WORLD ECONOMIC FORUM

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Industry Agenda

Shaping the Future of Construction

Lessons from leading innovators and disruptors

Prepared in collaboration with The Boston Consulting Group

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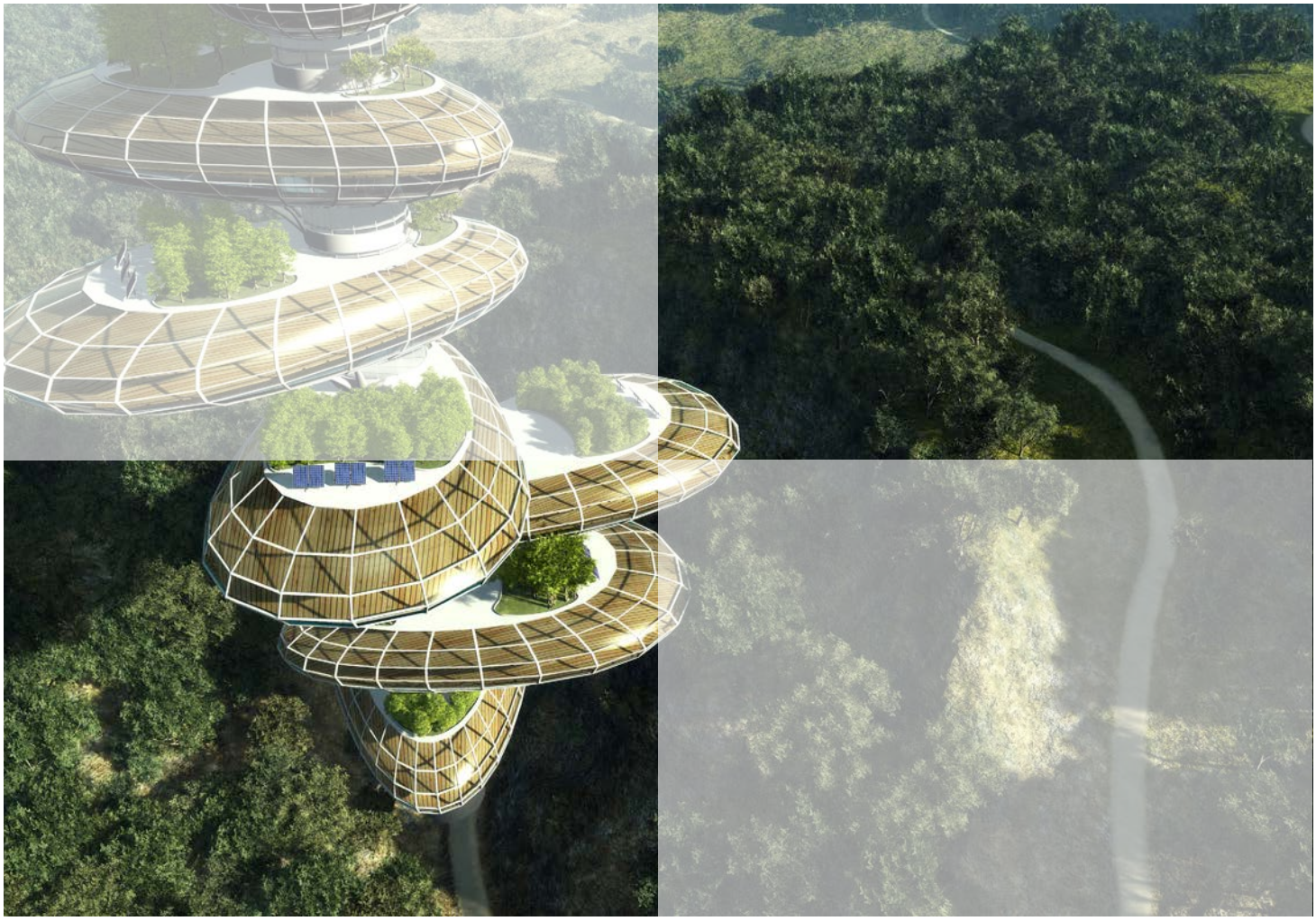

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Preface

This document offers a preview of the World Economic Forum Future of Construction report to be published in the first quarter of 2017. It is a summary of the key lessons, presenting seven of the 10 lighthouse innovation cases to start the discussion on the issues they raise. The forthcoming full report will include additional chapters that discuss the way forward for the industry and contain policy recommendations to help governments create an enabling environment that fosters a broad adoption of innovation.

Context and Objectives of the Report

Scope

The full report is the second publication of the multi-year Future of Construction project, guiding and supporting the Engineering and Construction (E&C) 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 level and outlined a comprehensive industry-transformation framework with over 30 measures and best practices. A key finding of is that many innovations have emerged but have not yet been broadly adopted. The second report looks at possible remedies, drawing key lessons 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 startups 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 (O&M) 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 E&C industry – in the form of 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 E&C 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, as well as other sectors with large-scale capital projects, including energy, transportation and even manufacturing industry.

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

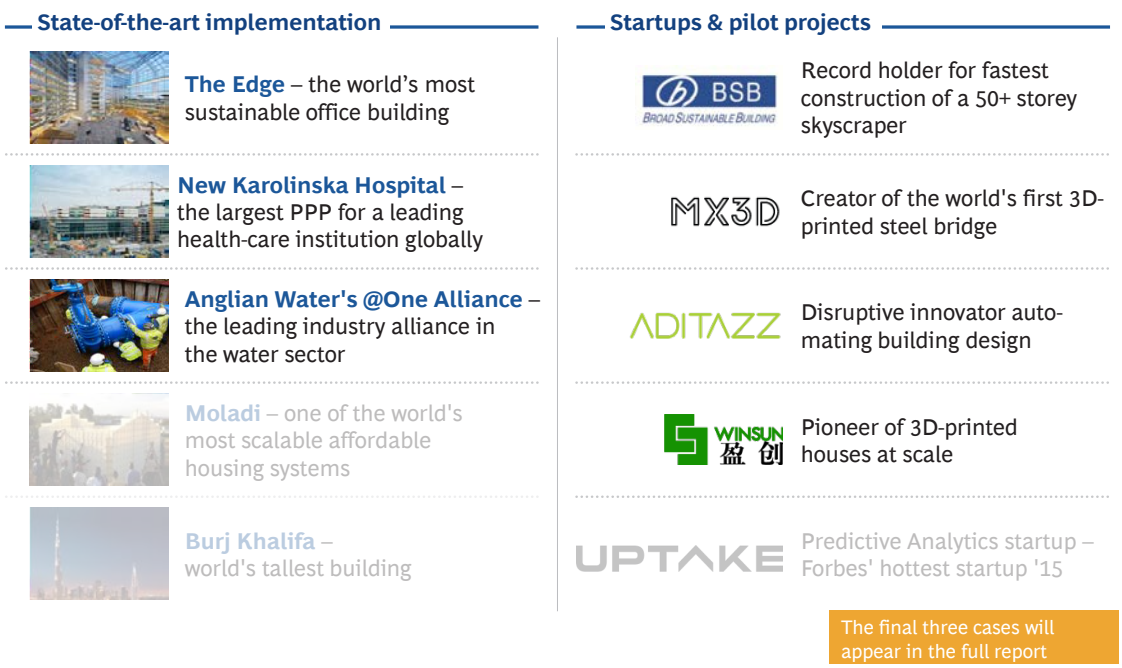
Finally, in view of the socio-economic importance of the industry, this report is also aimed at members of academia and civil society. The industry will rely on effective collaboration with all stakeholders for its future success.

