



## *Innovation Insight*

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### The impact of emerging technologies on the construction industry

Calie Pistorius



The focus of this report is on the impact of emerging technologies on the construction industry. The objective is to provide a wider overview, which can inform an encompassing discussion on the strategic business opportunities, risks and threats presented by emerging technologies and technological change on the industry. These insights can support decision-making and underpin the development and implementation of corporate innovation strategies, informed by an assessment of companies' own technological capabilities and dependencies.

This report is not intended to be a historic review or an exhaustive discussion on the impact of technology and specifically emerging technologies, on the construction industry. Instead it discusses a *selected number of relevant and recent* developments. It is not intended to cover every individual reported use of an emerging technology in construction or all emerging technologies. A number of illustrative examples and cases highlight the implementation of specific major emerging technologies and their impact on construction. These are often signals of what is on the horizon, which will hopefully stimulate action and discussion.

An analysis of the technology-related impact, strategic opportunities, threats and risks also needs to account for a range of other factors, including the evolving economic climate and markets, industry structures, political developments and regulatory environments as well as social trends. Mindful of importance of these contexts, this report focuses on the technological aspects.

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**DeltaHedron Ltd** is a UK-based business consulting firm with a global reach, specialising in the management of technological innovation. We support our clients with the development and implementation of innovation strategies, underpinned by an assessment of the impact, strategic business opportunities, risks and threats presented by emerging technologies and the dynamics of technological change.

We shall be delighted to discuss strategic business opportunities and risks, as well as the tracking and identification of emerging technologies, and innovation strategies to translate technological opportunities into business success.

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## Innovation Insight

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***DeltaHedron Innovation Insight*** is a series of white papers, reports and newsletters exploring aspects of the technological future and technological innovation, with a specific focus on the strategic impact, business opportunities, risks and threats presented by emerging technologies and the dynamics of technological change

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***'Anticipating what can happen in the future is one thing,  
knowing what to do about it is quite another'***

# The impact of emerging technologies on the construction industry

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## Executive summary

### Context

This report focuses on the impact of emerging technologies on the construction industry, with an emphasis on recent trends.

The vantage point of DeltaHedron's approach is one of exploring the strategic impact and the business opportunities, risks and threats presented by emerging technologies and technological change. These insights support decision-making and underpin the development and implementation of corporate innovation strategies, informed by an assessment of companies' own technological capabilities and dependencies.

### A strategically important industry

The construction industry is one of great strategic importance on the regional, national and global levels. Economic growth, quality of life, competitiveness and security all depend on new infrastructure and the maintenance of older structures. Construction is key to the success of

many other industries and sectors, and hence is also a political priority.

Globally, the construction industry is one of the largest industrial sectors, accounting for 13% of global GDP. Recent estimates indicate that it is worth circa \$10 trillion annually and that this will rise to \$14 trillion by 2025, with an expected growth of 3.6% per annum. Due to its size and the nature of its operations, the construction industry is a major employer, with circa 7% of workers globally working in construction.

### An industry dogged by concerns

The construction industry is, however, also a troubled one and has been dogged by many concerns for some decades. The industry is characterised as being risk averse, resistant to change and not very innovative. Compared to other industries, construction exhibited alarmingly low productivity growth of only 1% over the last two decades. It is one of the least digitalised industries, with very low investment in R&D.

Waste, environmental friendliness and energy efficiency remain problematic.

The industry is experiencing labour shortages in a number of countries. This is not helped by the fact that safety is a concern, with relatively high mortality and injury rates. In the UK, the recent Farmer Review (October 2016) highlighted the construction industry's challenges, particularly with regard to the labour market.

The industry is also burdened by a number of structural problems, including the misalignment of interests and incentives of stakeholders, which is reflected in non-ideal approaches to contracting and risk-sharing. The industry is fragmented and not always transparent. Construction projects are increasing in complexity and size, yet inefficiencies in project management, logistics and procurement as well as execution persist.

There are some encouraging signs that this is changing, with innovative companies in the industry leading the charge. In general, however, there is cause for concern.

### **An industry ripe for disruption**

A number of forces are pressuring for change and there are calls for a 'reinvention of construction'. The construction industry is indeed ripe not just for change, but for a much more serious disruption.

A range of emerging technologies, including those which will enhance digitalisation and automation of the industry as well as new materials, will be catalysts for disruption. The emerging technologies will have a transformative impact on the industry and contribute towards addressing the challenges it faces. The disruption will, however, change the nature of the industry.

The disruption of an industry brings huge opportunities for those who seize them. This is true for the construction industry as well. A number of progressive companies in the industry are already riding the next wave. They have digitalised and are adopting innovative business practices and emerging technologies.

At the same time, the impact of the emerging technologies also pose risks and threats for industry laggards who fumble the future. This is not a time for companies in the construction industry, governments for that matter or those who are considering entering the industry, to be complacent.

Following a disruption, it is also not uncommon for the industry hierarchy to change, with new companies emerging as industry leaders.

As is often the case when industries are disrupted, there will also be successful new entrants. The new entrants will leverage new technologies and typically also bring new organisational cultures and industry dynamics, new business models and new best-practices, some of which were developed in other industries. In fact, some of the new entrants will no doubt come from other sectors – such as manufacturing.

'Constructech' start-ups, analogous to the fintechs and insurtechs which are disrupting the financial and insurance industries, will also contribute to the disruption of construction and fill industry niches where they have competitive advantages.

### **Embracing innovation**

The construction industry's general risk averseness, resistance to change and 'lack of innovativeness', are fundamental to many of its other woes.

The key is for the construction industry, as well as individual companies, to embrace innovation in its broadest sense. An innovation mindset and culture must be developed and the quest for innovation and the 'innovation premium' should be fundamental objectives.

Technological innovation is important, but it should be blended with other types of innovation such as business model and organisational innovation to achieve ultimate business success.

Equally important is the recognition of the importance of different innovation modes. A reliance on incremental innovations only, is a flawed strategy. They are important to achieve continuous improvement, but this should not become a comfort zone or a cover for resistance to fundamental change when that becomes necessary. The impact of incremental innovations have a tendency to run their course, and their further pursuit then becomes one of diminishing returns. Very often this is the time when radical and disruptions are required to bring renewal and stimulate growth. The construction industry seems to have reached that point.

### **Technology-related trends**

A number of trends in the construction industry are technology-related, either driven to a large extent by digitalisation and other emerging technologies, or impacted by technology. These

include the trend towards a sensitivity for the environment and eco-friendliness, energy efficiency and renewable energy sources. Conservation of natural resources and reducing carbon emissions will stimulate the 'greening of construction'. This will have an impact on the design of buildings and the way in which they are used, as well as on the construction process.

Smart buildings and infrastructure of the future will be 'intelligent' and engage actively and proactively in and with their environment, and with the humans and animals in the environment. They will have the ability to sense the status of and changes in their environment, make decisions, intervene and respond, and communicate with people, other buildings and devices; and increasingly anticipate, learn and adapt their behaviour.

The design of smart buildings need to be future-proofed. The electronics and sensors which provide the intelligence for smart buildings evolve very fast, and a building will probably accommodate several generations of electronic devices and systems.

### **The impact of emerging technologies**

A number of emerging technologies are collectively driving change in the construction industry. They will have a transformative impact on the industry and contribute towards addressing the challenges it faces.

#### **Digital transformation and digitalisation**

Digital transformation is one of the most significant global trends. It impacts every sector of society, driving progress, economic growth and quality of life. No industry is left untouched.

The construction sector has exhibited very little productivity growth during the last two decades. Mindful that there is a direct correlation between the extent to which an industry is digitalised and productivity growth, it is not surprising to note that construction is one of the least digitalised industries.

Digitalisation of the construction industry is one of the forces which will accelerate disruption. Digital-related technologies such as mobile and cloud-based applications will underpin a number of other emerging digital and data technologies. These will in turn enhance the quality of data driven decision-making and productivity.

As part of the digitalisation process, the construction industry will increasingly adopt

practices which are common cause in other industries, such as software-as-a-service (SaaS), Enterprise Resource Planning (ERP) and bring-your-own-device (BYOD). Emerging data technologies such as big data, analytics, machine learning and artificial intelligence (AI) all have applications in the construction industry, and will multiply the impact of digital transformation as they have done in other industries; as will virtual reality (VR) and augmented reality (AR), Building Information Modelling (BIM), the Internet of Things (IoT), geolocation and blockchain.

Collectively, digital emerging technologies will enhance logistics, supply chains and procurement. An interesting development is the emergence of digital markets in building materials, in which constructechs have taken the lead; similarly, for the market for peer-to-peer rental of equipment, which is enabled by data sharing platforms.

Increased digitalisation brings with it greater cyber security risks, posed not only by viruses, malware and ransomware which can disable and disrupt systems, but also criminal cyber activity which include the theft of commercially sensitive and personal data. These breaches carry significant legal, financial, reputational and operational risks.

#### **Automation technologies**

A number of emerging technologies are contributing to the automation of construction, lending weight to the notion of 'construction as a production process'. They will contribute significantly to productivity enhancement.

3D printing is finding increasing applications in construction, including the printing of parts and models but also modular panels and even entire buildings. There are many reports of buildings being 3D printed in a matter of days. This is often combined with modularisation and off-site manufacturing, which are important trends in their own right. Large 3D printers specifically designed for construction use a technique known as 'contour crafting', with cement as the 'ink'.

Robotics is also set to impact on construction, ranging from robots involved in site preparation and waste clearance to brick laying and welding.

Drones and autonomous vehicles have many construction applications. They can be fitted with a range of image, video and related sensors. This enables them to conduct aerial mappings and surveys, safety inspections as well as recordings of

project progress. In addition, they also find application in data relay, site security and safety.

Wearables refer to textiles and other devices worn by a person, which can send (and receive) information gained from IoT sensors. The information can reflect the person's physical and emotional state, movement and position as well as other environmental variables.

### New materials

By their very nature, new builds and retrofitting consume vast amounts of construction materials. Trends in materials of the future will redefine how projects are conceptualised, designed and executed as well as the life cycle trajectories of the projects. Given the large volumes concerned, even small improvements in performance can have significant impact productivity, durability and safety; and similarly for reductions in cost.

Concrete and steel remain widely used, with work continuing to improve the performance of both. Recent advances have seen the emergence of lighter, more flexible and versatile forms of concrete, including self-consolidating, self-healing and self-compacting concrete.

