, as it is data that underlies accurate modelling and predictions. Unfortunately, some project owners are relatively inexperienced and unsophisticated in regard to collecting, storing and using data: they may have a lot of data available, but it tends to be unstructured, decentralized and thus, inaccessible to facility departments. Accordingly, Aditazz has now added yet another service to its repertoire: data-integration whereby time stamps are extracted from health records and the information obtained is used to improve hospital efficiency. This new service enables clients to gain even more benefit from the Aditazz solution.

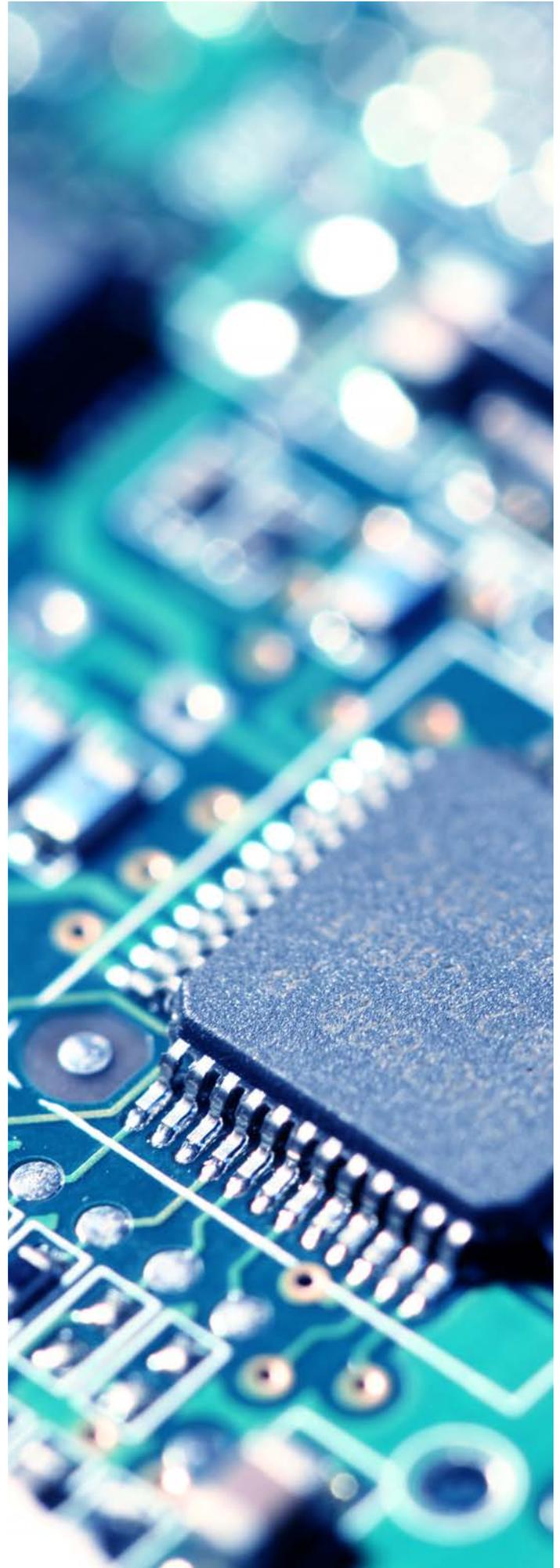


Lessons learned

- **Take an outsider perspective that challenges the status quo and produces disruptions to the industry**
A background in semiconductor design enabled Deepak and his team to question the basic assumption of the design process – line-by-line drawing of plans – and then to generate an alternative to it.
- **Be unreasonably aspirational (“Think Big”) when thinking about innovation**
Vision and purpose-driven leadership helped to attract investors and employees and kept the workforce undeterred in the face of seemingly insurmountable obstacles.
- **Create multi-disciplinary teams that can provide a holistic solution**
The challenge was so complex that it could only be resolved by a unique combination of diverse skills – semiconductor technology, mathematics and design.
- **Take users’ needs into account when developing software and the go-to-market strategy**
To overcome client resistance, Aditazz based its solution on the set of architects’ pain points in the proposal process and addressed IP issues effectively.
- **Embrace business-model innovation alongside tech innovation**
Aditazz has created a hybrid business model of software products plus professional services in order to offer design and technical solutions with in-house project-delivery capabilities as the market is not prepared to use the platform independently.
- **Develop minimum viable products quickly and conduct early pilots to demonstrate value to investors and clients**
Aditazz launched a viable platform early on, and then continued to refine it constantly, on the basis of project experience.
- **Launch new products in a beachhead market and scale up later**
By specializing initially in hospitals, Aditazz has been able to show that its technology is capable of designing any complex building without losing focus.

“
The approach to designing buildings has not fundamentally changed through BIM: instead of drawing the plans for the pyramids with a stick in the sand, you now draw your BIM models with a computer mouse.
”

Deepak Aatresh, Chief Executive Officer, Aditazz





Winsun

Demonstrating the viability of 3D printing at construction scale



The challenge

Construction today is deeply entrenched in traditional processes that are unproductive and unecological.

Construction has remained fundamentally unchanged throughout history. Vertical projects still require workmen to add layers of building materials, either wood, bricks, or concrete, one on top of the other. This approach is ill-suited to the modern age in three key respects.

First, it keeps productivity low. Just when a productivity boost is desperately needed: our era of rapid urbanization demands a surge in affordable, high-quality housing and infrastructure. Over the last 50 years, productivity in construction has barely risen, while most other industries have seen tremendous gains.

Second, construction today is heavily reliant on the skills of individuals. In many developed countries, such skills lack prestige and demographic change has reduced the size of the workforce. Accordingly, labour costs are high and the demand for new construction cannot easily be met. In many developing and emerging countries, construction projects often proceed with a low-skilled workforce and the quality and the useful life of buildings is often compromised as a result.

Third, traditional construction methods produce large amounts of waste, noise and dust, in defiance of modern environmental standards.

The idea

Construction units such as walls or columns can be pre-fabricated off site by means of 3D printing, which has the potential to be used for other applications in the future.

Yingchuang Building Technique (Shanghai) Co. Ltd, or Winsun as it is known, started off as an advanced building materials supplier. The company was specialized in complex interior decor (for opera houses, for example) and non-standard exterior structures. It has more than 125 national and international patents across its various product lines.

The company has made a point of continuously enhancing its materials and moulding technology. When it reached the limit of what is possible with traditional materials and technology, it ventured into large-scale 3D printing – a move aimed at further improving its production processes, increasing its design options and reducing waste.