Summary of Key Lessons

The E&C industry has been slow to move away from its traditional approach, though new (digital) technologies are generating major changes and offering great potential, as described in the previous report, *Shaping the Future of Construction – A Breakthrough in Mindset and Technology*. Adoption remains slow, however, 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 that question, we have analysed two types of lighthouse innovation cases: Prominent projects that took a state-of-the-art approach to implement innovation, and disruptive startups – as well as pilot projects – that demonstrate what the future of the industry might look like. Flagship projects include *The Edge,* the world's most sustainable office building; the *New Karolinska Hospital* in Stockholm, the largest ever hospital PPP project*; Anglian Water's @one Alliance*, a leading alliance in the water sector; and *Moladi*, an affordable building system that is unusually scalable. The disruptive startups and pilot projects include the Chinese construction company *Broad Sustainable Building*, which made international headlines by constructing a 57-storey skyscraper in only 19 days; Amsterdam's *MX3D*, which uses robots to 3D-print a steel bridge; *Aditazz,* based in Silicon Valley, which uses design-automation principles from the semi-conductor industry to revolutionize the design of health-care facilities; and *Winsun*, which has pioneered at-scale 3D-printing of houses.

Figure 1: 10 Lighthouse innovation cases analysed to identify Key Success Factors

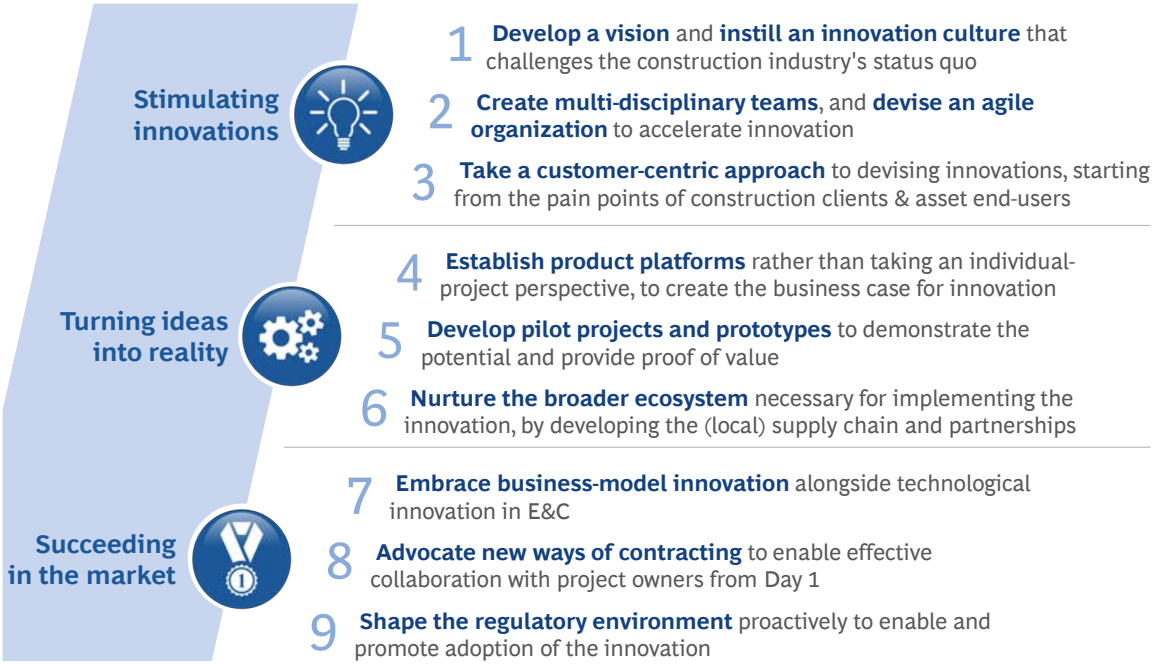


Source: World Economic Forum; BCG analysis

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

From the analysis, 3x3 key success factors were identified for innovation in the construction ecosystem according to *stimulating innovations*, *turning ideas into reality* and *succeeding in the market,* as shown below. The figure lists those success factors, and the discussion summarizes the lessons from the lighthouse innovation cases.

Figure 2: Key Success Factors for innovation in the construction ecosystem



Source: World Economic Forum; BCG analysis

1. Develop a vision and instill 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, breaking with the usual project-to-project thinking, and it has created the momentum for change by setting clear targets and communicating success stories openly among the workforce.

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, startups have a lot to teach established companies, when it comes to adopting an **outsider perspective and an attacker mindset.** Gijs van Velden, COO and co-founder of the robotics 3D-printing startup *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 startup *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 then to generate a visionary alternative to it.

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 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 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 and multifunctional teams to knock down barriers between units to end siloed thinking**. The 3D-printing startup *MX3D,* in setting out to print a pedestrian steel bridge in Amsterdam, chose a high-profile project that others in the E&C space could immediately relate to and wanted to be part of. In fact, one of the key ingredients of MX3D's success today is its collaboration with the prominent companies ABB, AirLiquide, ArcelorMittal, Autodesk, and Heijmans, which contributed their respective expertise (in robotics, welding gases, metals, design software, and E&C) 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.

The power of interdisciplinary teams is also 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. 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 startup, sets out to demolish data siloes within client organizations in order to integrate disparate data sources. When developing and tailoring the platform for a client, Uptake's diverse team members have to work hand in hand – software engineers, Big Data specialists and construction industry experts alike.

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*: 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, US, and Poland into strategic roles. In addition, the different overlapping project phases benefit from knowledge exchange, which is fostered through personnel rotation; in other words, some of the staff moves already from an uncompleted phase to a newly launched phase so as 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.