A number of innovative alternative materials with promising construction applications are emerging. These include, for example, ETFE which is 99% lighter and also stronger, eco-friendlier, better at light transmission and more flexible than glass; permeable concrete replacements which can absorb significant amounts of water as well as insulating materials and adhesives. Kinetic materials have the ability to convert movement to energy, and can be used in flooring and roads.

There are signs of a resurgence in the use of wood and timber, fuelled by the emergence of cross laminated timber (CLT) panels and related products. CLT panels are strong, light and durable, and their use has been approved for use in high rise buildings.

Following the Grenfell Tower fire tragedy in London in June 2017, there will be a renewed focus on the use (or not) of cladding and fire retardant materials as well as building codes, planning and inspection to prevent and contain fires.

Green construction materials will no doubt become increasingly prevalent, driven in part by regulations, demand from customers who are more environmentally sensitive as well as economic benefits. We will probably also see the need for suppliers of green construction materials

to prove that the materials have been procured from green and eco-friendly sources, in a manner similar to which there is a requirement for consumer products to be ethically sourced. These may be tied to existing green credentials such as BREEAM and LEED.

### Workforce, skills, training and education

A number of countries are experiencing labour shortages in construction, including the UK, US and Australia. It is also not easy to attract new talent. The global financial crash of a decade ago is still reverberating, but the industry's image, safety record and other challenges are not helpful either.

Disruption of the construction industry will necessarily have an impact on the labour market, driven in part by the emerging technologies and the dynamics of technological change.

As new technologies emerge, the nature of work and jobs change. It is typical for disrupted industries to experience technology-related labour upheavals, particularly during transitional periods. New types of jobs requiring new types of skills emerge. As mature technologies become obsolete, the jobs and skills they require, phase out.

The construction industry desperately needs to improve its productivity. This will provide further impetus for the increasing prominence of productivity enhancing technologies and practices, such as off-site modular construction, 3D printing, robotics and drones. The adoption of these technologies will lessen the demand for some skills currently required in construction, but will also precipitate the creation of new jobs, requiring new skills.

The use of data driven technologies such as big data, analytics and artificial intelligence will similarly also change the nature of work in construction-related professions such as architecture, quantity surveying, building management and to an extent also structural engineering.

The next generation of construction workforce will work in a industry which differs in many respects from the industry we know today. Many of the young people entering the industry will be 'digital natives', who will naturally accept, if not demand, digitalisation. They need to be prepared for the new types of jobs which will be required in the new digitalised and automated construction world – many of which do not even exist today.

Universities and other training institutions need to embrace the emerging new technological regime in construction. They need to focus research and enterprise on the development and enhancement of the new technologies and related business practices and ensure that their curricula are designed to train constructors who can create the future. Perhaps we should also consider the notion of disruption when thinking about construction education.

It is also necessary to ensure that the current workforce understands the new technologies and the benefits and opportunities they bring; as well as the risks and threats of ignoring them. Senior decision-makers in particular need to take note – it is very much in their gift to embrace innovation and benefit from the innovation premium, and to adopt emerging technologies and lead the disruption charge.

The question is not so much, “what will it cost?”, but rather “what will it cost if we don’t do it?”.

### **Recommendations**

From a strategy viewpoint, decision-makers in construction companies as well as governments need to consider the broader evolving landscape and the drivers which will contribute to the disruption of the construction industry.

The impact of emerging technologies is only one of those drivers, albeit a very important one. They will be catalysts and accelerators for change.

It is important for companies to recognise the strategic importance of a structured approach to the management of innovation, particularly technological innovation. An innovation strategy should be an integral part of the corporate strategic plan.

The dynamics of technological change will always impact on the fortunes of companies and countries. Emerging technologies will continue to substitute and replace mature technologies, and disrupt industries.

Companies should consider the importance of formally assessing their ‘technology dependencies’ as part of the risk management process. They should gain an understanding of which technologies they critically depend and rely on, whether it be technologies which constitute their (current) competitive advantages, underlie the products they make, services they render, are used in their operations or on which their logistics and supply chain and customers rely. At the same time, they should be mindful that the same applies for their competitors.

Assessing the impact and the strategic business opportunities, risks and threats presented by emerging technologies and the dynamics of technological change should be integral elements of the innovation strategy in the construction industry.

Does your company have an innovation strategy – and if so, can you describe it and determine whether it is working? If not, do you sometimes find yourself wondering what happened.... not even to speak of what can happen and which interventions should be made to shape the future?

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## 1. Introduction

### Context

This report focuses on the impact of emerging technologies on the construction industry, with an emphasis on recent trends.

The vantage point of DeltaHedron's approach is one of exploring the strategic impact and the business opportunities, risks and threats presented by emerging technologies and technological change. These insights support decision-making and underpin the development and implementation of corporate innovation strategies, informed by an assessment of companies' own technological capabilities and dependencies.

### **The construction industry**

The construction industry is one of great strategic importance on the regional, national and global levels. It is a large industry in terms of its size, economic scope and the number of people employed in the sector. Yet it is a troubled industry, with serious challenges including productivity, safety, waste, energy efficiency, environmental friendliness and labour shortages in some countries. The industry is characterised as being risk averse, not very innovative and with low investment in R&D and digitalisation.

The industry is also burdened by a number of structural problems, including the misalignment of interests and incentives of stakeholders, which is reflected in non-ideal approaches to contracting and risk-sharing. The industry is fragmented and not always transparent. Construction projects are increasing in complexity and size, yet inefficiencies in project management, logistics and procurement as well as execution persist.

There are encouraging signs that some of this is changing, with a number of innovative companies in the industry leading the charge. In general, however, there is cause for concern.

The industry is ripe for disruption, driven by a number of factors. A range of emerging technologies, including those which will enhance digitalisation and automation of the industry as well as new materials, will be catalysts for the change. The emerging technologies will have a transformative impact on the industry and can contribute significantly towards addressing the challenges it faces.

The disruption of an industry brings huge opportunities for those who seize them. This is true for the construction industry as well.

As is often the case when industries are disrupted, there will also be successful new entrants. They will leverage new technologies and typically also bring new organisational cultures and industry dynamics, new business models and new best-practices, some of which were developed in other industries. In fact, some of the new entrants will no doubt come from other sectors – such as manufacturing. 'Constructech' start-ups, analogous to the fintechs and insurtechs which are disrupting the financial and insurance industries, will also contribute to the disruption of construction and fill industry niches where they have competitive advantages.

**"The evidence reviewed indicates that the construction industry and its labour model is at a critical crossroads in terms of its long-term health. Whilst the diagnosis points to a deep-seated market failure, there are certain industry trends and wider societal changes happening now that represent both unprecedented risk and opportunity for the industry and its clients. If the opportunities are not harnessed, the risks may become overwhelming"**

Mark Farmer, Farmer Review of the UK Construction Labour Model, October 2016

At the same time, the impact of the emerging technologies also pose risks and threats for industry laggards who fumble the future. This is not a time for companies in the construction industry, governments for that matter, or those who are considering entering the industry, to be complacent.

Following a disruption, it is also not uncommon for the industry hierarchy to change, with new companies emerging as industry leaders.

### **Products and their underlying technologies**

Ultimately users deploy products, which are based on one or more technologies. In addition to a discussion of emerging technologies, this report also refers to a number products, as examples of

how the technologies are implemented and to illustrate a number of features. The report is not intended to be a comprehensive or exhaustive survey of all available products or technologies in the construction industry, but instead focuses on main thrusts with the emphasis on a number of recent developments and trends in emerging technologies.

### Roadmap of the report

In order to place the discussion in context, it is useful to commence with a consideration of the 'state-of-the industry' in a broader sense. We note a number of challenges facing the industry, related economic and social trends as well as increasing expectations and demands - the notion of an 'industry ripe for disruption' and the rise of the constructechs.

The following section explores a number of issues relating to theme 'reinventing construction', specifically the notions of 'smart buildings of the future', the importance of design and a number of best practices aimed at enhancing productivity – specifically on-site execution, modularisation and off-site manufacturing, retrofitting, collaborative working and workflow as well as peer-to-peer rentals.

The main body of the report then discusses recent trends in emerging technologies which will impact on the construction industry. They are grouped in the categories 'digitalisation and digital transformation', 'automation technologies' and 'construction materials'. The distinction between the first and second categories become blurry in some cases, given the extent to which digitalisation is embedded in many other technologies.

The impact of emerging technologies on the construction industry will certainly also affect the labour market, the future nature of work in the industry and skills requirements for the future. This in turn will require universities and other educational institutions to consider how they will ensure that the next generation is equipped to take full advantage of new technologies in a future construction world that will in many respects be very different from the one we know today. At the same time, it is also necessary to ensure that the people currently in the industry understand the

new technologies and their impact – including those who make big decisions and do the designs.

The report is concluded with a summary discussion and recommendations. A paper by DeltaHedron entitled '[Instead of seeing the future, start making it](#)', which was published in the New Statesman *Spotlight on Emerging Technologies* (July 2017), is attached as an appendix.

In this report, the term 'construction industry' is used in a broad sense, and also relates to other industry nomenclatures such as 'built environment', 'Engineering and Construction' and 'Infrastructure', where appropriate. Related industries, which are not covered in any great detail in this report include transport, facilities management and real estate management.

## 2. Profile of a challenged industry

### 2.1 The strategic importance of the global construction industry

The construction industry is one of global strategic importance. Economic growth, quality of life, competitiveness and security all depend on new infrastructure and the maintenance of older structures. Construction is also key to the success of many other industries and sectors.

Globally, the construction industry is one of the largest industrial sectors, accounting for 13% of global GDP. Recent estimates indicate that it is worth circa \$10 trillion annually and that this will rise to \$14 trillion by 2025, with an expected growth of 3.6% per annum. Due to its size and the nature of its operations, the construction industry is a major employer, with circa 7% of workers globally working in construction. A recent report from the McKinsey Global Institute (MGI, February 2017) estimates that the world will need to spend \$57 trillion on infrastructure by 2030 to keep up with global GDP growth<sup>1</sup>.

Construction is a high cost and high risk economic activity, with a long-term focus. Hence its performance is a useful indicator of the health of the wider economy.

In the UK, construction output is worth more than £110 billion per annum and contributes 7% of GDP.

<sup>1</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future>

The construction industry accounts for approximately 3 million jobs, circa 10% of total UK employment. About 25% of construction output is in the public sector and 75% in the private sector<sup>2</sup>.

In Australia, the construction industry is worth A\$300 billion per annum, contributes 8-10% to the Australian GDP and employs a similar proportion of the population<sup>3</sup>.