The company's entry into 3D printing began as early as 2005, with the invention of a spray nozzle, one of the key components of its first, and still widely used, 3D printer. The spray nozzle was used to experiment with cement and other advanced materials. Driven by Chairman and Founder Ma Yihe, a materials engineer, the company kept refining the technology and the materials composition to improve outcomes, enable material collection and output control. In addition, in 2008, the company developed the first continuous 3D printer with integrated collection,

data analysis of materials and a printing-output control system. A third major achievement was setting up the world's largest 3D-construction printer, some 10 metres wide, 6.6 metres high and 150 metres long.

In 2013, thanks to its expertise in materials and experience, Winsun succeeded in 3D-printing a residential house for the first time and more specifically, a batch of ten houses, making global headlines. The technique uses a special ink made of cement, sand and fibre, together with a proprietary additive. In a kind of pre-fabrication approach, the company prints the walls in the factory and assembles the building on site.

The basic process begins with the client's design (in the form of a Computer-Aided-Design (CAD) 3D model). The spray nozzle adds the material layer by layer, each layer being between 0.6 and 3 centimetres thick, until a wall of the desired shape and size is completed. The technology is able to produce hollow structures, accommodate piping, wiring and insulation as specified. The finished wall parts are transported to the construction site, installed on traditional foundations and reinforced with traditional steel structures or cement in keeping with regional building regulations. The unpolished walls can then be supplemented with various fittings or finishes according to customer preferences.

In principle, the applicability of the technology seems unlimited. Winsun is already developing prototypes for use in infrastructure assets, such as columns for bridges or pipes for water systems. It will no longer be necessary to erect temporary formwork on the construction site. Instead, 3D-printed moulds ("printed formwork") are installed and filled with reinforced concrete. Winsun also has plans to apply its technology to the construction of high rises (buildings of 100 metres or more), by using a mobile printer that could print directly on the construction site.



The impact

The 3D-printing revolution is cutting construction times and costs in a significant way, increasing quality and environmental standards and offering a glimpse into the imminent transformation of the industry.

By using 3D printing technology, Winsun has increased productivity and made it possible to realize significant cost savings. A standard house can now be built for about \$30,000.

In particular, by printing the walls in a factory prior to assembling the building on site, Winsun can greatly increase the speed of construction. New buildings can now rise one storey per day, which is much faster than standard construction processes. For example, construction of a two-storey 1,100 sqm mansion took one day of printing, two days of assembly, with internal bar structures erected in advance, requiring three workmen only.

Winsun's technology is also far more environment-friendly than conventional reinforced concrete. In keeping with the circular economy or closed-loop concept, it can source 50% of the ink material from construction waste or mine tailings. What's more, the printing process minimizes waste in the actual construction process and Winsun's modular dry construction method is dust-free. Overall, the Winsun approach saves 30-60% of material relative to traditional construction. So, the technology has particular appeal for advanced economies, where labour costs and environmental standards are high.

For developing and emerging countries, this technology offers a further advantage. It can mitigate the shortage of skilled construction workers and improve the quality and accuracy of the end product.

One final benefit is that Winsun's technology enables greater freedom of design. Clients now have a wider range of design options. Buildings can now be tailored to individualized customer needs and specialized applications and applications, which to date had only been possible with costly and labour intensive formwork.



Since 2014, when it printed its first ten houses, Winsun has developed a number of prototypes to showcase its technology, including a mansion of 1,100 square metres, a six-storey apartment building, an ancient-style traditional Chinese house, a wave-shaped house and smaller movable buildings.

Arguably the most important showcase project is the company's first 3D-printed office. Recently opened in Dubai for the *Dubai Future Foundation*, the building was printed in Suzhou, cut in pieces for shipping and transported to Dubai, where it was assembled and finished within a couple of weeks. Compared to traditional on-site construction, the Winsun process saved about 80% on construction costs, 60% on labour costs and 60% on waste. Winsun partnered with the international design and engineering firm Gensler on the project for structural engineering. Interestingly, Winsun is also the supplier of Dubai's 3D-printed "Smart Palms", which provide not only shade, but also decentralized WiFi and charging stations.

However, Winsun has now advanced beyond testing and prototyping and it is already scaling up its technology. To date, the company has sold more than 100 houses of various types, many of them in Dubai, the largest with a floor space in excess of 5,000 square metres. The company is also negotiating with the Egyptian and Saudi Arabian governments over the construction of thousands of affordable homes, as well as a local Saudi factory. The prototype for a simple affordable house, developed together with design and engineering specialist Gensler, has already been marketed in Africa. Here as elsewhere, the ideal delivery model for Winsun is based on turnkey contracts, whereby the company leverages its 3D printing technology to the full: for the exterior, structural components and for the interior, including decor and even furniture.



The barriers to innovation, and the solutions

Scepticism and lack of knowledge about the potential of 3D printing in construction among designers, architects and developers requires Winsun to educate the market via prototypes.

The main barrier facing this transformative technology is the scepticism of designers, project developers, governments and end-users. For those with a conservative mindset, it seems just too good to be true that high-quality buildings can be constructed via 3D printing.

In response, Winsun has been investing heavily in producing prototypes for various applications to showcase the new technology and demonstrate its technical feasibility. The company realized very early on that it can win clients over by inviting them to visit the factory so that they see the prototypes with their own eyes. To show the viability of 3D printing for high-rise construction, the company is going to buy land near Shanghai and erect a demonstration building more than 100 metres high and with 200,000 square metres of floor space.

Designers today are still-unwilling or unable to recognize the potential of 3D printing. To overcome this resistance, Winsun is collaborating with architects at the *Cornell Design Institute, Tongji Design Institute or Jiaotong University* and educating them to incorporate the new possibilities of 3D-printed design into their work. In the future, Winsun also plans to set up a cloud-based platform to connect the company and its clients to designers. Designs will be uploaded on the platform for clients to review, make an initial choice and request a virtual model or printed prototype to be viewed in an exhibition centre. Once approved, the final design is sent to the 3D printing factory. Winsun is also raising awareness and creating enthusiasm by training architects with its textbook on 3D printing in architecture.

Another major impediment to scaling up Winsun's technology is the lack of explicit regulation for 3D printing. Most building codes and procurement standards simply make no mention of 3D printing technology and in response, Winsun is pursuing a two-pronged approach. First, it creates a "minimum viable product", combining its 3D-printed building components with traditional beams, columns, insulation and structural fillings to comply with existing building codes in China or elsewhere. (The codes generally set standards for reinforced masonry up to a building height of 66 metres and for concrete above 66 metres.) Second, Winsun is actively setting standards and shaping the regulatory environment for 3D printing, working closely with China's national construction department to amend existing building codes that are still focused on classic brick and mortar masonry. Thanks to this collaboration, construction standards and building

codes for 3D printing construction are evolving. In summer 2016, the Chinese State Council and Ministry of Housing and Urban Development indicated that they will actively study 3D printing construction technology and begin to adopt it in the real estate market.