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 accelarators 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 Building Systems,* which provides low-tech affordable buildings. The company knows how crucial it is to **develop solutions in tune with the 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 adapting to local conditions, and conscientiously using local suppliers and labour. And when people knock on the buildings' walls, as they tend to do, they hear a reassuring solid sound similar to that of traditional brick-and-mortar construction. Rival affordable solutions, involving hollow panel structures and wood, are rejected as being unstable or vulnerable to the weather. So 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 perspective**. 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.** *Uptake* has taken a similar 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 – in much the same way that insights from machine and engine properties have been taken from the railways 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. As for *BSB*, to facilitate high-rise construction it has developed a technology platform based on steel-frame floor plates and structural columns; by tailoring that platform through a simple menu online though, clients can promptly customize the building that they commission.

The concept of product platforms is not confined to the realms of information technology, but is 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 E&C industry is highly 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 (VC) funds. *MX3D,* for example, required just $1.5 million to launch its venture into autonomous robotic 3D printing, yet it struggled to raise this seed capital in the construction sector, as construction companies are very risk-averse and hence reluctant to invest in emerging technologies. Similarly, the multi-year research-and-development of *Aditazz's* design automation platform was made possible only thanks to the strong backing of a VC fund. In the case of the *New Karolinska Hospital*, the main contractor Skanska decided to invest heavily upfront into developing a comprehensive lifecycle BIM model – going far beyond the contractually mandated BIM usage – as the company is operating within the framework of a 40-year PPP contract.

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 pre-fabrication specialist *BSB* quickly developed a minimumviable product to demonstrate the power of its technology for high-rise construction. This rapid prototyping has featured prominently in BSB's guerilla-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 multi-storey building. For Winsun, these prototypes have proved to be a very effective marketing vehicle, and have enabled further development of its technology.

Another success factor that is typical for software startups can also be applied in the construction industry: **continuously improve the minimum-viable product, via project experience and client feedback.** Consider the case of *BSB* again: 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 the common issue of steel corrosion. Or consider the predictive-analytics startup *Uptake* again: 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 the data; and continuously applies construction-industry know-how that it has acquired through its strategic partnerships.

6. Nurture the broader ecosystem necessary for implementing the innovation, by developing the (local) supply chain and creating partnerships with non-construction companies

E&C companies operate in a project-based and fragmented industry, and have to collaborate with ever more new 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 suppliers and distributors.** 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, bringing suppliers of different sensors into creative contact with Philips to develop its Ethernet-connected LED lighting panels) and also with various startups (to develop the building app, for example), and in that way succeeded in integrating these innovations into the building without increasing costs.

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 company, 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 own 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* in Stockholm 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 sub-contractors 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.

One final case in point: in 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.

7. Embrace business-model innovation alongside technological innovation in E&C

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 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 design and technical solutions but also has in-house project-delivery capabilities – a necessary add-on, as the market is not yet willing to use the platform independently. 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 the market through open communication and innovative forms of marketing.** One example is that of *BSB*: to raise awareness and increase acceptance of its disruptive 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 technology platform available to local franchisees and thereby benefi the local economy.

8. Advocate new ways of contracting to enable effective collaboration with project owners from day 1

Among the major barriers to innovation, according to industry experts, are traditional contracting and procurement models, such as the basic bidding system (the lowest bidder wins the contract). Innovators should therefore **advocate other forms of contracting, with a longer-term and performance-based approach**. Such an approach has eased one concern facing *Anglian Water's @one Alliance*: the Alliance favours close collaboration with suppliers from the very start of a project (during the planning stage), but that early collaboration 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.

The success of an innovation often depends on the role of the project owner. So it is crucial for innovators to **collaborate closely with project owners regarding approvals and client demands across project phases.** 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 (moving towards 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.

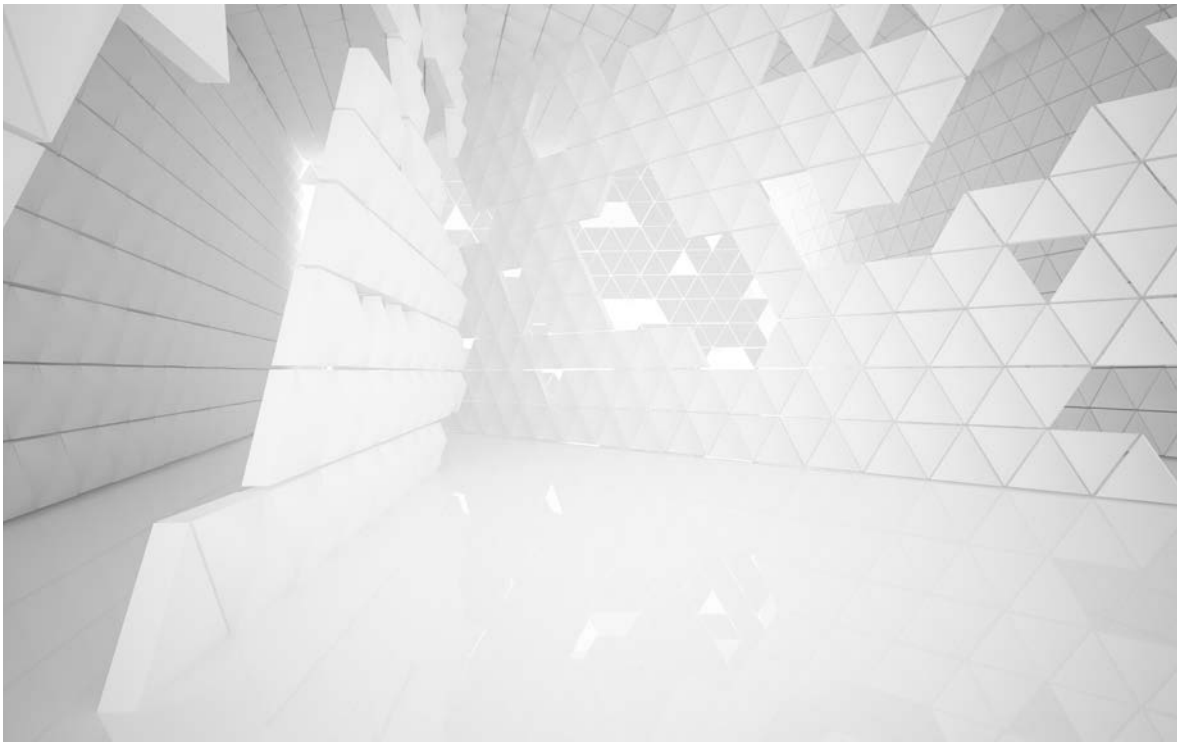
9. Shape the regulatory environment proactively to enable and promote adoption of the innovation

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 very 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.
Successful innovators **engage with regulators early 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. Governments can provide a huge stimulus for innovations through strategic public investments and target-setting. Innovators can actively push and advocate for those supportive measures. *Uptake,* for instance, 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 their 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.