*"We also continue to observe enormous cost and time overruns of construction projects, with our recent analysis finding average cost and time overruns relative to original budget and schedule at 70% and 61%, respectively..."*

McKinsey

No surprise then, that construction, in one way or another, is also a political priority in many countries. Yet, construction is a challenged industry which has been dogged by many concerns

for some decades. Given the importance and size of the industry, it is imperative that these be resolved – ‘something’s gotta give’, as the saying goes.

The industry is ripe for disruption and a number of forces are increasing pressure for change. The adoption of emerging technologies in construction will be a significant catalyst for the disruption of and change in the industry. That is the focus of this report.

## 2.2 Challenges in the construction industry

A number of performance metrics and characteristics of the industry indicate that the construction industry is underperforming and emphasises the cause for concern. This section examines a number of those areas, related trends which are impacting on the sector as well as rising demands and increasing expectations.

### 2.2.1 Risk aversion and lack of innovation

The construction industry is known as a risk averse and conservative industry with significant inertia. The industry has, on the whole, continued to rely on traditional approaches, methods and technologies for a long time, despite the growing

complexity of projects and emergence of new technologies. Other industries have been much more innovative and swifter in adopting new technologies, and have reaped benefits which have eluded the construction industry.

Innovation, and technological innovation in particular, drives progress. There is overwhelming evidence to show that innovative companies and industries perform better – they benefit from the ‘innovation premium’. Innovations come in many shapes and forms. Technologies are continuously being improved, leading to ‘better, faster and cheaper’. At the same time ‘last year’s model’ becomes obsolete. Some technologies evolve at a gentle pace driven by incremental innovations, whereas others change rapidly. From time to time the technological, business and societal landscapes are disrupted by

radical innovations, often coming from unexpected and completely different industries than the one in which they impact. Innovation is much more than

merely developing and adopting emerging technologies or implementing a digitalisation strategy. It requires an ‘innovation mindset’ to be embedded into a company, its culture, values and value-chain, and decision-making priorities. The article [“Instead of trying to see the future, start making it”](#), expands more on this.

The construction industry is not widely characterised as one that is known for rapid innovation – although there are encouraging signs that this is

changing, at least in some quarters. The lack of innovation and R&D in the construction

*“Compared to other industries, the built environment has been slower to react to this change. In some ways, we have been in catch-up mode, clutching tightly to the status quo...”*

Aurecon

*“...the architecture industry is not known for its fast adoption of technology”*

Design Boom

<sup>2</sup>

[https://www.designingbuildings.co.uk/wiki/UK\\_construction\\_industry](https://www.designingbuildings.co.uk/wiki/UK_construction_industry)

<sup>3</sup><http://www2.progressclaim.com/thank-you-InnProdReport2016ACIF3>

industry are manifestations of the industry's traditional resistance to change. This has led to underinvestment in technology, particularly digitalisation.

McKinsey Global Institute's productivity survey indicated that the biggest barriers to innovation by construction companies are underinvestment in IT and technology more broadly as well as a lack of R&D<sup>4</sup>.

Digitalisation is discussed extensively in following sections, but it is worth noting here that the construction industry is one of the least digitised of all industries – in Europe it is in last position and in the US it is only ahead of agriculture. Given the direct relation between the level of digitalisation and productivity growth, this a flashing red light. The construction sector also ranks in the lower range of sophistication in the Global Purchasing Excellence Survey published by McKinsey's Procurement Practice<sup>5</sup>. The low levels of digitalisation and procurement of the construction industry do, however, provide huge opportunities – there is much room for improvement.

Research and Development (R&D) spending in construction is well behind that of other industries, with less than 1% of revenues being invested in R&D – compared to 3.5-4.5% for the automobile and aerospace industries, for example. The notion that construction is a 'low tech' industry is sometimes offered as a reason. It can be argued, however, that this assumption in itself, is one of the fundamental problems.

The *Farmer Review* (2016) emphasises the lack of R&D and innovation in the construction industry in the UK. It notes, for example, the disproportionately low take up of R&D tax credits by SMEs in the construction industry; and that construction is the lowest performing industry

"... this is symptomatic of a lack of interest in or incentive to consider modernisation.... Terminology such as 'modern methods of construction' or 'prefabrication' are often viewed with suspicion..."

Farmer Review of the UK Construction Labour Model, October 2016

<sup>4</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

when comparing R&D spend across different UK industry sectors.

The Farmer Review also discusses a number of the reasons being put forward for the lack of R&D in construction in the UK. This includes "numerous financial failures of businesses who have invested heavily in different approaches that would have benefited both

construction productivity and predictability but were never adopted by clients at scale". Successful innovations need two components to be successfully

implemented, viz, the 'design component' and 'diffusion in the market'. It is the latter component of innovation that the Farmer Review refers to as having failed.

The image of a slow moving, risk averse and dangerous industry with low productivity which is resistant to change may also contribute to the labour shortages currently experienced in a number of countries and its inability to attract sufficient new talent.

The Australian *Construction Industry Innovation and Productivity Report* (2016)<sup>6</sup> investigated the attitude of construction companies towards innovation, technology and the adoption of new technologies. The report notes the 'disconnect' between perceptions and reality. Respondents generally acknowledged (90%) that it is valuable to stay up to date and that increased productivity was the primary benefit of implementing new technology. However, only 37% believed that the construction industry (in Australia) is an early adopter of new technology.

It is important to note – specifically in a technology-focused report such as this one – that technology, technological innovation and the associated impact, opportunities, risks and threats should not be considered in isolation. 'Technology' is one element, albeit an important one, of a larger

"....there is no mainstream shift towards embracing such thinking as a catalyst for process and productivity improvement"

Farmer Review of the UK Construction Labour Model, October 2016

ecosystem where economic, social, political, environmental, technological and other factors all interact to shape the ‘real-world’. Similarly, ‘innovation’ is certainly not constrained to technological innovation. Innovation can and does drive all industries, be it ‘finance, fitness or fashion’. Very often it is a combination of innovations and trends in a number of industries which cause disruptions. Whereas technological innovation can contribute significantly towards addressing the construction industry’s challenges, it should be considered and implemented within the context of and in conjunction with broader changes and innovations (a number of which are referred to in following sections).

In this report we argue that technological innovation can contribute significantly towards solving or at least bringing relief, to the construction industry’s dilemmas. In order to enable this, it is necessary for the construction industry to invest in innovation – technological and otherwise.

### 2.2.2 Persistent low productivity

The construction industry globally has a dismal productivity compared to other industries, with very little growth. The productivity dilemma in the construction industry is not a recent phenomenon, though. It has lagged other sectors for many decades. The MGI explored construction labour productivity in 39 of the world’s largest construction

**“Yet despite the substantial benefits that would come from raising the sector’s productivity, and despite the fact that the challenges are well known and have long been discussed in the industry, progress has been limited. The industry operates in a way that seems to evolve only very slowly at best, and it is beset with misaligned incentives among owners and contractors and with market failures such as fragmentation and opacity”**

McKinsey

economies, representing every continent and in every stage of development.

They found that construction productivity has remained static at a only 1% growth since 1995, the worst of any industry when compared with growth of 2.8% in the world economy and 3.6% in manufacturing, for example. In a sample of countries analysed, less than 25% of construction firms matched the productivity growth achieved in the overall economies where they were active over the past decade.

In the UK, productivity in construction has also been essentially flat since 1994. This is in contrast to other industries, such as manufacturing for example, where output per hour worked in 2015 was more than 50% greater than 1994 levels<sup>7</sup>. The low labour productivity is creating substantial cost

burden to the industry, its customers, other sectors as well as national economies and indeed the global economy. Significant value is being lost.

It is worth noting that fragmentation in the industry skews the productivity picture somewhat. The MGI study also found that the construction sector is split into two main categories, viz. large scale operators, typically engaged in heavy construction; and a large number of smaller companies which tend to be engaged in a fragmentation of more specialised and niche areas (such as electrical, mechanical and plumbing). The latter group often acts as subcontractors. The productivity of the larger players is typically 20-40% higher than that of the smaller companies.

**“Given the size and value of our industry, the potential for growth is enormous if we harness suitable and sustainable technologies. But in order to achieve it, we must dismantle our perceptions of how technology fits into our workplace and decipher the barriers we are coming up against in their implementation...”**

[Australian] Construction Industry Innovation and Productivity Report, 2016

<sup>7</sup>

<https://www.gov.uk/government/publications/construction-labour-market-in-the-uk-farmer-review>

"Other industries have shown that first movers can build a sustainable competitive advantage. In the construction sector, this is also likely to be the case. Over the next decade, these winners of tomorrow will take the lead in technology innovation and digitization. Resisting change is no longer an option..."

McKinsey

Even though the productivity dilemma is a very serious concern, it also presents an opportunity, if it can be fixed. MGI estimates that productivity in construction can be increased by 48-60% by addressing seven major areas (discussed in sections below), a number of which are technology-related. They note that there is a \$1.6 trillion opportunity to close the gap, which would meet about 50% of annual global infrastructure requirements. This is equivalent to boosting the global GDP by 2%. The World Economic Forum estimates that a 1% increase in productivity globally could save \$100 billion per annum<sup>8</sup>.

### 2.2.3 Low profit margins

The construction industry is exhibiting very volatile and endemic low profit margins, typically in the bottom-quartile compared with other industries<sup>9</sup>.

"In July 2017 it was reported that more than 40,000 construction companies in the UK are on the brink of collapse. There was an increase of 22% in the number of construction companies with 'significant financial distress' compared to the previous year"

Construction Index

estimate that construction companies can achieve circa 1% higher margins on average by increasing their productivity by 25%.

MGI estimates the average profit margin to be circa 4.4%. Their study also indicates that there is a correlation between productivity and profitability, and concludes that productivity matters for the individual company. They

### 2.2.4 A poor safety record

Health and safety issues in construction, across the entire construction value chain and including materials as well as in the buildings and infrastructure delivered, will always be high priorities. However, as is the case in productivity, the health and safety record in construction is an area of major concern. From a fatality and injury viewpoint, construction is one of the most dangerous sectors globally.

Technology, particularly emerging technologies and new materials, can contribute significantly towards improving health and safety in construction. New technologies can also contribute to enhanced decision-making and automation, both of which can lead to reduced human error.

Better training can also contribute to better safety in construction, using new technologies such as virtual reality, online courses and mobile applications.

#### **Safety in UK and Australian construction**

Construction remains one of the most hazardous industries in the UK, accounting for about a quarter of all fatal injuries to workers<sup>10</sup>. The majority of fatal accidents in the UK involve small businesses and nearly half of reported injuries occur in refurbishment activities.