Given industry scepticism and environment restrictions, Winsun needs to select its markets wisely. Germany is a key target and a promising launch pad for Winsun's global expansion, in view of its high environmental standards, abundant recycling of construction waste and wide experience in manufacturing. Other promising markets are Australia and the Middle East. Saudi Arabia and Dubai, a hub for 3D printing, would be strategic partners. Dubai's objective is to gain a 25% share of 3D printing in construction by 2030.

To exploit the technology fully and gain maximum benefit from scaling up, Winsun needs to produce large volumes. Accordingly, the company has developed an ambitious plan for expanding its 3D printing technology nationally and globally via so-called dream factories. These are approximately 100 franchise factories (owned and operated by partners), located throughout China, that recycle materials locally from urban waste and produce 3D-printed components for 5,000,000 square metres of construction per year. These dream factories would also supply ink to a number of smaller production capacity "Ant Factories" that would print prototypes for clients and serve as local exhibition spaces for pre-ordered designs. The first dream factories in Shanghai is now in the planning stage as is a 3D printing creative park (exhibition space) in Baotou. Winsun will continue its R&D efforts to rapidly scale up production, while also forging close ties with local partners.

Another Winsun strategy for scaling up is through partnerships. The company president, Ma Yihe, aims to form a 3D-industry alliance with Chinese and international real estate and construction companies, thereby securing additional capital (equity investment) for the company's global expansion programme. Winsun will also form partnerships with mining firms to access their mining residuals.

Some barriers to pre-fabrication cannot be overcome easily and will need a workaround. In remote regions with poor road infrastructure, building sites might prove inaccessible to large pre-fabricated components transported from distant factories. So, Winsun is studying the potential of using smaller, mobile printers to operate directly on site.

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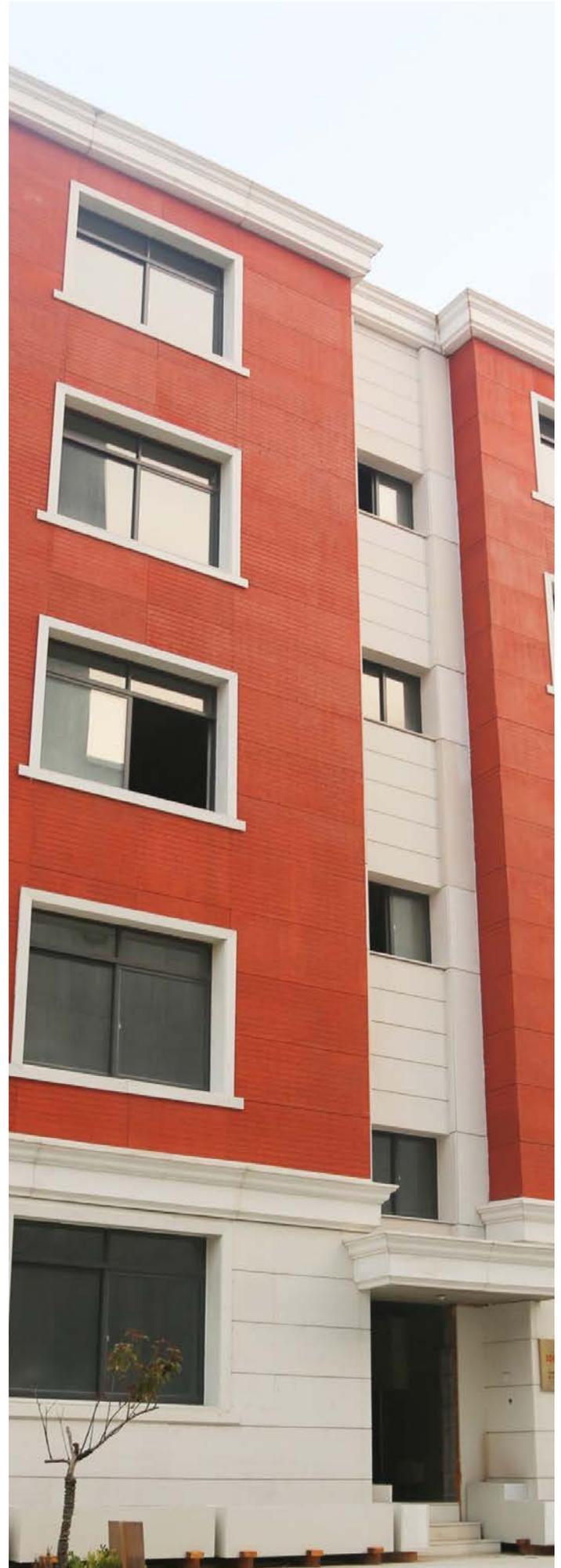
If you do not believe it is possible, we will print a prototype.

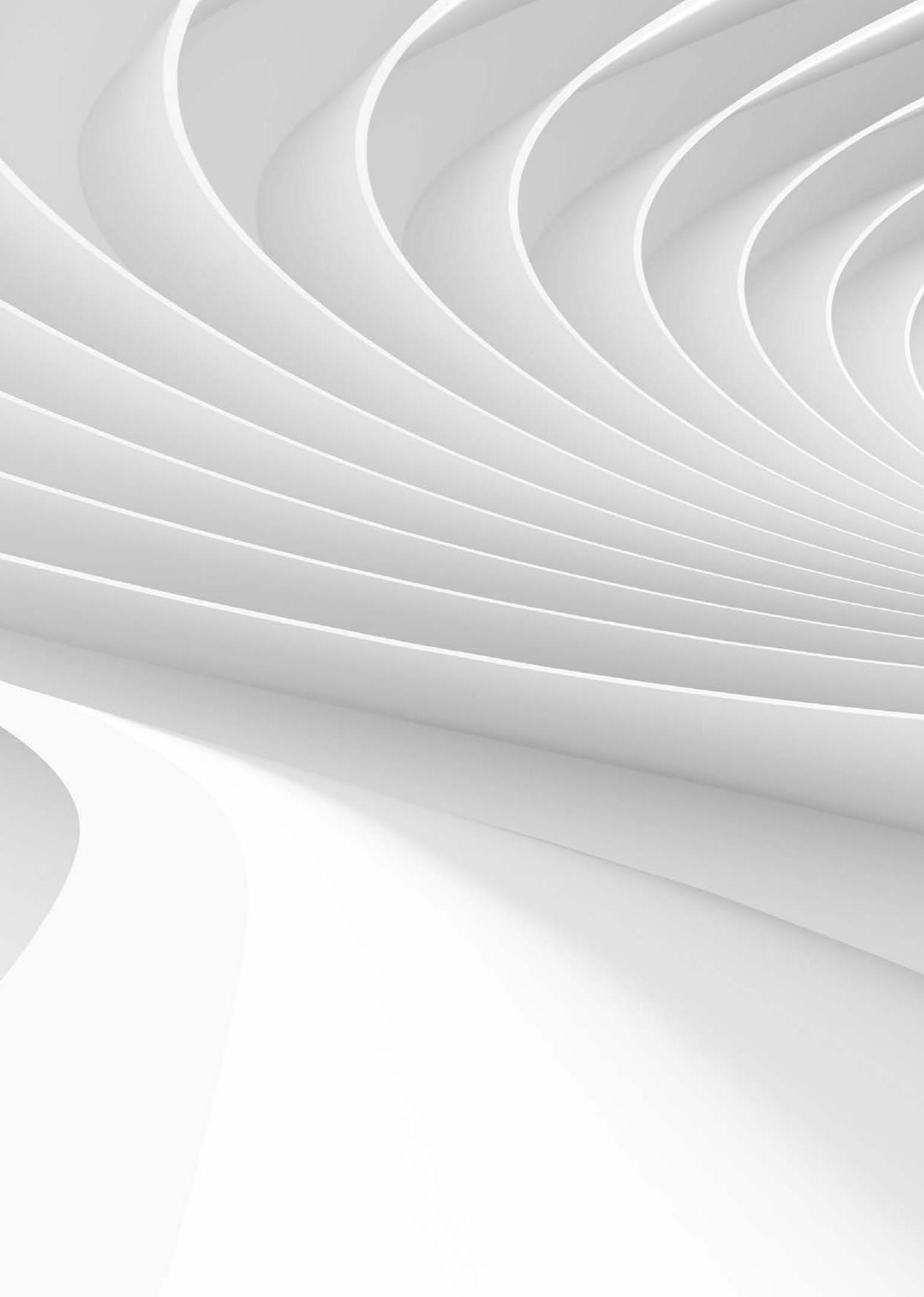
”