Note, however, that certification is not always necessary for market entry. *MX3D* has developed a minimum viable product that is already being commercialized and marketed. 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 no easy task, but it is certainly worth pursuing. Successfully implementing innovations is what turns potential into impact, as these case studies show. Read their inspiring stories on the following pages.



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 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.

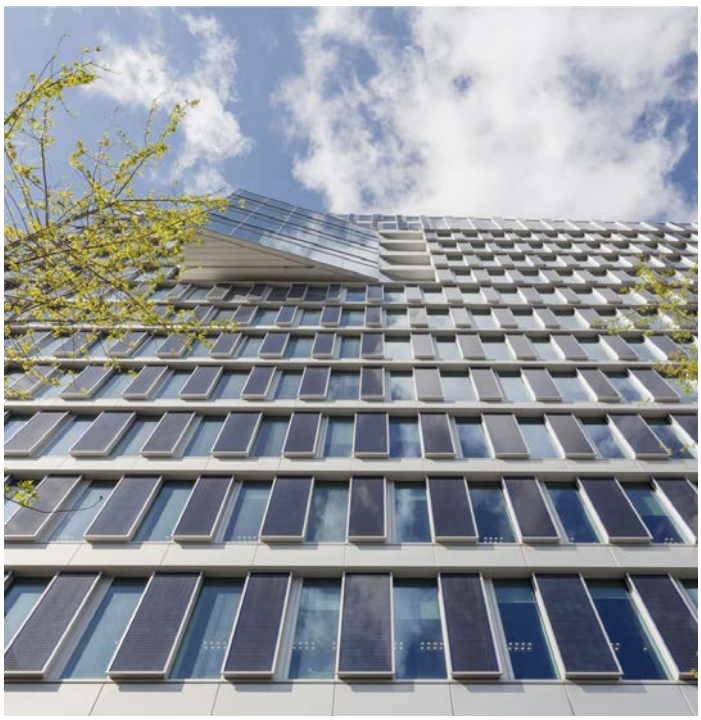
The Edge is aptly named. It is at the very forefront of office-building accomplishment, maximizing the productivity of its occupants, minimizing the running costs and the environmental impact.

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 kilogrammes of CO_2 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

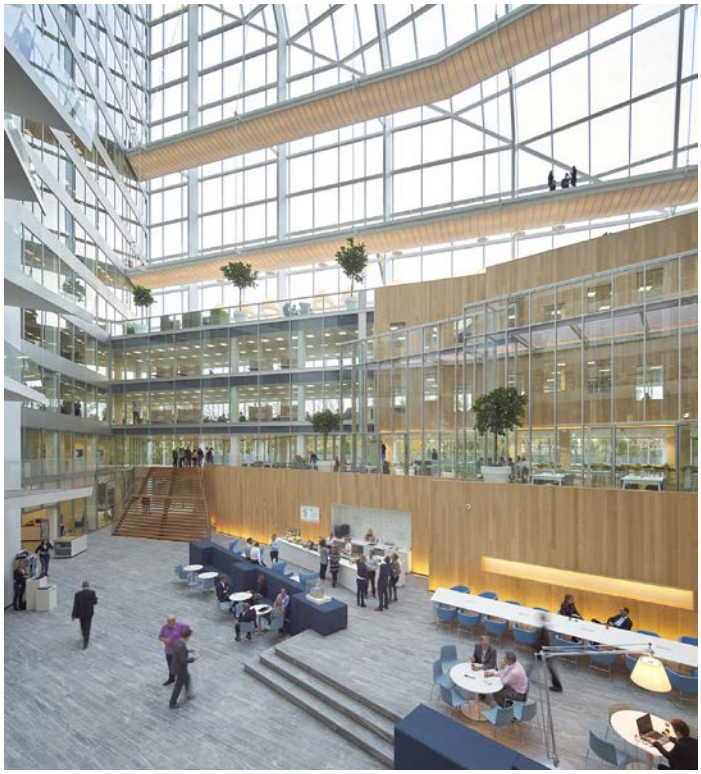
long after the initial design phase, contributing ideas throughout the construction process, and collaborating with suppliers – for instance, on developing that safe plastic for cable insulations. Another factor certainly was that Deloitte – particularly Erik Ubels, at the time still Chief Information 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.

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.

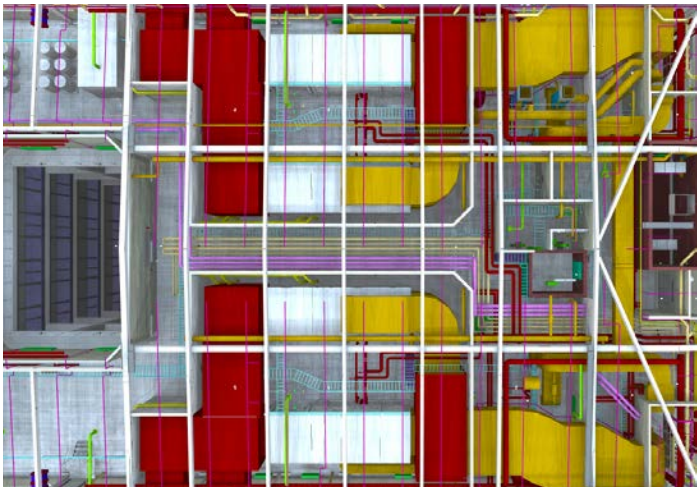
The idea

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 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.

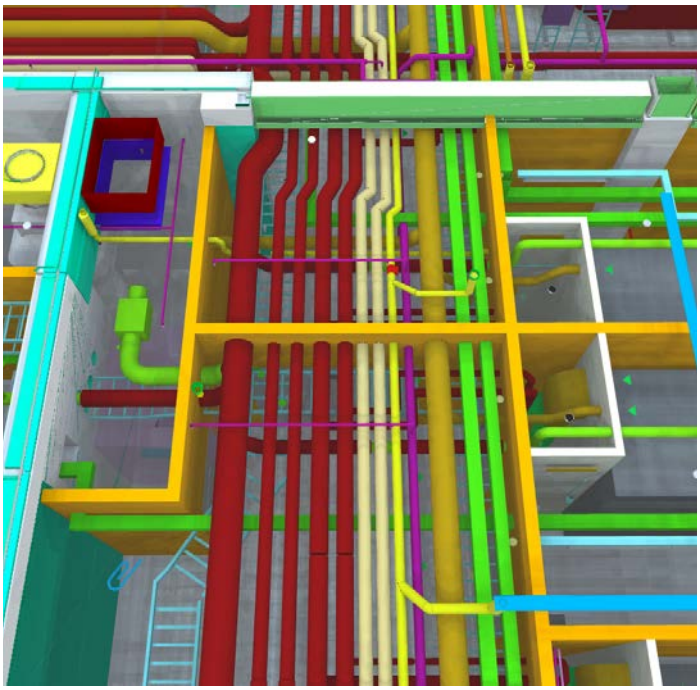
A recurring challenge for all BIM projects is the lack of standardized data formats and systems. At NKS, about 400 design consultants were involved, all

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.