Health and Safety Executive (HSE) data in the UK indicates that 6 fatal injuries occurred in the waste and recycling sector in 2015/16, with 30 fatalities occurring over the last 5 years. It is estimated that 5% of workers in the sector sustain a non-fatal workplace injury per annum, with an estimated 5,000 reported injuries per year since 2009/10<sup>11</sup>.

HSE believes that there is a lack of awareness on obligations<sup>12</sup>. It conducted 1,840 visits to small refurbishment sites during June and July and again in October in November of 2016. They found that 49% of sites did not meet safety standards. In 2015, similar investigations on small refurbishment sites found problems on 46% of the sites visited<sup>13</sup>.

The London [Grenfell Tower tragedy](#) in June 2017 highlighted again the importance of safety in

<sup>8</sup>

[http://www3.weforum.org/docs/WEF\\_Shaping\\_the\\_Future\\_of\\_Construction\\_full\\_report\\_.pdf](http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report_.pdf)

<sup>9</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>10</sup> <https://hbxl.co.uk/5-construction-trends-2017/>

<sup>11</sup>

[http://www.theconstructionindex.co.uk/news/view/lie\\_bherr-launches-new-safety-programme](http://www.theconstructionindex.co.uk/news/view/lie_bherr-launches-new-safety-programme)

<sup>12</sup> <https://hbxl.co.uk/5-construction-trends-2017/>

<sup>13</sup>

[http://www.theconstructionindex.co.uk/news/view/ha\\_if-of-sites-fail-refurb-blitz](http://www.theconstructionindex.co.uk/news/view/ha_if-of-sites-fail-refurb-blitz)

construction, particularly regarding fire-retardant materials.

A similar health picture is reported in Australia. Building and construction workers there are at higher risk of death or injury than those in many other sectors, accounting for 12% cent work-related fatalities in 2013-14<sup>14</sup>.

### Safety in US construction

In the US, construction reported the highest number of worker deaths in 2015 of all industries, with 21.4% of work-related deaths coming from the construction industry<sup>15</sup>. Both the number of total worker deaths (937) and the fatal injury rate (10.1 per 100,000 full-time equivalent workers) increased in that year<sup>16</sup>.

In the construction industry in the US, the four leading causes of worker deaths, known as the ‘Fatal Four’, were falls, being struck by objects, electrocutions and getting caught in or between objects. The Fatal Four were responsible for 64.2% of all construction worker deaths in 2015 in the US<sup>17</sup>, with an increase in total construction worker deaths for each of the four categories. The Occupational Health and Safety Administration (OSHA) in the US recently increased penalties by 78% for violations of non-compliance.

“During the past decade, more than 10,000 claims have been made for vibration white finger and carpal tunnel syndrome, according to the Health and Safety Executive (HSE) in the UK. Workers at risk are those who regularly use power tools such as concrete breakers, sanders, grinders, hammer drills, chainsaws, hedge trimmers, powered mowers and more”

Phys.org

### 2.2.5 Waste

Construction waste remains a serious problem. Conventional wisdom has it that the “greenest building is the one that has already been built”, but the thinking is now that it may rather be the

“building that is least likely to be torn down”<sup>18</sup>. Durability, with less frequent replacement and lower maintenance costs can contribute towards environmental sustainability, if buildings incorporate environmentally friendly features.

Construction has traditionally faced many issues when it comes to the handling, creation, and recycling of wasted materials. A study from the National Association of Home Builders (NAHB) in the US found that an estimated 3,000 kg of waste are created from the construction of a 186m<sup>2</sup> building<sup>19</sup>. These squandered materials are all standard materials used to construct a building, including wood, brick, insulation and drywalling. However, only an estimated 20% of these leftover

“Construction as we know it today is wasteful, costly, and often over budget”

The Balance

construction materials are actually re-purposed or recycled, according to the American Institute of Architects (AIA). It estimates that “anywhere from 25-40% of the national solid waste stream is building-related waste.” In 2009, the Construction Materials Recycling Association (CMRA), which was rebranded as Recycling Today in 2013, estimated that construction and demolition waste from building construction was around 325 million tons annually<sup>20</sup>. A recent report from the British Council for Offices (BCO) notes that emerging technologies such as virtual reality and 3D printing can contribute significantly towards reducing waste in office construction<sup>21</sup>.



Video clips showing waste in construction can be seen [here](#) and [here](#)

<sup>14</sup><https://phys.org/news/2016-03-smart-vests-workers-safety-heart.html#nRlv>

<sup>15</sup>

[http://www.webwire.com/ViewPressRel.asp?ald=2093\\_07](http://www.webwire.com/ViewPressRel.asp?ald=2093_07)

<sup>16</sup><https://phys.org/news/2017-06-wearable-technology-dollars-industry.html>

<sup>17</sup><http://www.constructconnect.com/blog/operating-insights/five-commercial-construction-trends-watch-2017/>

<sup>18</sup><https://www.treehugger.com/green-architecture/what-greenest-home.html>

<sup>19</sup>

[http://www.webwire.com/ViewPressRel.asp?ald=2093\\_07](http://www.webwire.com/ViewPressRel.asp?ald=2093_07)

<sup>20</sup>

[http://www.webwire.com/ViewPressRel.asp?ald=2093\\_07](http://www.webwire.com/ViewPressRel.asp?ald=2093_07)

<sup>21</sup><http://www.fm-world.co.uk/news/fm-industry-news/3d-printing-and-vr-tech-could-cut-office-construction-waste/>

## 2.2.6 Energy conservation and efficiency

As the global demand for energy rises, there is also an imperative towards energy efficiency and conservation. This is coupled to greater use of renewable and environmentally friendly energies such as wind, solar and hydro as well as a reduction on the dependence on fossil fuels and of carbon emissions.

Buildings consume almost 40% of the total energy consumed worldwide<sup>22</sup>. Yet, it is estimated that 30% of energy in buildings is wasted<sup>23</sup>. Commercial spaces account for 20% of energy consumption in advanced economies and circa 16%+ in developing economies. About 50% of the energy is consumed in office space and much of it is wasted. A recent McKinsey report on the Internet of Things<sup>24</sup> estimates that intelligent energy management systems can reduce energy in offices by 20%, for example.

### The energy performance gap

The PROBE study (Post Occupancy Review of Buildings and their Engineering), which assessed 23 buildings previously featured as ‘exemplar designs’ in the

“Green construction will continue to influence the global construction industry for the foreseeable future. This includes design, construction, maintenance, renovation, operation, recycling and demolition...”

in-use energy consumption can be 5-10 times higher than compliance calculations carried out during the design stage<sup>25</sup>.

Building Services Journal between 1995 and 2002, revealed that actual energy consumption in buildings is often twice as much as predicted. More recent studies have suggested that

The use of emerging technologies can contribute significantly towards addressing the energy performance gap. A recent report indicated that a prefabricated ‘passive house’ can reduce energy consumption by up to 90% with a consistent internal temperature, compared to a typical home, irrespective of the weather<sup>26</sup>.

### Energy storage

In the built environment, the incorporation of underground facilities to utilise ground source heating and cooling, and the ability to generate, store and share energy through integrated systems are being considered. The use of large battery storage facilities are being discussed, linked to the ability of infrastructure to ‘exist off the grid’. Tesla, for example, is working with an Australian company which announced that the Tesla Powerwall (a [rechargeable] solar charged lithium-ion battery) will be a standard inclusion in their homes<sup>27</sup>. The idea is to have a battery that can store energy generated by sources such as solar panels or even by Tesla’s electric vehicles. The stored power can then be used as required, including in the event of a power outage. It is also claimed that the Powerwall can reduce residential power costs by 92%.

### Smart communities

The focus on the environment and energy is of course not limited to single buildings, but is also considered in terms of smart buildings in smart precincts in smart cities.

“The amount of energy used by data centres is already circa 3% of the world’s electricity - 416.2 terawatt hours, creating 2% of the global greenhouse gas emissions. This represents the same carbon footprint as the aviation industry. It is predicted to triple in the next decade...”

Balfour Beatty

<sup>22</sup><http://www.sbwire.com/press-releases/research-offers-10-year-forecast-on-building-automation-systems-market-by-future-market-insights-802622.htm>

<sup>23</sup>[https://www.greentechmedia.com/articles/read/how-the-internet-of-things-will-differ-across-industries?utm\\_source=feedburner&utm\\_medium=feed&utm\\_campaign=Feed:+GreentechMedia+\(Greentech+Media\)](https://www.greentechmedia.com/articles/read/how-the-internet-of-things-will-differ-across-industries?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed:+GreentechMedia+(Greentech+Media))

<sup>24</sup><http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world>

<sup>25</sup>

[https://www.designingbuildings.co.uk/wiki/Performance\\_gap\\_between\\_building\\_design\\_and\\_operation](https://www.designingbuildings.co.uk/wiki/Performance_gap_between_building_design_and_operation)

<sup>26</sup><http://trendintech.com/2017/04/26/new-prefab-houses-reduce-energy-consumption-by-up-to-90-percent/>

<sup>27</sup><https://futurism.com/a-company-just-announced-that-tesla-will-be-included-in-all-of-their-homes/>

Smart buildings must be integrated into their communities.

### **Legacy structures**

Whilst there is no doubt that the use of emerging technologies can contribute significantly to a better future in construction, dealing with aging and legacy structures remains a huge problem.

Energy waste in older buildings is mainly due to a few major factors. Ineffective and damaged insulation and windows create energy leakage. Heating, ventilation and air conditioning (HVAC) are energy hungry. Whereas inefficient old bulbs can be replaced by energy efficient ones, old



**Video clips showing energy efficiency in construction can be seen [here](#) and [here](#) and [here](#)**

buildings are often fitted with old lighting systems which are not only inefficient, but also needs to be switched on/off manually rather than by light-sensitive or motion sensors. Advances in lighting technology can deliver energy savings of circa 20%. HVAC and lighting account for 70% of the utility bill for most commercial and industrial facilities<sup>28</sup>. New technology can capture a significant amount of the heat and moisture released by chimneys and recycle it into other uses within the building.

### **2.2.7 Detrimental environmental impact**

The World Economic Forum estimates that constructed objects account for 25-40% of the world's total carbon emissions, and that 30% of global greenhouse gas emissions are attributable to buildings<sup>29</sup>.