Ma Yihe, President and Chief Executive Officer, Yingchuang Winsun, People's Republic of China

Lessons learned

- **Shape the regulatory and market environment**
Being at the forefront of 3D printing in construction, Winsun is actively shaping the regulatory environment, working closely with construction departments and regulators on regional and national level to adapt and enhance building codes.
- **Develop minimum viable products early on to demonstrate the power of technology and stake a claim to the market**
In the absence of specific regulation, Winsun created a viable and adaptable prototype, which once adapted by means of steel structures and insulation material, was considered compliant with existing regional building codes.
- **Reduce scepticism by providing vivid proof of concepts and dispel diffidence through training**
In the face of widespread scepticism among designers, developers and clients, Winsun has energetically set out to educate the market and demonstrate the viability of its technology by creating impressive prototypes and actively publicizing them. Moreover, the company liaises with architects and designers to train them and instill the 3D printing approach into their design thinking.
- **To extend your reach, seek partners – but make sure they are the right partners**
Innovative technologies often struggle to gain acceptance. Winsun is putting considerable effort into identifying the most promising markets, picking optimal partners to leverage the technology's benefits and expanding its target clientele.





Uptake

A predictive analytics platform disrupts the industry from within via strategic partnerships



The challenge

The ever-expanding mass of data generated by the Engineering and Construction (E&C) industry still awaits proper capture, analysis and exploitation to be able to benefit from a slice of this trillion-dollar opportunity

During all project phases, from planning to Operations & Maintenance (O&M), E&C accumulates a profusion of disparate data, collected from sensors embedded in equipment and buildings, as well as from design records, planning software, and project control systems. Unfortunately, the vast and varied volume of data is not captured or analysed systematically. Much of it remains siloed among different stakeholders and gets lost over the project's lifecycle.

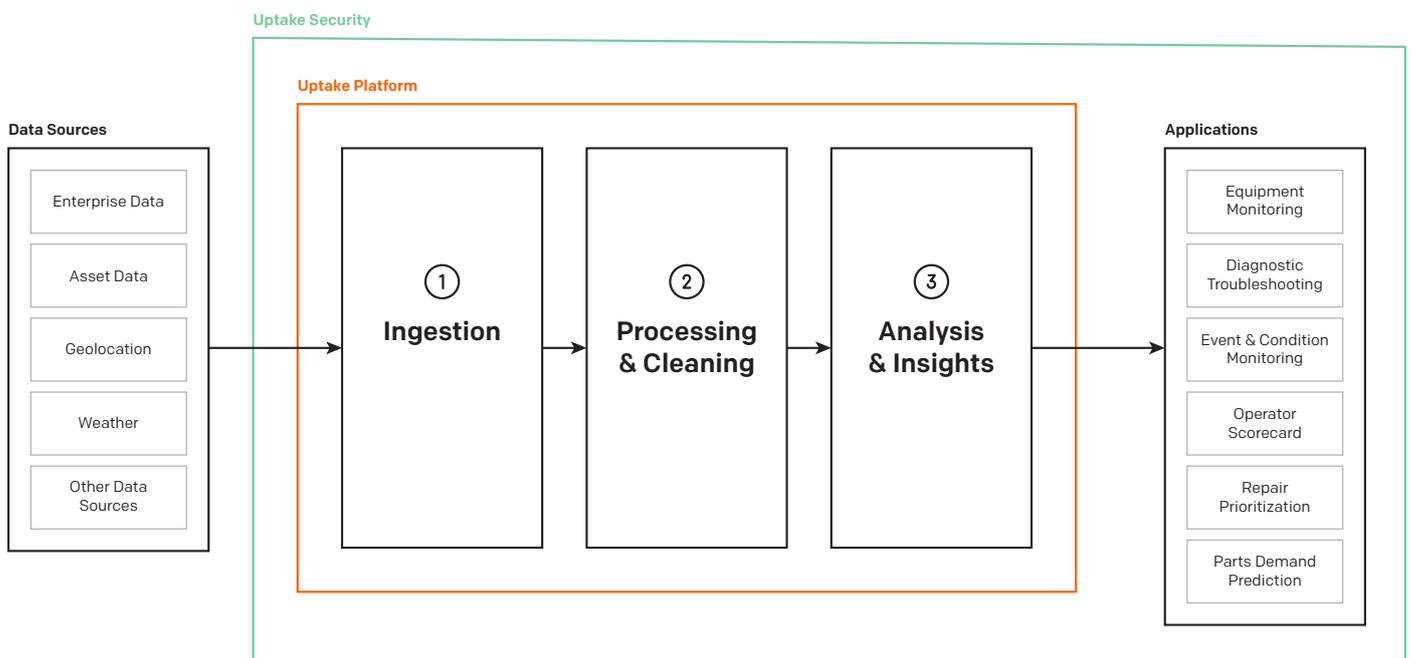
In the near future, this unruly data mass will proliferate exponentially as the industry continues to digitize, through the use of drones, Building Information Modelling (BIM), wireless sensing, 3D scanning and other technologies. Companies can capitalize on it—the opportunity is there for the taking. The so-called Internet of Things (IoT) is expected to generate up to \$11.1 trillion annually by 2025, including an annual \$4.6 trillion for industrial applications, such as predictive maintenance and operations management. This is a particularly relevant and inviting opportunity for E&C companies that are typically low-margin businesses and therefore, keen to improve their profitability. The latter can be achieved in two ways namely, by optimizing planning, design, engineering, construction and O&M as well as identifying new revenue streams through the use of data. Yet, legacy IT systems are holding them back, creating barriers to capitalizing on digital transformation with speed.