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.

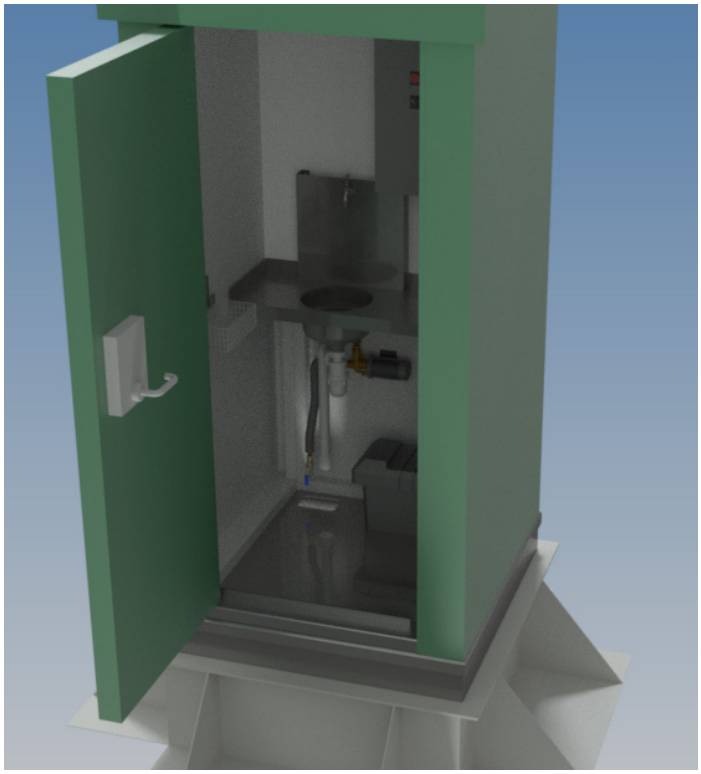
The @one Alliance was developed by analysing and benchmarking supply-chain models from different sectors (retail, manufacturing, etc.), and six key elements were identified as characterizing these models: alignment, incentives, collaboration, integrated teams, visible programmes and minimizing of waste. 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.

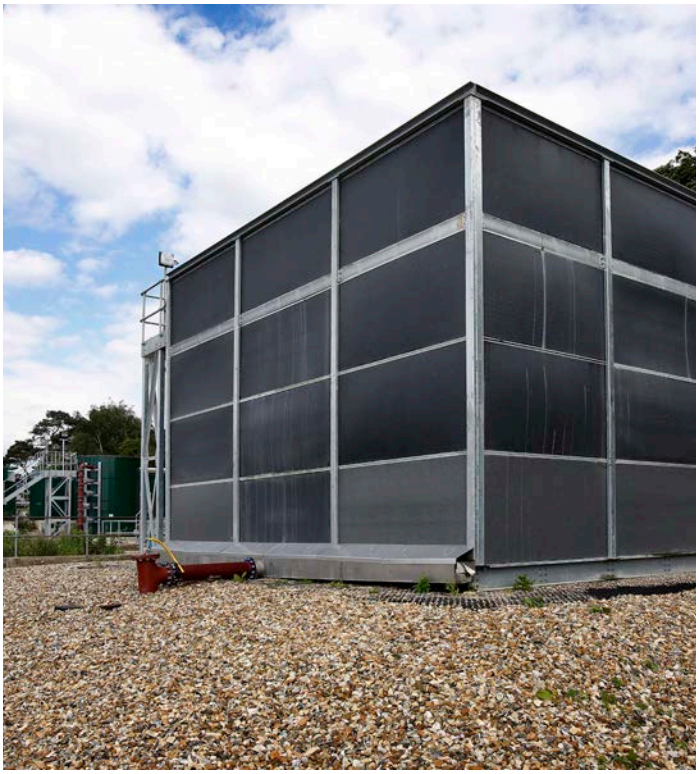


This approach to product-based delivery can be illustrated by looking at a number of simple examples. First, there are the "sampling kiosks" used for checking the water quality at reservoirs. Traditionally, each kiosk was individually built on site on a large concrete base, and required a large lead 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.