### **Green construction**

There is an increasing drive towards the 'greening' of the construction industry, driven by a need for more environmental sustainability, including the reduction of carbon emissions and waste as well as enhanced efficiency of energy and usage of other natural resources such as water. The aim is to minimise negative effects on the environment (air, water and earth), climate change as well as on human health.

'Green construction' is an approach to build using environmentally friendly processes. The need is not only with regard to the construction process and materials, but rather the total life cycle use of the buildings, roads and other infrastructure.

Sustainable construction will become more the norm than the exception going forward. Green construction will continue to influence the global construction industry for the foreseeable future. This includes design, construction, maintenance, renovation, operation, recycling and demolition. Technology and technological innovations will contribute significantly in this regard. Construction companies and developers are realising the importance of sustainable construction practices, with more businesses showing greater corporate social responsibility.

"The UK aims to build four million solar-powered homes by 2020. In San Francisco, it is a requirement that all new buildings of 10-storeys or more must include solar panels..."

Governments worldwide are implementing legislation to ensure that newly built structures are adhering to green building practices.

Not surprisingly, the advantages of green building compared to conventional buildings include easier maintenance, improved air quality, water and energy efficiency as well as a high return on investment. Green buildings can provide significant long-term savings, including a decrease of 8-9% in operating costs, value increases of 7.5%, return on investment improvements of 6.6% and reducing of maintenance costs by 13%<sup>30</sup>.

<sup>28</sup><http://blog.schneider-electric.com/building-management/2017/06/21/keeping-evolution-buildings-part-2-buildings-today/>

<sup>29</sup>

[http://www3.weforum.org/docs/WEF\\_Shaping\\_the\\_Future\\_of\\_Construction\\_full\\_report\\_.pdf](http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report_.pdf)

<sup>30</sup><http://blog.schneider-electric.com/building-management/2017/06/21/keeping-evolution-buildings-part-2-buildings-today/>

McGraw Hill Construction estimated green non-residential construction to be worth circa \$140 billion in 2015 and continually rising each year<sup>31</sup>. It is

reported that the top driver for green building is client demand – increasing from 35% in 2012 to 40% in 2014 – while the biggest obstacle to creating green buildings is higher perceived first costs. In addition to greater demand for greener commercial buildings, there is also an increasing quest for greener residential buildings and the ‘healthy home’. More owners and tenants will demand energy-efficient features in new buildings (and retro-fitted to old ones).

The home and work environment of an individual has a major impact on the person’s wellbeing and thus, consumers are increasingly inclined towards aesthetically pleasing green buildings, which help alleviate both physical and mental problems.

#### **Green certification**

As the imperative for green construction gathers momentum, there will be an increasing emphasis on ‘green certification’. More developments across the world will strive to obtain green certifications such as BREEAM and LEED. The world is expected to see its number of green certified buildings double by 2018<sup>32</sup>. We can also expect to see a requirement for the suppliers of building materials to be able to demonstrate that the materials were obtained from environmentally-friendly sources and with ethical practices. This will require technologies to provide a traceable and auditable record of the supply chain of the materials.



Video clips showing green buildings can be seen [here](#) and [here](#)

“More developments across the world will strive to obtain green certifications ... The world is expected to see its number of green certified buildings double by 2018...”

#### **2.2.8 Labour shortages and skills availability**

There is a [global shortage of workers](#) with appropriate construction skills<sup>33</sup>, with the shortage being more pronounced in some countries than in others. Noting that up to 50% of the costs in

“There is a global shortage of workers with appropriate construction skills...”

construction can be labour-related, the labour shortage escalates the costs of projects.

This in turn, provides impetus for automation and mechanisation in the construction industry, which can also result in higher productivity.

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#### **2.2.9 Other contributing factors**

A number of other factors are also contributing to the challenges in the construction industry. The industry has recently been described as being:

“...extensively regulated, very dependent on public-sector demand, and highly cyclical. Informality and sometimes corruption distort the market.... Contracts have mismatches in risk allocations and rewards, and often inexperienced owners and buyers find it hard to navigate an opaque marketplace. The result is poor project management and execution, insufficient skills, inadequate design processes, and underinvestment in skills development, R&D, and innovation... It is indicative of the broken dynamics of the construction industry that owners, contractors, and suppliers do not agree on

#### **Rethinking home insurance and mortgages**

The rules for home mortgages may need to be rethought regularly, as attitudes and cultural norms shift, no doubt causing some upheaval in capital markets. Some predict that houses which are printed with non-flammable materials may no longer have a need for fire insurance; and that once houses can be reprinted for less than the cost of re-roofing them, it may in fact be possible to do away with a significant amount of the need for house insurance altogether.

<sup>31</sup><http://www.constructionworld.org/forecasting-construction-trends/>

<sup>32</sup>2

<https://www.worldbuild365.com/news/2avltewfc/indu>

[stry-news/exciting-trends-shaping-worldwide-construction-in-2017](#)

<sup>33</sup><http://www.turnerandtownsend.com/en/insights/international-construction-market-survey-2017/global-construction-industry-economic-overview/>

the perceived importance of particular root causes.”<sup>34</sup>

### **Smart buildings**

Buildings of the future will be smart buildings, discussed in more detail below.

### **Economic environment**

The reverberations of the global economic recession, although triggered almost a decade ago, are still being felt. The economic troubles also contributed to shifts in the labour market, and to an extend to the current labour shortages in many economies.

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### **Regulation**

As noted above, the construction industry is highly regulated, although more so in some countries than others. Construction-related regulation is often complex and relate to what can be built where, building standards and codes, health and safety, environmental issues, waste and disposal, water and energy, traffic and labour. In the UK, Singapore and Finland, for example, BIM is mandated for public construction projects.

### **Costs**

Because construction is a labour-intensive industry, direct and indirect labour costs make up 30-50% of a company's cost structure<sup>35</sup>. Global inflation in 2016 was 1.6%, but the global construction cost inflation was 3.7%, compared with 2.9% in 2015<sup>36</sup>.

### **Social and related trends**

Although not necessarily a challenge, construction of new buildings and infrastructure as well as the retrofitting and maintenance of existing structures must also adapt to evolving social trends, norms and legislation. Trends which can have an effect on the construction industry as well as the nature and use of buildings, cities and infrastructure include:

- **Sharing economy**  
The sharp increase in sharing services such as AirBnB and Uber are indicative of a larger trend of sharing and renting, rather than owning. There have been recent reports

indicating how homes of the future may be designed as being ‘AirBnb-ready’<sup>37</sup>, i.e. purpose-designed for sharing. Features of such homes may include more flexible spaces, additional bathroom and kitchen facilities and storage as well as separate entrances.

- Globalisation and changing demographics.
- Urbanisation and affordable housing<sup>38</sup>. The world’s urban population is increasing by 200,000 people per day, all of whom need to be affordably housed and provided with supporting infrastructure<sup>39</sup>.
- A more mobile workforce, an increase in the gig economy and working from home.
- Autonomous, driverless and electric vehicles will impact on the design of residential homes. Garages may no longer be required (although the requirement for the storage space they provide will remain) and homes will have more structured ‘pick up/drop-off zones’ for Uber and taxis. Those who continue to own their vehicles will have electric vehicles, which will require home charging facilities, including facilities for visiting guests. Autonomous and electric vehicles will also require a new generation of smart roads and public transport infrastructure as well as a charging ecosystem.
- Safety and security issues, including protection against natural disasters such as hurricanes, tornados and floods, earth quakes and fires; terrorism and social unrest, cyber attacks and criminal activities; and disasters caused by human error, including nuclear and chemical accidents. A research project was recently launched to investigate measures to seek terrorism prevention ideas for buildings<sup>40</sup>.

#### **2.2.10 The Farmer Review (October 2016)**

The UK Government requested the Construction Leadership Council (CLC) in February 2016 to look at ‘the labour model in the construction industry,

<sup>34</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>35</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>36</sup><http://www.turnerandtownsend.com/en/insights/international-construction-market-survey-2017/global-construction-industry-economic-overview/>

<sup>37</sup><https://www.fastcompany.com/3058520/your-future-home-will-be-designed-for-sharing-by-airbnb>

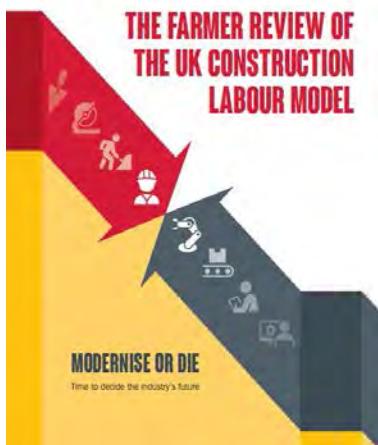
<sup>38</sup><http://www.rics.org/uk/news/news-insight/news/how-to-solve-the-construction-and-engineering-talent-gap/>

<sup>39</sup>[http://www3.weforum.org/docs/WEF\\_Shaping\\_the\\_Future\\_of\\_Construction\\_full\\_report\\_.pdf](http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report_.pdf)

<sup>40</sup><http://www.washingtontimes.com/news/2017/apr/9/survey-seeks-terrorism-prevention-ideas-for-buildi/>

together with the skills pressures and other constraints that limit housebuilding and infrastructure development in the UK'. The CLC commissioned Mark Farmer to undertake the review.

The findings and recommendations of the Farmer Review were published in October 2016<sup>41</sup>. They sketch a gloomy picture for the UK construction industry and reaffirm the broader picture reflected in this report. Tellingly, the subtitle of the Farmer Review's report is "Modernise or die, time to decide the industry's future".



The Farmer Review notes that "The construction industry and the clients that rely on it are at a critical juncture and it is time to review the seriousness of the future outlook. Deep-seated problems

have existed for many years and are well known and rehearsed, yet despite that, there appears to be a collective reluctance or inability to address these issues and set a course for modernisation.... Many of the features of the industry are synonymous with a sick, or even dying patient".

The Farmer Review highlights the following symptoms of the UK construction industry:

- Low productivity.
- Low predictability.
- Structural fragmentation.
- Leadership fragmentation.
- Low margins, adversarial pricing and financial fragility.
- Dysfunctional training funding and delivery model.
- Workforce size and demographics.
- Lack of collaboration and improvement culture.
- Lack of R&D and investment in innovation.
- Poor industry image.

The Farmer Review identifies three root causes for the problems in the UK's construction industry, viz.

- The evolution of a 'survivalist shape', structure and commercial behaviours, characterised by low capital reserves and high demand cyclicity.
- Non-aligned interests of the industry and its clients, which are reinforced by traditional procurement protocols and a deep-seated cultural resistance to change pervading across both parties.
- No strategic incentive or implementation framework to overcome the issues or to initiate large scale transformational change.