The idea

Ingest disparate, real-time and historical data onto a scalable and fast-analysis platform to generate valuable insights

Uptake is a predictive analytics software company, founded in 2014 by Groupon co-founders Brad Keywell and Eric Lefkofsky in Chicago. It provides predictive analytics solutions for fixed and mobile assets, covering industries including rail, mining, aviation, agriculture, energy and construction. The company offers a predictive analytics platform, which uses real-time and historical data from heavy equipment as well as contextual information about weather and the environment to optimize operations for equipment owners. Construction firms, for example, can prevent unscheduled downtime, extend the lifespan of machinery and improve equipment dispatching and planning.

Uptake's unique business model revolves around strategic partnerships with leading industrial companies, in order to access large data sources, industry expertise and installed base. Uptake leverages strategic partners' expertise to identify industry challenges and develop relevant solutions. Solutions that address partners' specific pain points and enable new data-driven business models and revenue sources. This industry partnership approach to building software ensures that applications are relevant and provide quantifiable value to end customers. In the words of its co-founder and CEO Brad Keywell: "We are choosing to deploy our speed and agility to innovate with an industrial partner who has a strong edge, rather than the traditional entrepreneurial disruption model of approaching an industry from the outside." The functioning of Uptake's platform can be divided into three steps:



1. *Data ingestion and integration.* Inputs include data of all types, including the client's machinery, business systems (e.g. SAP, ERP, CRM), design files (e.g. CAD, BIM), satellite imagery or Geographic Information Systems (GIS), weather and geography. This abundance of disparate real-time data is screened instantaneously, secured by encryption and sorted by the platform, ensuring that only the data points relevant to a particular analysis are used to drive predictions and that others are disregarded. It's a feature known as "data integrity." The platform provides a holistic view of the client's business and breaks up the data silos of business units, teams, projects and processes.
2. *Data analysis.* The single unified approach—in which all data types are standardized or "translated into a common language"—enables real-time analysis and rapid multiple iterations on Uptake's servers to generate practical insights—and continually improved results. As of January 2017, the platform can run more than 1 million data science models per hour thanks to a team of more than 60 data scientists, many of whom have PhDs from leading research institutions around the world. Those models detect patterns in the data and generate predictions.
3. *Workflow integration.* The insights are translated back into the initial language of the client's system and integrated into the client's workflows through applications that run on Uptake's platform. Applications designed for specific industries or uses make Uptake's findings actionable for a broad spectrum of stakeholders within an organization. As an example, these could include alerting machine operators or building managers to potential disruptions and generating recommendations for ways to mitigate those risks as well as capture new opportunities. Thanks to this translation, it is relatively easy to integrate Uptake's solution into a client's legacy system, as no change is required to the client's IT landscape. Unlike a system that provides raw data to a single person or department within an organization, Uptake's solutions propose specific actions for the right person at the right time within an organization.

“
Working with Uptake can be a transformative experience that unearths new value sources for industry incumbents. At the end of this process, clients might say ‘I am a technology company that just happens to sell iron’.
 ”

Trevor Mecham, VP Construction and Agriculture

Uptake's platform is designed to be Original Equipment Manufacturers (OEM)- or vertical-agnostic. Built on a single-code base, the platform aggregates and anonymizes data to share insights across multiple verticals. This cross-learning platform can be applied to different industries and integrates insights from a variety of high-value, heavy equipment industries such as agriculture and mining, where data is collected very frequently to offset the remoteness and extreme conditions of their operations. The experience from autonomous equipment, combined with GIS in agriculture, could generate insights that are relevant for autonomous E&C equipment, such as drone-led bulldozers.

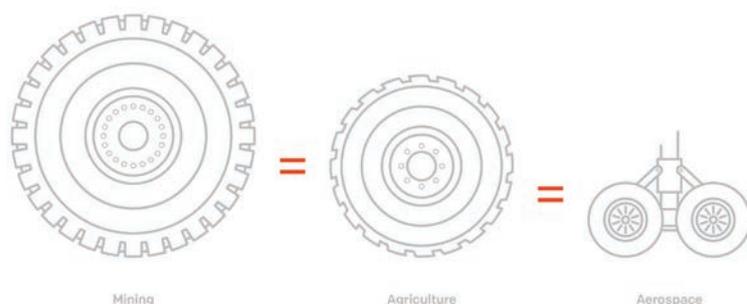
By enhancing its data and insights via iterations and machine-learning algorithms, Uptake continuously improves its platform and upgrades its services for clients. The platform is embedded with world-class security controls, ISO 27001 process and kept ahead of potential vulnerabilities through a proactive security software development program.

The impact

The construction industry now has a powerful way of turning data into value. The Uptake approach has enabled clients to boost the productivity of their equipment and generate new revenue streams.

Uptake's platform provides two main benefits for E&C companies. First, a direct benefit whereby construction firms can now deploy their fleets with increased efficiency. Second, since the platform enables equipment manufacturers to develop new service offerings, such as refined diagnosis and repair solutions, E&C companies can now derive greater value and longer working lives from their machinery, thanks to prognostics and improved maintenance.

E&C companies, as owners of equipment, will benefit from Uptake's monitoring solutions, e.g. performance monitoring, asset benchmarking, reminders of maintenance cycles, planning insights, e.g. forecasting operational disruption, identifying trends and efficiencies, and optimization of processes and assets, e.g. supply-chain improvements, fuel-efficiency measures, minimizing of unscheduled downtime.



Consider just one example of the power of Uptake's solutions: Uptake produces comparative health scores for the client's various assets and is able to predict major system failures, thereby enabling the client to optimize equipment allocation and maintenance. In addition, the platform can alert the client's troubleshooting teams to imminent failures - with close to 100% accuracy - and identify the root cause of the problem. Uptake's diagnostic function indicates the exact part of the equipment that needs repair and specifies the requisite tools and replacements. For one pilot customer, the overall outcome is an estimated 30% reduction in workshop time, 10% reduction in unnecessary repairs, e.g. 'no defect found' and 40% reduction in repeat visits to the repair yard. This translates into considerable projected savings, with an average fleet of 3,000 engines being monitored and yielding up to more than \$22 million annually.