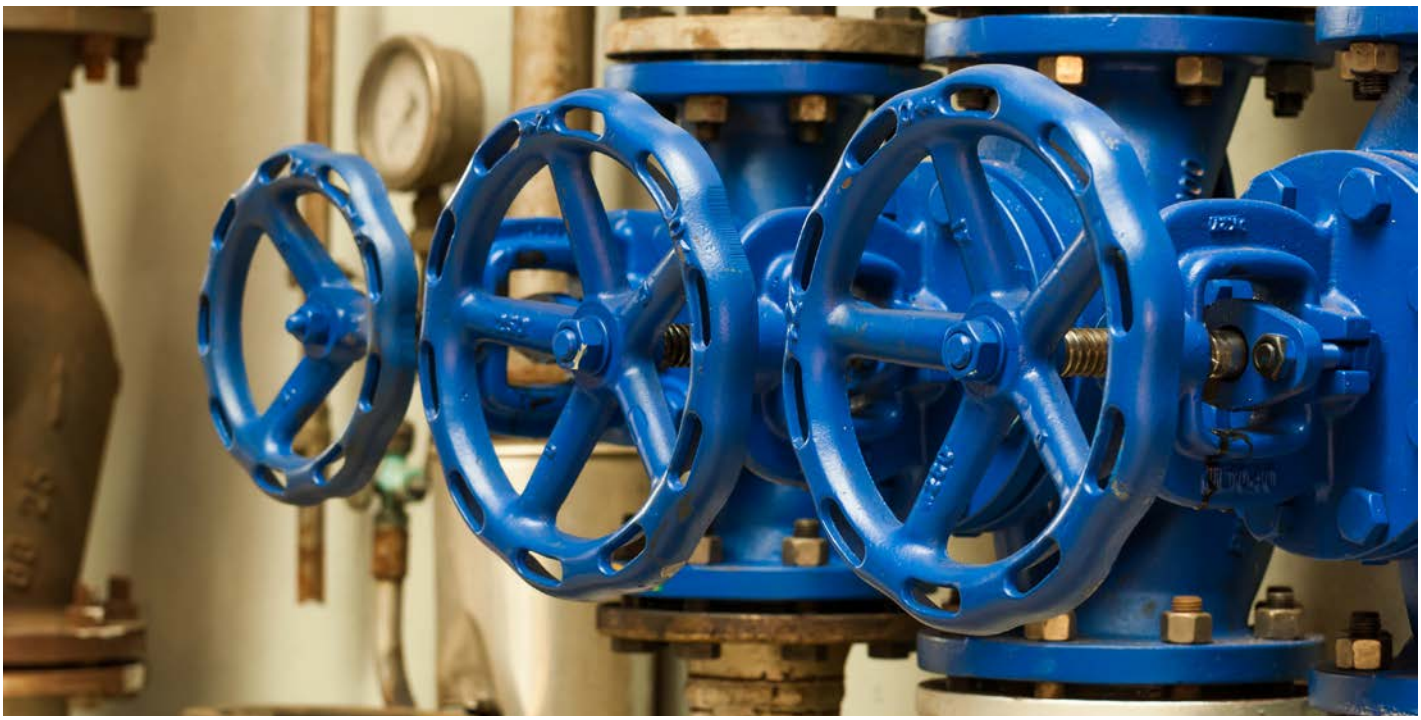
The BIM model can be reviewed virtually by the delivery team – including sub-contractors, suppliers, and health and safety specialists – and by the operating team in a digital rehearsal room using immersive technology (augmented reality) before construction even begins. (The safe-to-operate and safe-to-maintain 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 (CO_2 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 (CO_2 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 or thinking.

BSB
BROAD SUSTAINABLE BUILDING

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 and 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.

> **"The E&C industry is not even in the Third Industrial Revolution, let alone in the Fourth; a step change is required."**

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.

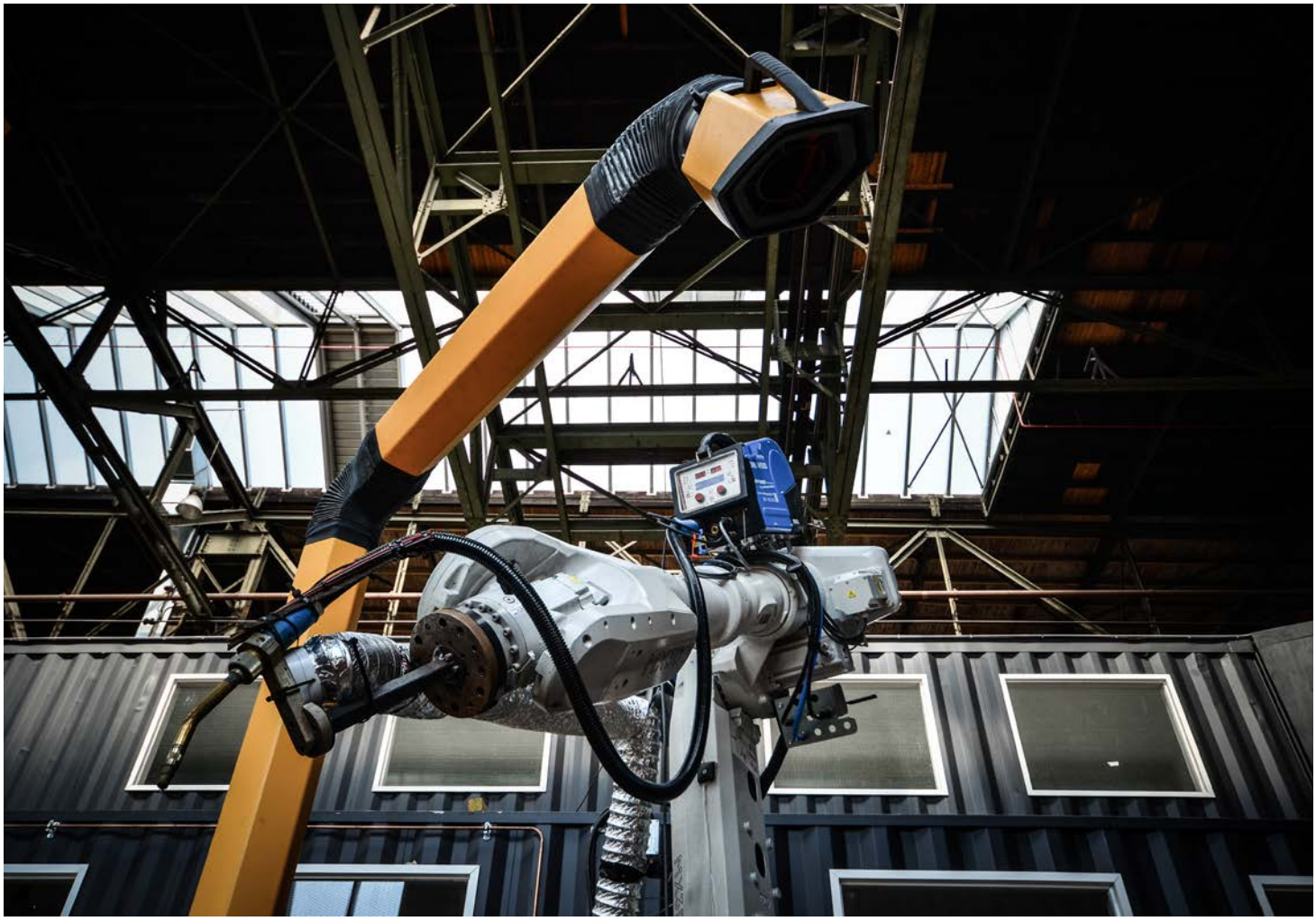
Lessons learned

- **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

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 autonomation of equipment, the engineering and construction (E&C) sector has been hesitant

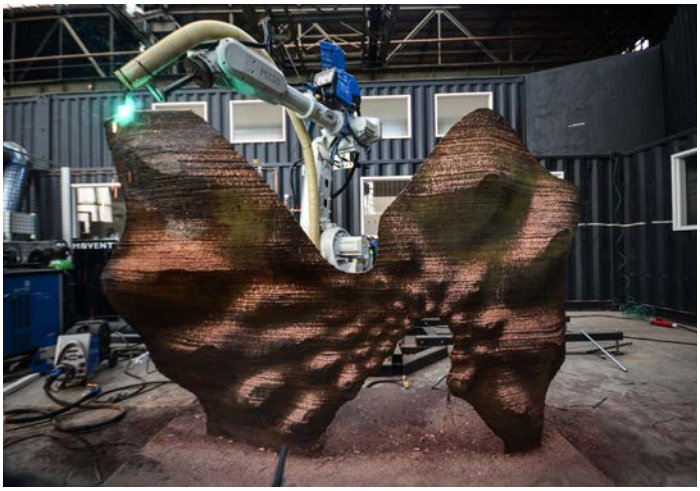
Over the past 50 years, the productivity of most industries has surged but it has virtually been at a standstill in construction. One of the main reasons for this is the difference in degree of automation. Manufacturing industries are currently experiencing the Fourth Industrial Revolution, with the autonomation 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.