The Review notes that although there is a 'deep-seated market failure', there is also 'both unprecedented risk and opportunity for the industry and its clients', and hence that "...if action is not taken quickly, ...it will become seriously debilitated. It is facing challenges that have not been seen before, which create an absolute imperative for change".

The Farmer Review made number of recommendations. From an innovation and technology viewpoint, it is interesting to note:

**Recommendation 4:** Industry, government and clients, supported by academic expertise and leveraging CLC's current Innovation workstream activity, should organise to deliver a comprehensive innovation programme.

**Recommendation 8:** Government should act to provide an 'initiation' stimulus to innovation in the housing sector by promoting the use of pre-manufactured solutions through policy measures.

The UK Government responded to the Farmer Review in July 2017<sup>42</sup>.



Video clips on the Farmer Review on construction can be seen [here](#) and [here](#)

<sup>41</sup>

<https://www.gov.uk/government/publications/construction-labour-market-in-the-uk-farmer-review>

<sup>42</sup>

<https://www.gov.uk/government/publications/construction-labour-market-in-the-uk-farmer-review>

## 2.2.11 Root causes of challenges in the construction industry

Table 1 below shows an analysis of root causes for the industry woes, presented by the McKinsey Global Institute (February 2017)<sup>43</sup>.

**Table 1: Root causes of challenges in the construction industry**

### External forces

- Increasing project and site complexities.
- Extensive regulation, land fragmentation, and the cyclical nature of public investment.
- Informality and potential for corruption to distort the market.

### Industry dynamics

- Construction is opaque and highly fragmented.
- Contractual structures and incentives are misaligned.
- Bespoke or suboptimal owner requirements.

### Firm-operational factors

- Design processes and investment are inadequate.
- Poor project management and execution basics.
- Insufficiently skilled labour at frontline and supervisory levels.
- Industry underinvested in digitalisation, innovation, and capital.

McKinsey Global Institute  
February 2017

Note the emphasis on the industry's underinvestment in digitalisation, innovation and capital. A number of the other root causes are also technology-related, either directly or indirectly, including suboptimal design processes, poor project management and execution as well as insufficient skilled labour.

## 2.3 Rising demands and increasing expectations in construction - an industry ripe for disruption

### 2.3.1 Great expectations

Innovation in the construction industry continues to be constrained by traditional hurdles. The McKinsey Global Institute's (MGI) Productivity Survey indicated that the biggest barriers to innovation by construction companies are underinvestment in IT and technology more broadly, and a lack of R&D<sup>44</sup>.

Despite the proven advantages of innovation – the ‘innovation premium’ – it is interesting to note that respondents to the MGI Construction Productivity Survey ranked underinvestment in innovation only seventh out of ten root causes of low productivity. It is also interesting to note that the MGI study<sup>45</sup> points out that “indicative of the broken dynamics of the construction industry that owners, contractors, and suppliers do not agree on the perceived importance of particular root causes”.

The MGI study suggests that productivity in the construction industry can be enhanced by 48-60% with cost-savings of 27-38%, by addressing seven areas simultaneously, shown in Table 2<sup>46</sup>.

**Table 2: Seven ways to improve productivity in the construction industry**

- Reshape regulation and raise transparency
- Rewire the contractual framework (8-9%; 6-7%)
- Rethink design and engineering processes (8-10%; 7-10%)
- Improve procurement and supply-chain management (7-8%; 3-5%)
- Improve on-site execution (6-10%, 4-5%)
- Infuse digital technology, new materials, and advanced automation (14-15%; 4-6%)
- Reskill the workforce (5-7%; 3-5%)

(The numbers in brackets show the potential increase in productivity and cost saving that can be attained by adopting best practices for those two measures, respectively)

McKinsey Global Institute (February 2017)

<sup>43</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>44</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>45</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>46</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

However, risk averseness and resistance to change in the industry should not be excluded as contributing to its challenges. This includes the industry's internal views of itself, the challenges it faces and the mechanisms and interventions required to address those. There are certainly progressive companies<sup>47</sup> and thinkers in the construction industry who are leading the innovation charge, digitising their companies, are at the forefront of adopting emerging technologies and are "more focused on horizon-scanning and innovation in the future"<sup>48</sup>. By and large, however, this seems not to be the case for the industry as a whole.

It is not obvious that there is a universal recognition in the industry of the need for innovation. However, it is important for the industry to recognise the link between innovation, productivity and competitiveness, and to take urgent action to address this. It is interesting to note the amount of venture-capital investment which has recently been pouring into modern construction methods and digital technologies for use in the construction sector<sup>49</sup>.

There is a widely held view that the construction sector has traditionally been conservative and resistant to new ideas<sup>50</sup>; and that it has tended to focus on incremental improvements rather than radical and disruptive innovations, "in part because many believe that each project is unique, that it is not possible to scale up new ideas and that embracing new technologies is impractical"<sup>51</sup>.

"An innovative company will also recognise the importance of radical and disruptive innovations and the rewards and benefits that can gained from them..."

improved steadily and little-by-little on a day-to-day basis by people all across the world. Infusing a culture of pursuing incremental innovation is

<sup>47</sup><http://www.aurecongroup.com/en/about/latest-news/2017/june/buildings-future-science-fiction-science-fact.aspx>

<sup>48</sup> <https://www.balfourbeatty.com/2050>

<sup>49</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

important and a key pillar of 'continuous improvement'. However, this is not enough. Focusing on incremental innovations alone is a flawed and unsustainable strategy.

An innovative company will also recognise the importance of radical and disruptive innovations and the rewards and benefits which can be gained from them. Emerging technologies present great opportunities but also strategic business risks and threats to companies' and industries' products, operations, supply chains, logistics, business and manufacturing processes. Very often it is not a question of 'what will it cost', but rather 'what will it cost if we don't do this'.

"Companies themselves should spearhead the industry transformation.

Tremendous opportunities are available through the application of new technologies, materials and tools..."

World Economic Forum

21

In order to succeed, companies – including construction companies – need to develop and adopt innovation strategies which form integral elements of their corporate strategies. Although many innovations are technological innovations, many are not, as pointed out above. Innovation can happen in any sector, industry or function. Very often technological innovations are blended with innovations in business models, marketing and finance, for example.

It is important to see the bigger picture and to manage the corporate innovation strategy holistically, rather than to focus only on the technological aspects. Technological innovation and emerging technologies are very important, but should not be considered or implemented in isolation.

### 2.3.2 An industry ripe for disruption

In order for the construction industry to deliver on national and industrial needs and expectations, step changes need to be achieved in productivity, quality and efficiency, reductions in waste and

<sup>50</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>51</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future>

increases in environmental friendliness and sustainability as well as safety.

Given the strategic importance of the construction industry and the continuing demand for new infrastructure, there is considerable pressure on the industry to perform at a higher level, driven by requirements in terms of volume and cost; more transparent markets and disruptive new entrants; more readily available new technologies, materials, and processes; and the increasing cost of labour with partial restrictions on migrant workers.

The World Economic Forum notes that the construction industry "has undergone no major disruptive changes; it has not widely applied advances in processes..."<sup>52</sup>.

These are classical signals of an industry ripe for disruption, particularly when it is characterised by low levels of technological innovation, adoption of new technology and R&D, and not enough digitalisation. The image of an 'old fashioned' industry does not help.

Not only is the construction industry ripe for disruption<sup>53</sup>, it is also "hungry for digital disruption... but the reality is, it is still a long way from reaping the full benefits of innovation"<sup>54</sup>.

### **Pressure for change**

There is significant pressure on the construction industry to change. A range of emerging technologies will collectively act as catalysts and contribute to a transformation of the industry. They include materials and technology-related business processes and best practices – particularly digitalisation – which will be major drivers for disruption in construction, as they have been in many other industries. New market entrants, some from other industries (such as manufacturing) as well as completely new types of players (such as constructechs), will use the new technologies to create new competitive advantages.

Labour shortages, rising wage rates and limits on migrant labour (in the US and perhaps the UK in a post-Brexit era) will encourage automation.

It is important to note that radical and disruptive innovations very often not only lead to better industry performance, but also disrupts the industry structure and hierarchy, as well as the basis of competition<sup>55</sup>.

Very often new companies become the industry leaders in the new technological regimes, and very often they come from completely different sectors or emerge as new types of entities who are

Early adopters of the new technologies. This becomes the new basis of competition as the older and mature technologies which were the bedrock of the incumbent companies, become obsolete. Established companies which have built their success on the base of a given technology, often have great difficulty in adopting a new technology and letting go of the old one. ['Instead of trying to see the future, start making it'](#) in the appendix expands on this issue.

### **2.3.3 The rise of constructechs – poised to disrupt the construction industry**

One of the 'signals of an industry being disrupted' is the emergence of flourishing new start-ups which use new business models and emerging technologies as their competitive advantage. In a manner similar to the disruption of the financial and insurance industries by fintechs and insurtechs, 'constructechs' are now starting to disrupt the construction industry.

The constructechs are (for the moment) focusing mainly on digital opportunities, with mobile and cloud-based technologies leveraging AI, analytics, robotics and AR/VR, as well as software products

" ... the disturbing regularity with which industrial leaders follow their core technologies into obsolescence and obscurity....We should not be surprised then, that very often radical innovations come from 'outsiders' .... and industry leadership changes hands"

Jim Utterback, MIT

<sup>52</sup>

[http://www3.weforum.org/docs/WEF\\_Shaping\\_the\\_Future\\_of\\_Construction\\_full\\_report\\_.pdf](http://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report_.pdf)

<sup>53</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future>

<sup>54</sup>

[http://www.insideconstruction.com.au/site/news/105\\_0782/construction-sector-ready-digital-disruption](http://www.insideconstruction.com.au/site/news/105_0782/construction-sector-ready-digital-disruption)

<sup>55</sup> [DeltaHedron, "Instead of trying to see the future, start making it", New Statesman, Spotlight on Emerging Technologies, 14 July 2017](#)

focused on BIM, project management and related construction applications.

CB Insights<sup>56</sup> identified 13 key emerging categories and subcategories where constructechs are active, including design, monitoring and safety as well as digital marketplaces. (CB Insights consider constructechs to be start-ups offering ‘software tools and platforms used by different participants in the industry, including architects, developers, builders and contractors’).