Uptake's initial success has not gone unnoticed by investors. They have valued the company at more than \$2 billion, the fastest ever to that valuation according to Pitchbook. And Forbes Magazine has ranked Uptake as the "hottest start-up of 2015," ahead of Uber, Slack or WeWork. Uptake is proving to be a very agile organization and is growing rapidly from week to week, with about 100 new employees hired during the second quarter of 2016.

The barriers to innovation, and the solutions

Gaining expertise through strategic partnerships with key industry players

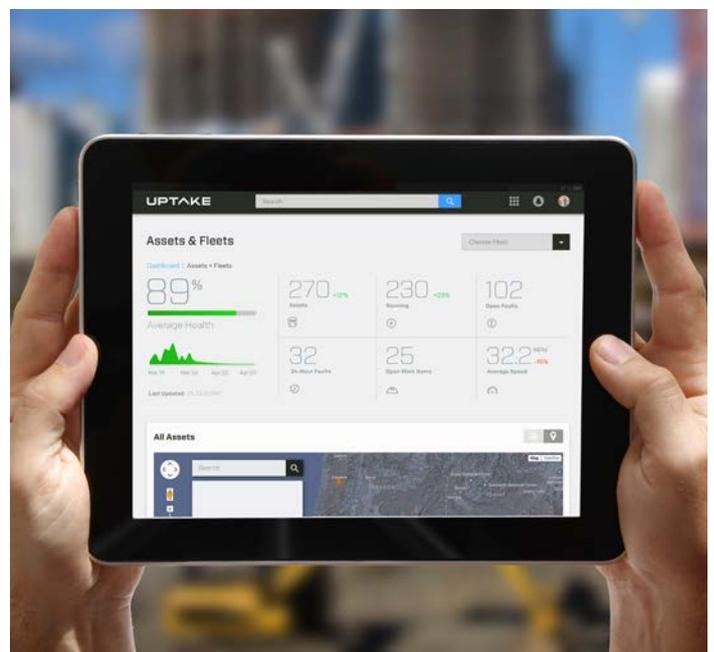
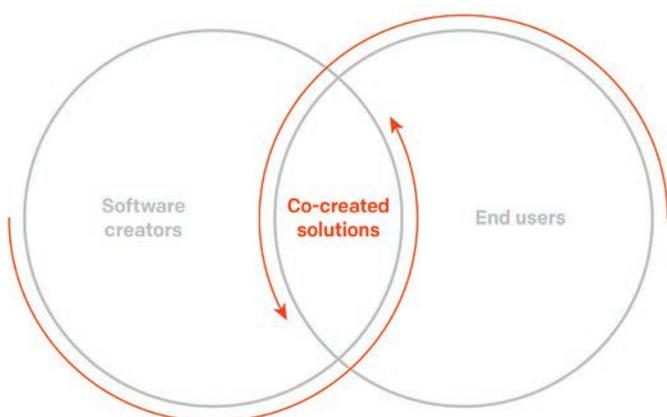
An early hurdle for Uptake was addressing the reservations expressed by conservative industries, particularly E&C. Many companies do not, or do not want to, recognize the added value of incorporating data analyses into their existing business models and operations. Also, many fear that big data solutions require changes to the process and IT setup, causing huge costs, business interruptions and system unreliability. So an important part of Uptake's strategy is to educate the market by identifying and highlighting opportunities to improve efficiencies in an enterprise as well as helping executives realize that those efficiencies can be realized through data analytics. The best way to pursue this strategy, Uptake decided, was to begin this journey with its industrial partners, including Caterpillar. The partnership approach is mutually beneficial because industry leaders can innovate rapidly

without having to develop massive capacity in non-core competencies, such as data science and software development. More specifically, a partnership ensures that Uptake focuses on solving real, complex and relevant industrial problems while bypassing development and learning cycles. The results are enormous savings in development time and resources for Uptake's partners and a software platform that delivers real, measurable value to partners and their end customers.

Among the added benefits of the partnership approach is access to data. Uptake's machine-learning algorithms rely on access to large pools of industry data. Such access enables the platform to improve in quality and accuracy over time. The more the platform is utilized, the more robust it becomes. However, Uptake initially lacked such broad access and to illustrate the value, opted to develop a platform configured on the basis of a restricted data set that helped to demonstrate its efficacy. When this initial version of the product was duly-applied to a restricted dataset of one of Caterpillar's subsidiaries—Electro-Motive Diesel Inc. (now Progress Rail)—it promptly showed its potential for optimization, scale-up and provided evidence of the value that Caterpillar was seeking to formalize a partnership.

Another challenge Uptake has overcome is the enormous diversity of the data being analysed given that the data comes from many different sources and formats. Therefore, Uptake normalizes and integrates it all into a central platform on which to run analytics. To enhance this task in the future, Uptake is pushing for standardized data formats—within the Association for Equipment Management Professionals, for instance, and jointly with other companies in a consortium defining and endorsing data standards, such as CAN and ISO. In this context, Uptake is playing an active role in shaping the market and regulatory environment.

Uptake is also working to move beyond client assumptions regarding tailored solutions versus a scalable, industry-independent, OEM-agnostic data platform. Uptake addresses this prevailing thinking in two ways. First, it deploys in-house industry experts who have a deep understanding of client needs and "speak the same



language.” Second, it dissolves the contradiction by adopting a single code base yet configuring the platform to the specific client situation and to different industries. This flexible and responsive approach is very much in keeping with Uptake’s entrepreneurial philosophy—start from clients’ pain points to develop new solutions while preserving the benefit of a single code base and feature abstractions to serve many markets.

As it seeks to scale further, it is targeting other key elements of the construction value chain—for instance, expanding into planning by including design firms. To this end, Uptake has developed adjacent applications for its analytics platform:

- With data on machine utilization, Uptake can help contractors in the bidding and tendering process to optimize machine planning and make a more accurate prediction of machine usage
- With data on buildings, Uptake could enable building designers to feed information about existing buildings, including performance and potential weak points, back into the planning and design process for new buildings
- With the increased use of sensors and smart equipment—such as smart meters, valves, and shadings—buildings are now creating massive amounts of data that can be used to enhance facility management and energy performance. From its experience with energy clients, Uptake could also help optimize air conditioning and heating as well as couple needs with optimal energy sources. For instance, historical data, in combination with up-to-date satellite imagery or weather data, could alert building managers to an imminent leak in one part of the roof in the event of heavy rain.

“
We are choosing to be disruptive with an industrial partner who has a strong edge, rather than disrupt the old-fashioned way from the outside.