Transform standard industrial robots 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 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 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.

> **"Using technology "to build what we could not build before"**
>
> Gijs van der Velden, Co-Founder and Chief Operating Officer

1 Anne C.M. Bekker (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/ISO[2] 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.

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

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.

ADITAZZ

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 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

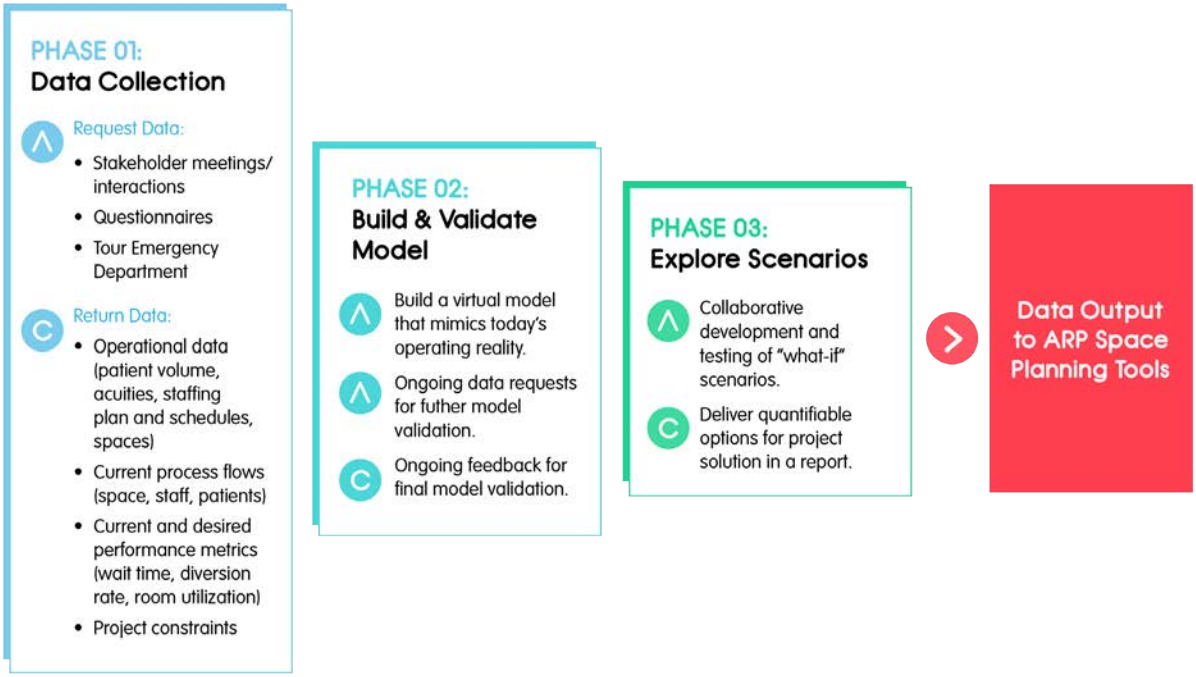
E&C could adopt design-automation principles from the semiconductor industry.

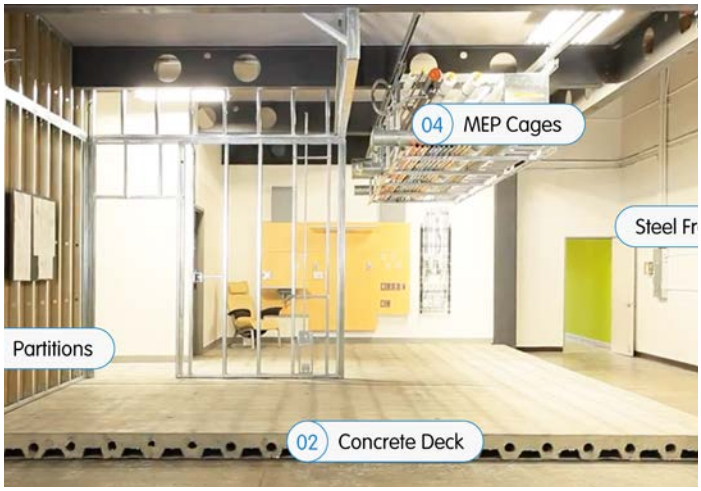
Aditazz Inc., founded in 2011 in Silicon Valley, aims to revolutionize the way buildings are designed. BIM is not enough. Although it propels design methods into the 3D digital world and facilitates coordination in later phases, the methods themselves are outdated. Aditazz has introduced a new way of 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. Cancer Center Analysis.png

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 automation 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.

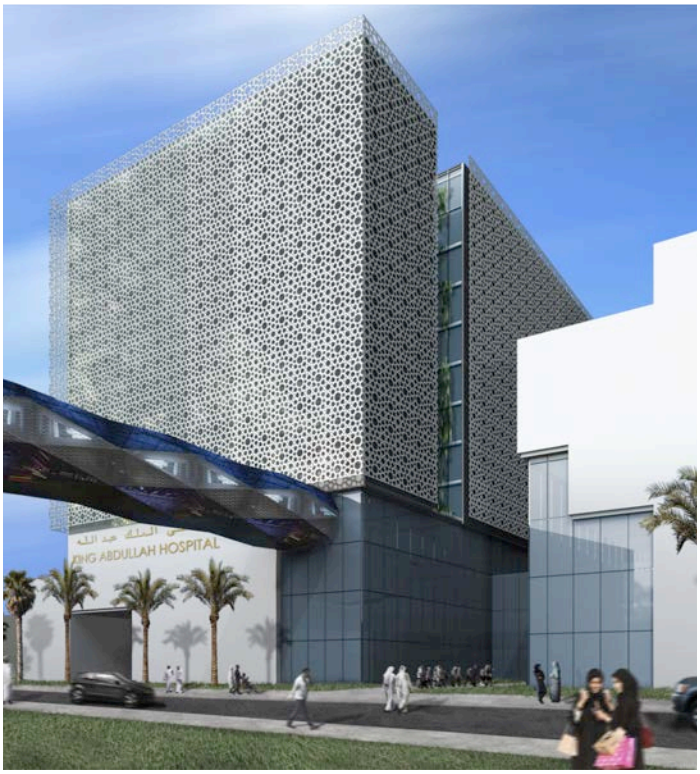
One further reason for ADE firms' reluctance to adopt the Aditazz platform is fear of losing Intellectual Property (IP) protection and their competitive advantage. To address this, the Aditazz platform separates customer IP from the product and ensures that a customer's data cannot be seen by users outside 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.