The major areas of activities were:

- Collaboration software was the largest category, and includes project and task management, digital scheduling, time tracking, bid management and take-off.
- Other collaboration tools, including BIM applications
- Project and task management
- [Drones](#)
- [Virtual and artificial reality \(VR/AR\)](#)
- [Robotics](#), used to automate traditionally manual jobs
- [Design technologies](#), such as CAD and [BIM](#)
- [Inventory and supply chain](#)
- Risk management
- [Monitoring and safety, compliance and safety](#)
- [Data and analytics](#)
- Financial management
- [Digital market places](#).

In July 2017 it was reported that 25 funding deals for constructechs worth \$169m had already been done in the US during 2017 .

### 3. Reinventing construction

There are many industry voices calling for the ‘reinvention of construction’<sup>57</sup>, anticipating an innovation-fuelled disruption. This section highlights a number of major contextual thrusts and trends in best practices. It sets the scene for a

more comprehensive discussion on emerging technologies in construction in following sections.

#### 3.1 Smart buildings of the future

Smart buildings and infrastructure of the future<sup>58</sup> will be ‘intelligent’ and engage actively and proactively in and with their environment, and with the humans and animals in the environment. They will have the ability to sense the status of and changes in their environment, make decisions, intervene and respond, and communicate with people, other buildings and devices<sup>59</sup>. They will be able to anticipate, learn and adapt their behaviour. This is in contrast to ‘dumb’ structures which at the one extreme are merely ‘containers’ (however aesthetically pleasing they may be) and completely static, without even the ability to act reactively.

Benefits from intelligent buildings will include lower operating costs, higher energy efficiencies, the improved productivity and health of occupants, and more effective physical and cyber security<sup>60</sup>.

“the smart home will be able to optimise energy use rather than just measure how much has been used...”

Many buildings already have a number of smart characteristics, i.e. their thermostats can regulate temperature, automatic switches can switch lights on and off if they detect motion (or not)<sup>61</sup>, and security alarms can alert us and summon help if there is an intrusion. Smart meters can measure energy use and transmit that to the utility company for automatic billing.

Smart buildings of the future will be able and enabled to do much more. For example, the smart home will be able to optimise energy use rather than just measure how much has been used<sup>62</sup>. Buildings will utilise local renewable sources, such as wind or solar, with local storage devices which will allow them to operate ‘off the grid’.

Smart buildings will be more multi-functional and configurable, as a response to [evolving societal](#)

<sup>56</sup> <https://www.cbinsights.com/research/construction-tech-startup-market-map/>

<sup>57</sup> See for example

<http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>58</sup> <http://www.aurecongroup.com/en/about/latest-news/2017/june/buildings-future-science-fiction-science-fact.aspx>

<sup>59</sup> <http://newatlas.com/swidget-smart-home-enabling-platform/50590/>

<sup>60</sup> <http://deloitte.wsj.com/cio/2016/10/26/iot-poised-to-transform-building-management/?mod=WSJBlog>

<sup>61</sup> <http://www.makeuseof.com/tag/smart-switches-vs-smart-bulbs-best-solution/>

<sup>62</sup> <https://www.thetimes.co.uk/article/3e6a3582-70b4-11e7-8eac-856e9b33761e>

trends. Smart buildings as well as the devices and appliances inside and attached to the buildings will be enabled with a multitude of sensing devices connected to the internet of things. As such, they will be generators and consumers of fast amounts of data.

We will see more automation and a greater proliferation of robots in buildings, including homes. Self cleaning<sup>63</sup> and automatic maintenance will become the norm rather than the exception. Local 3D printers will be able to print parts required for maintenance, which will be installed by robots. Smart buildings will have 'smart locks'<sup>64</sup>, which can be operated remotely or via near field devices (such as smart phones). They will integrate face and voice recognition as well as other biometrics such as finger print and retina scanning.

Smart homes will communicate not only with other devices but also with humans, and they will do so in ways which humans can literally understand. Smart bots such as Amazon's Echo, Google's Alexa and Apple's Siri and their associated host systems already interact with humans in natural spoken language<sup>65</sup>. Smart homes will be able to respond to commands, answer questions and make suggestions and recommendations for actions and decisions.

Unified Inbox is a small Singaporean company, offering a product which turns regular text messages into instructions for appliances. With your home added to the contacts list on WhatsApp, for example, a quick text message will instruct the home to "make a coffee"; "mow the law" or "preheat the oven to 120 degrees at 20h00"...

Increasingly, smart homes will be designed so as to be telehealth-enabled<sup>66,67</sup>. Building construction can be as big a factor as sleep, diet or exercise impacting on the health of people. Sustainable buildings have been shown to improve occupants' cognitive function and sleep quality<sup>68</sup>. This will include built-in sensors which can monitor

personal health parameters and connect interactively to the telehealth infrastructure.

"Increasingly, smart homes will be designed so as to be telehealth-enabled..."

Smart buildings will be enabled by a range of emerging technologies, including those discussed in this report and others which are yet to reveal themselves. Their use also comes with a cost of course, including increasing use of data and the risks of cyber crime; as well as increased use of energy, hopefully offset by more energy efficient devices and materials.



Video clips showing smart buildings can be seen [here](#) and [here](#)

### 3.2 The importance of design

Successful innovations have two components – an 'invention component' and a 'adoption and diffusion into the market' component. It is often said that "new inventions create new knowledge, but successful innovations create new wealth". In a previous section the importance of innovation in any industry was emphasised. It was also noted that the construction industry in particular has been lacking in many aspects of innovation. In order to boost the industry's productivity and address its other challenges, it is critically important this is rectified.

This section focuses on design as a key element of the innovation process. It is integral to the

construction industry. Design does not only determine "what the building will look like", but places the structure on a life cycle trajectory.

"Design trumps technology – technology is the supporting act to design..."

Aurecon

<sup>63</sup><https://www.domain.com.au/news/roomba-vacuum-maker-irobot-is-betting-big-on-the-smart-home-20170724-gxhydf/>

<sup>64</sup><http://time.com/4024386/august-smart-lock/>

<sup>65</sup><http://fortune.com/2017/03/13/smart-condo-conundrum/>

<sup>66</sup><https://www.digitaltrends.com/home/smart-home-future-will-telehealth/>

<sup>67</sup>[DeltaHedron Innovation Insight, No 1.2/17, "Developments in emerging digital health technologies"](#)

<sup>68</sup>

<http://idahobusinessreview.com/2017/06/09/better-health-through-healthier-buildings/>

Choices made during the design phase with regard to principles and materials, for example, have a huge impact on the building throughout its life cycle. It will determine the manner in which it can be constructed and at what cost, energy efficiency, eco-friendliness, safety, ease of maintainability and feasibility of alterations and retrofitting, lifecycle costs and total cost of ownership, as well as a range of issues pertaining to the short, medium and longer term uses of the building (or road or bridge, for example). Great design is core to the 'Building of the Future'.

Whereas technology choices – and cognisance of emerging technologies – are very important, it is only one element of great design. One recent report puts it that "Design trumps technology – technology is the supporting act to design"<sup>69</sup>.

**"...construction as a production system would have a major impact on construction productivity"**

McKinsey

The McKinsey study<sup>70</sup> identifies design as one of the seven important ways in which construction productivity can

be improved. They estimate that the adoption of best practices in design and engineering processes and an increase in standardisation in construction can enhance productivity by 8-10% and bring about cost savings of 7-10%. They recommend improvement of the design process and outcomes, ensuring early collaboration from all parties involved and encourage repeatability of design across projects. Once the basics are in place, institutionalising value engineering into the design process with a greater focus on constructability should be a high priority; and similarly for 'Design for manufacture'. They note that there is still a way to go on this – as only 50% of respondents to the MGI Construction Productivity Survey indicated that they have a standard design library. This concept should be integrated into the design process from its conception.

McKinsey is of the view that treating construction as a production system would have a major impact

on construction productivity.<sup>71</sup> The MGI is promoting the concept of 'production system' in construction and suggests that its adoption could lead to a tenfold increase in productivity. Construction products, whether residential, commercial, industrial or infrastructure can benefit significantly from manufacturing-related best practices.

Inadequate attention to design and engineering can lead to unnecessary and costly project delays and overruns. Design flaws and inefficiencies have a cascading effect which impact detrimentally on productivity and cost. MGI notes that they continue to observe enormous cost and time overruns of construction projects. Their recent analysis found that average cost and time overruns relative to original budget and schedule to be 70% and 61%, respectively<sup>72</sup>.

#### **Future proofing designs**

Designs should make sense today and tomorrow. The design of the building should hence be such that it can accommodate current and future generations of technology. Buildings, roads and bridges also need to be maintained during their lifetime, and many will be retrofitted and altered.

**"Design should make sense today and tomorrow..."**

In addition to adopting 'design for manufacture and assembly' (DFMA) approaches, designers should also ensure that designs are 'maintainable' and 'alterable'. Emerging technologies, particularly digital-related technologies which are installed in the buildings, evolve very swiftly. Even though the lifecycle of a building will typically be much longer than a consumer device, designers should also think about the recycling issues when the structures are demolished.

### **3.3 Best practices aimed at enhancing productivity**

In addition to the benefits which emerging technologies and new materials can bring, several best practices which can improve productivity in construction have also been identified. This report

<sup>69</sup>

<http://www.aurecongroup.com/en/markets/property/buildings-of-the-future/designs-that-make-sense.aspx>

<sup>70</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>71</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>72</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

considers a number of these which are technology-related or enabled. It is important to stress again that there are also many other best practices which are not technology-related or to a much lesser degree<sup>73</sup>, which are equally important with regard to their contribution to productivity enhancement, but which are not discussed here.

### 3.3.1 On-site execution and off-site manufacturing

#### **On-site execution**

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The building process lends itself to the possibility of massive enhancements through innovation. Whereas much of the 'what' and a lot of the 'how' are determined in the design phase, productivity in the execution phase can be improved significantly.

"Building sites are increasingly turning to mobile-operated, cloud-powered software systems and apps to make operations more manageable. Vital data, such as timesheets, performance reports, task allocation records and all other field coordination aspects, are sorted in one central program. This allows managers and site supervisors to get on with critical build requirements, rather than get bogged down in time-consuming admin..."

World Build 365

McKinsey<sup>74</sup> identified on-site execution as another one of the seven important ways in which construction productivity can be improved. They estimate that global construction productivity can improve by 6-10% if best-practices in on-site execution are adopted, with potential cost savings of 4-5%. They recommend the introduction of rigorous integrated planning and collaborative performance management, more collaboration to reduce waste and variability, and better mobilisation of projects. Once the basics are in place, the focus should shift to better workforce and central planning. The use of a single source of

data by all stakeholders on a project will ensure that everybody has access to all the data, the same data and all at the same time.