”

Brad Keywell, co-founder and CEO

Lessons learned

- **Form partnerships with key industry players**
Through its partnerships with established industry leaders, Uptake has succeeded in overcoming market resistance and refining its technology solutions to resolve critical industry pain points. What is more, the prestige of these partners has boosted Uptake’s own reputation and credibility as well as heightened its efficacy in educating the market. Thanks to the partnership approach, Uptake can be seen as “disrupting industries from the inside” rather than simply acting as an external force. This approach also ensures that Uptake shares in the risk of its solutions and possesses a common agenda to yield positive outcomes for both parties.
- **Get data scientists out of the office**
At Uptake, data scientists are outfitted with steel toe boots, which they wear when they go into the field to learn about a partner’s industry from the ground up—literally. Their field research ensures that Uptake is solving real, complex and relevant industrial problems.
- **Start with a client’s pain points when tailoring a solution**
Uptake’s entrepreneurial approach of starting from its clients’ pain points is rare in the E&C industry. Together with its clients that manufacture, own or operate heavy equipment, Uptake develops and scales up data-driven business models to generate additional revenue streams.
- **Eliminate changes in workflow to reduce adoption challenges**
Uptake’s solution can be easily integrated into its clients’ legacy system, as no change is required to the existing IT landscape. This encourages increased adoption rates and means that integrated insights proposing specific recommendations for action are delivered to the right person at the right time within an organization.
- **Execute with speed to truly innovate.**
The average company takes 12-18 months to roll out a new data science model. At Uptake, its data science team can deploy a model in three days. Uptake’s entrepreneurial approach pairs incredible speed with ambitious execution to yield its innovative solutions.
- **Break down silo thinking and systematically incorporate lessons from other industries**
Uptake’s unified approach makes it easier for the company to integrate and analyse disparate data sources and generate productive insights. The platform is built on a single code base (OEM- or vertical-agnostic) allowing for lessons learned to apply across verticals.

The Way Forward

Responsive and Responsible Leadership – the theme of the Annual Meeting 2017 in Davos – reminded all participants about the responsibility they have to serve the public good, not least the communities they operate in. In particular, the companies involved in infrastructure and urban development create long-lived assets, which not only can provide protection and shelter against weather but also can serve as landmarks defining our cities for decades, and enhance the productivity and well-being of their tenants, users, businesses and communities.

Looking ahead, the construction industry needs to innovate to live up to six key challenges:

1. **Project delivery**, i.e. reducing cost, time and uncertainty in completing large-scale construction projects
2. **Lifecycle performance**, i.e. reducing the total cost and increasing the total value of ownership of constructed assets across the whole lifecycle, taking into account repurposing and the asset's end of life
3. **Sustainability**, i.e. reducing the adverse environmental and social impact during the construction and operation of assets
4. **Affordability**, i.e. reducing the costs of high-quality buildings and infrastructure and creating inclusive cities and communities
5. **Disaster resilience**, i.e. creating assets, networks and types of governance that improve resilience against extreme weather events, natural and man-made disasters
6. **Flexibility/Liveability/Well-Being**, i.e. creating healthy, liveable and end-user-oriented buildings and assets that enhance the well-being of communities and that are flexible enough to accommodate changing notions of property and usage in a sharing economy

When asked to name the greatest positive impact the industry can have on society, industry leaders in Davos voted for *sustainability* – encompassing the delivery of projects and life of assets. In viewing construction as the assembly of materials, the concept of circularity is a compelling one – reducing waste, reusing and recycling towards a closed-loop economy.

As the challenges are so broad and diverse, the project looked beyond the 10 case studies and engaged a broader audience to develop new solutions to the six challenges listed above. Six working groups have been established under the auspices of the World Economic Forum's Future of Construction initiative. These groups comprise more than 60 experts – drawn from the private sector, academia, civil society and government – who have now jointly produced more than 45 mini-essays, each proposing a solution and describing its potential impact, the barriers inhibiting its implementation, and the next steps needed for making it a reality. The topics are as diverse as the challenges and as the participants' areas of expertise. The mini-essays are accessible on the project's knowledge-sharing platform (www.futureofconstruction.org). The textbox below provides an overview of the main ideas.

Box: Overview Working Group Mini-Essays

Working Group 1: Project Delivery

The solutions developed by this working group cover a wide range of topics and take a number of approaches, from conceptual essays – on the success factors, for instance, and a new management theory for megaprojects – to more practical solutions, such as project alliancing for effective infrastructure delivery and a management tool for design coordination.

Professor *Aaron Shenhar* and *Vered Holzmann* have analysed successful mega projects, such as the London Olympics or NASA's Apollo mission, and identify three success factors: a clear vision, full alignment of all stakeholders, and adapting to complexity.

Along similar lines, *Bob Prieto*, from Strategic Program Management, and *Roger Bayliss*, from Skanska, suggest a new theory for the management of large complex projects, encompassing the following elements: strengthened project foundations and frameworks, sharper focus on flows rather than just increased differentiation of tasks, recognition of the implications of the unbounded nature of these projects, and embracing the use of modern technology.

Architect *Tiago Guerra* argues that uncertainty can be reduced through more integrated delivery as well as through new technologies that enable a more effective collaboration and communication. However, increased collaboration must itself be effectively managed.

A mini-essay by *Ian Redmayne* and *Bisrat Degefa*, from WS Atkins, recounts how they developed a design coordination management tool to provide a single source-of-truth platform for all stakeholders to identify design issues in complex projects.

For *Mathew Katapuram*, from Aecon Construction, the topic is how to incorporate flexibility into long-term public private partnership contracts to facilitate the use of new technologies by using output performance specifications.

Other mini-essays discuss project-alliancing for effective infrastructure delivery (*Perti Lahdenperä* and *Pekka Petäjämäki*, Finnish Transport Agency), effective knowledge transfer within a global company (*Syed Mateen Akhtar*, Saudi Aramco) and across the industry (*Bob Prieto*), a new project scoping approach to improve project delivery in developing countries (*Mark Tcach*, MCC), and the outline of an international infrastructure support system (*Christophe Dossarps*, Sustainable Infrastructure Foundation).

Working Group 2: Lifecycle Performance

The solutions discussed by the Working Group include the private and public sector perspective. From the private sector perspective, *Amanda Marcandali* and *Marc Ribo*, from Abertis, share best practices from its (PPP) contracts that improve safety and maintenance over the lifecycle of toll road concessions.

From the public sector perspective, *Alex Lubbock*, from the UK Infrastructure Project Authority at the Cabinet Office, discusses the impact that public clients can make on the value of infrastructure assets and highlights the importance of a clear construction strategy and reducing costs at the pre-construction phase. Among the key features are: a transparent infrastructure and construction pipeline, fair payments that enable private-sector investment in innovation and new capabilities, collaborative procurement models fostering early contractor involvement, mandating the use of BIM Level 2, and “government soft landing” for a smooth transition from design to actual construction.