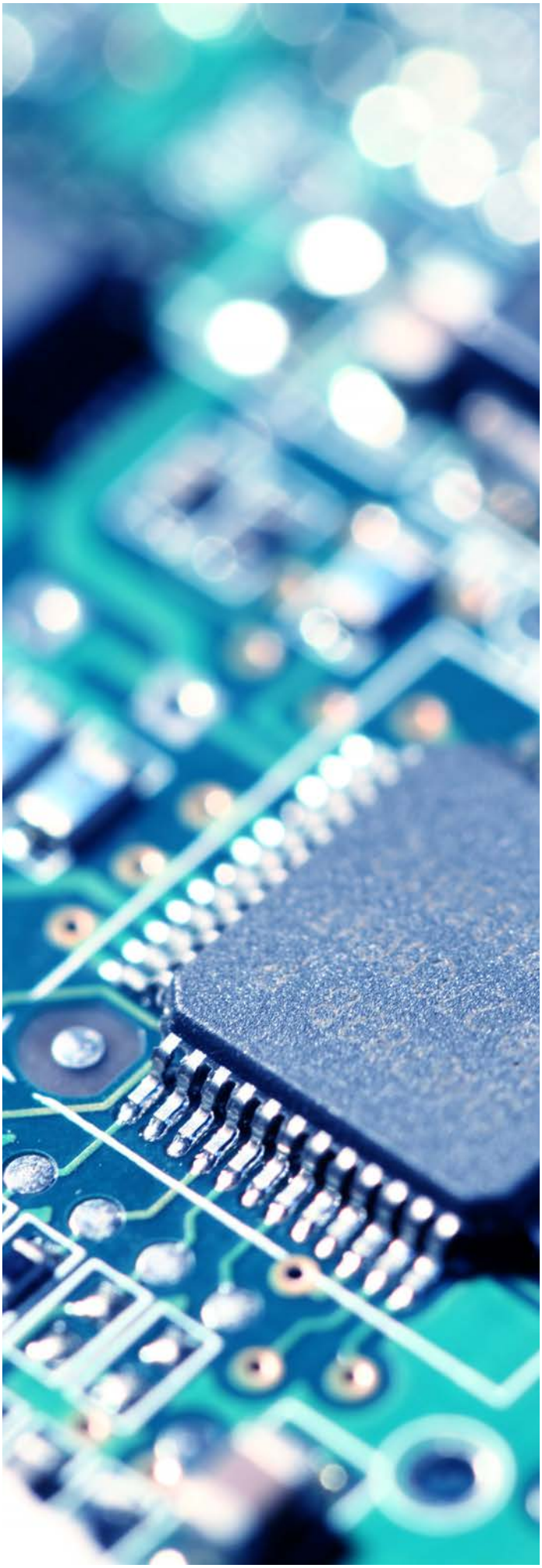


Lessons learned

- **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 component 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.

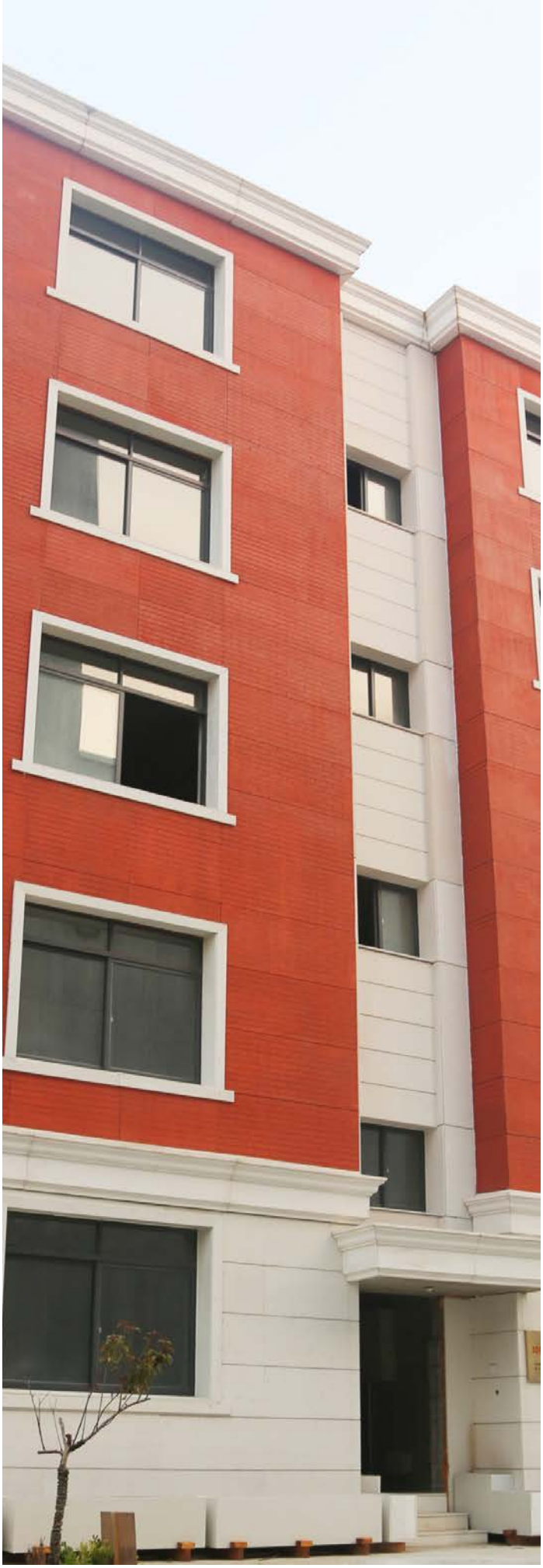
Some barriers to pre-fabrication cannot be overcome easily and will need a workaround. In remote regions with poor road infrastructure, building sites might prove inaccessible to large pre-fabricated components transported from distant factories. So, Winsun is studying the potential of using smaller,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

> **"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.



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