Working Group 3: Sustainability

The solutions discussed by the working group on sustainability cover many different aspects of the topic, notably materials and energy. On the material sides, for instance, the themes include: the advantages of increasing the use of alternative cementitious materials rather than carbon-intensive cement in concrete (a subject of joint research and collaboration by *The Durst Organization* with universities, local government and industry participants); advanced accounting of embodied emissions in materials; a sustainability concept for the *US Army Corps of Engineers* and its managed water resources; and capacity-building for sustainable cooling and energy-related topics, such as on-site energy generation and decentral energy supply.

Working Group 4: Affordability

The working group on affordability produced several solutions regarding the financing of housing and infrastructure, proposing a mix of *financing instruments*, including housing vouchers, and tax credits for low-income housing; mandatory local banking credits; crowdfunding; and microfinancing or solitary bonds. Other proposals for improving affordability include applying capital efficiency and design rethinking.

Architect *Aaron Schwarz*, of Plan A Architecture, argues the case for mixed-use affordable housing development – seeking to integrate housing with social infrastructure, business and leisure activities to gain social acceptance for new projects.

Working Group 5: Disaster Resilience

The solutions proposed by this working group include all the main dimensions of disaster resilience – assessment, prevention, mitigation of existing risks, and better preparedness and faster response to disasters. More specifically:

A comprehensive building emergency management assessment methodology, applied to flood risks for commercial real estate, is presented by *Franz Jenowein*, from JLL. *Sherena Hussein*, from the Brookfield Centre in Real Estate and Infrastructure, describes successful examples from master planning of resilient infrastructure in existing urban areas, such as New York’s Hudson Yards project. A framework to assess the resilience of (ageing) transport infrastructure is proposed by *Arjan Hijdra*, from the Dutch Ministry of Infrastructure and Environment, and *Paolo Craviolatti*, from the Global Infrastructure Institute.

Monica Altamirano, from Deltares, puts forward some nature-based solutions for disaster resilience.

A key challenge is climate change. A web-based climate-change decision-making tool, developed by *Colombia’s Ministry of the Environment and Sustainable Development*, provides a one-stop information source, including real-time maps, regional vulnerability assessments, and information on mitigating measures. To respond effectively to disasters, all stakeholders need to work together: effective public-private-citizen collaboration and coordination is essential. *Marc Ribo* (*Abertis*) and *Elisabet Vilodamiu* (*Institu Cerdà*), describe the Crisis Management Service, a scalable coordination framework that was first developed in Spain and that has since been replicated in Chile. The service creates partnerships that bring together private operators of highways, telecommunications, electricity, water and others to improve coordination within the private sector and between private companies and public authorities in case of crisis to make societies more resilient.

Working Group 6: Flexibility/Liveability/Well-Being

The common theme of the different solutions developed by this working group is that of end-user orientation. *Ron Bakker*, of PLP Architecture, issues a call for using more natural-plant-based materials like timber and bamboo, which tend to be more sustainable and more beneficial to users’ well-being than many mined or processed materials.

Two mini-essays by flooring producer *Tarkett* take a different perspective: first, showing the potential of new flooring materials to improve indoor air quality; and second, discussing “intelligent” floors that can detect when patients or old people fall in their homes or in hospital.

New technologies are also at the centre of other solutions on offer. *Jakob Lange*, of BIG, describes how The Hyperloop can revolutionize transport. Finally, *Julia Huss*, from AkzoNobel, describes the case of TUDO de Cor, a house-painting project in a Brazilian favela. The project demonstrates the power of community-driven collective action and shows how changes to the built environment can benefit people’s self-perception, purpose in life, position in society and general well-being.

The 10 Lighthouse innovation cases also show the positive impact of innovations on all the six challenges above. Their stories should serve as an inspiration and as an incentive to embrace the opportunities offered by new digital technologies and business models in the industry. The key success factors can help companies to stimulate innovations within their organization, turn new ideas into reality and succeed in the market. Corporate leaders have a responsibility now to make their own companies part of this industry transformation. They should also intensify cross-company collaboration – sharing best practices, developing the larger supply chain, setting industry standards, conducting joint industry marketing and coordinating their engagement with the public sector.

Governments must play their part too. As smart regulator, long-term strategic planner and incubator, and forward-looking client, a government is deeply involved in constructed assets, and should ensure to remove barriers to innovation and create an environment that is conducive to real technological advances.

A review of the case studies and mini-essays indicates a few key enablers for the transformation of the Engineering and Construction sector. One such enabler is digital talent: the construction industry critically needs to attract, retain and develop this digital talent, especially as skilled labour is now in short supply, owing to demographic shifts in the workforce. (In the US, for example, over the past three decades, the average age of construction workers has increased by seven years and the proportion of soon-to-be retirees has surged.)⁶ When students and young professionals are asked to identify the most important element of a job, they cite *learning and career development* almost at the top (second only to *interesting job content*). Yet only 17% of respondents in the construction industry agreed that their company was fulfilling their expectations in respect of *learning and career development*, and a mere 12% think that the industry is investing enough to *recruit and retain talent*.⁷

Another key enabler is sufficient financing for construction innovations. These innovations could contribute crucially to closing the global infrastructure gap. Simply providing more funding and reducing the risks of projects is not the answer to the huge infrastructure deficit. Innovations in Engineering and Construction are needed to reduce costs, time and uncertainty of delivery.

During the next year of the Future of Construction initiative, the aim is, therefore, to tie all elements together – innovation and new technologies, sustainability and circular economy, talent and skills, and investment in and financing of built assets – and to explore how business and governments can advance from to better serve their clients and society.

A successful implementation of the success factors and policy recommendations will help to accelerate innovation in the construction industry and thereby achieve higher productivity, greater sustainability and enhanced affordability.

“

There has always been a mismatch between the need for infrastructure assets and the capital to fund them. By leveraging all the remarkable innovations that have emerged in recent years, we have a new opportunity to narrow that gap.

”

John Beck, President and CEO of Aecon Construction

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Endnotes

- 1 See French Ministry of the Environment, Energy and the Sea (2016).
- 2 See Building and Construction Authority (2016).
- 3 See USACE (2016a).
- 4 See USACE (2016b).
- 5 See World Economic Forum (2013); World Economic Forum (2014); World Economic Forum (2015).
- 6 See United States Department of Labor (2015).
- 7 Survey conducted among more than 150 students, young professionals and industry members as part of the Future of Construction project between October 2016 and February 2017. Detailed results will be published on www.futureofconstruction.org.



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