A number of technology-related practices and emerging technologies which can contribute towards better on-site execution and process enhancement are discussed in the sections below. They include various manifestations of digitalisation and automation, prefabrication and modularisation, the use of robotics and drones as well as construction techniques (such as lean construction). There is an increasing need for software-based applications, aimed specifically at the construction industry<sup>75</sup>. An increasing number of industry-specific products are appearing on the market. The use of digital technologies in conjunction with approaches such as lean construction in the execution phase will enhance productivity considerably.

Computer-Aided Design (CAD) has been around for a long-time and can hardly be referred to as an emerging technology anymore. However, it remains an important element of digitised construction projects and hence warrants mentioning here. Used in isolation, CAD is restrictive. If it is complemented by BIM<sup>76</sup>, building simulation software and related applications, its impact is significantly enhanced.

#### **Modular and off-site construction**

Modularisation and off-site manufacturing are important innovations, and are elements of a production approach to construction.

The use of modular units and off-site manufacturing of construction products (sometimes also referred to as permanent modular or prefabricated construction) can bring significant benefits, and are gaining ground in the construction industry<sup>77,78,79</sup>. The Farmer Review is very supportive of the concept of modular off-site manufactured construction in the UK<sup>80</sup>.

<sup>73</sup> See for example

<http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>74</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>75</sup> <https://www.skysite.com/tag/construction-industry-trends/>

<sup>76</sup><https://thebimhub.com/2017/06/30/aec-industry-trends-driving-toward-connection/#.WWXdjYjyvcs>

<sup>77</sup><http://www.constructconnect.com/blog/operating-insights/five-commercial-construction-trends-watch-2017/>

<sup>78</sup><http://www.constructiondive.com/news/5-trends-shaping-the-future-of-off-site-construction/447248/>

<sup>79</sup><http://www.constructiondive.com/news/off-site-modular-construction/447747/>

<sup>80</sup>

<https://www.gov.uk/government/publications/construction-labour-market-in-the-uk-farmer-review>

It is useful to think in terms of ‘construction modules’, such as entire bathrooms fitted into dormitory rooms, rather than just accepting that everything in a building needs to built ‘from scratch’ and on-site. ‘One-off designs’<sup>81</sup> are expensive and often unnecessary if prefabricated modules utilising ‘reusable designs’ are available. The reusable design can likewise use a product platform approach, as is used in automobiles<sup>82</sup>. This allows for flexibility and configuration of the modules.

One of the major advantages of modular thinking is that the modules can be manufactured off-site in a factory and then transported for fitting and installation on the construction site. The entire module need not of course be shipped fully assembled. Instead it can done in a ‘flat pack’ style containing sub-assemblies, which can be assembled (rather than built) on-site.



Modular housing units being installed

Although modular construction has been used for decades, it is attracting increasing interest for commercial construction applications. The Modular Building Institute estimates that modular construction holds about 3% of the market share

of new construction and expects it to grow to 5% by 2020<sup>83</sup>. The modular industry is expected to rise 6% globally by 2022. Sweden is a world leader, with circa 84% of detached homes built with pre-fabricated timber elements, compared with 15% of pre-fabricated Japanese semi-detached/detached homes. Compare this with just 5% in the UK, US and Australia<sup>84</sup>. In Australia, it is estimated that 3% of construction industry revenue is generated from off-site construction. However it is estimated to grow to at least 10% within 20 years<sup>85</sup>.

*“A large skyscraper in Tokyo is ‘continuously’ producing modular living units. Residents can order a ready-to-use modular unit which is 3D printed on the top floor of the building, and then lowered into place by cranes. Disused or faulty pods are dismantled and can be reprinted...”*

Inhabitat

Owners are recognising that modular construction can look just as good as on-site construction and be completed cheaper and faster. The world’s tallest modular construction project (461 Dean, a 32-story residential tower in New York City<sup>86</sup>) was completed in 2016,. The building is not without controversy though<sup>87</sup>.

Projects such as this and the 142-room AC Hotel in Oklahoma City are proving that modular can be done cheaper and faster. Off-site prefabricating of materials<sup>88</sup> can achieve LEED certification and benefit construction productivity. Using modular approaches, construction times can be reduced by up to 30%-50%.

Modular buildings are built to meet existing building codes in controlled environments where quality and consistency can be carefully monitored. This also avoids delays caused by unpredictable environmental conditions which

<sup>81</sup><http://www.aurecongroup.com/en/about/latest-news/2017/june/buildings-future-science-fiction-science-fact.aspx>

<sup>82</sup> Think for example of the ‘3 Series BMW’, for which there are many models, but all use the same basic platform.

<sup>83</sup><http://www.constructconnect.com/blog/operating-insights/five-commercial-construction-trends-watch-2017/>

<sup>84</sup><https://www.worldbuild365.com/news/2avltewfc/industry-news/exciting-trends-shaping-worldwide-construction-in-2017>

<sup>85</sup><http://builtoff-site.com.au/issue-01/disruption-collaboration-and-reassembling-the-jigsaw/>

<sup>86</sup><http://www.constructconnect.com/blog/operating-insights/five-commercial-construction-trends-watch-2017/>

<sup>87</sup><https://www.treehugger.com/modular-design/norman-oder-worlds-tallest-modular-building-and-phantom-20-percent-savings.html>

<sup>88</sup><http://www.kaleida.co.uk/what-construction-trends-should-we-expect-in-2017/>

might put a project behind schedule and increase costs.

Off-site construction is particularly suited for a number of structure types, including schools, dormitories, hospitals, office buildings, hotels, retail shops as well as residential homes<sup>89</sup>. Modular homes offer home owners and developers a number of benefits. Prefabricated, prefinished volumetric construction (PPVC) is an approach which integrates off-site capabilities and in effect transforms the construction site into a manufacturing site, with the advantages of improved safety, less waste and greater efficiency<sup>90</sup>. Other advantages of prefabricated construction<sup>91</sup> include eco-friendliness, enhanced safety, flexibility, speed and reduced site disruption.

### 3.3.2 Retrofitting

Images of new buildings, bridges and roads typically come to mind when we think of the construction industry. However, a significant part of the industry is engaged with refurbishment, retrofitting and maintenance. In the UK, approximately 60% of construction output is new build, whilst 40% is refurbishment and maintenance<sup>92</sup>.

When considering the impact of emerging technologies, it is important to also include in the thinking the use of these technologies for refurbishment, retrofitting and maintenance.

Retroactive use of [Building Information Modelling \(BIM\)](#)<sup>93</sup> for buildings which were not originally built with BIM is indeed possible. This has been utilised in major retrofitting projects, such as the renovation of an emergency room at an old hospital. In this case, BIM was used to maintain the integrity of the original medical centre while also introducing an entire new wing to the hospital. Thus, BIM was effectively used to renovate a building and attain LEED Silver — an impossible feat without BIM technology.

<sup>89</sup>[https://www.worldbuild365.com/news/2avltewf/in\\_dustry-news/exciting-trends-shaping-worldwide-construction-in-2017](https://www.worldbuild365.com/news/2avltewf/in_dustry-news/exciting-trends-shaping-worldwide-construction-in-2017)

<sup>90</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future>

<sup>91</sup><http://www.constructionworld.org/7-benefits-prefabricated-construction/>

“The HouseZero project is an extreme retrofit of an existing building, the home of The Harvard Center for Green Buildings and Cities at the Harvard University Graduate School of Design (GSD). The objective is to “demonstrate how to transform this challenging building stock into a prototype of ultra-efficiency that will use no HVAC system, no electric light use during the day, 100% ventilation, almost zero energy, and produce zero carbon emissions, including embodied energy of materials....”

Treehugger

### 3.3.3 Peer-to-peer rentals

Construction equipment represents significant capital investment. Some estimates indicate, however, that contractors' equipment is unused for 70% of the time<sup>94</sup>, a very inefficient use of capital. Peer-to-peer rental can effectively improve asset use, and is enabled by telematics-related information. Sharing of usage data will enable contractors to connect with one another more easily, which can in turn enable less expensive renting for those needing machines and more profitable for those renting them out. It is estimated that machines could pay back about 25% of their purchase price annually in this environment.



Construction of a timber home

<sup>92</sup>

[https://www.designingbuildings.co.uk/wiki/UK\\_construction\\_industry](https://www.designingbuildings.co.uk/wiki/UK_construction_industry)

<sup>93</sup><https://www.thebalance.com/how-can-bim-mitigate-construction-risks-845317>

<sup>94</sup>[http://www.huffingtonpost.com/john-rampton/major-tech-trends-are-sha\\_b\\_12771280.html](http://www.huffingtonpost.com/john-rampton/major-tech-trends-are-sha_b_12771280.html)

#### 4. Emerging technologies in construction

It is evident that emerging technologies can and are contributing significantly to the disruption in and transformation of the construction industry<sup>95</sup>.

**"It is evident that emerging technologies can and are contributing significantly to the disruption in and transformation of the construction industry..."**

The recent McKinsey study<sup>96</sup> suggests seven major areas which can contribute to productivity enhancements

in construction (see also [Table 2](#)).

The McKinsey study estimates that one of these areas, viz. the adoption of best practices with regard to the infusion of digital technology, new materials and advanced automation, can contribute 6-10% to productivity increases and 4-5% to cost savings in the industry.

From the viewpoint of the impact emerging technologies can make on the construction industry, it is important to keep in mind that technological advances can also contribute significantly to some of the other factors described in the McKinsey study, including [rethinking design](#) and engineering processes, improving [procurement and supply-chain](#) management, improving [on-site execution](#) and [reskilling the workforce](#). The technology-related aspects of these are discussed in the relevant sections of this report.

This section discusses a range of emerging technologies with an indication of their use in construction, and an emphasis on recent trends. The term 'technology' is interpreted fairly broadly here and the discussion is presented with regard to digitalisation and digital transformation, automation and new materials. The automation related technologies are in large digitally enabled, and also includes process technologies.

In the assessment of the impact, strategic business opportunities, risks and threats of emerging technologies, it is important to distinguish between the underlying technology and trends, potential applications and products on the market or in development.

For example, the same technology can underpin a number of different products, offered by the same or different vendors. Similarly, a given product or innovation is often based upon more than technology. This distinction is important when the discussion turns to potential new applications of emerging or mature technologies. Also, if a given product has succeeded or failed in the market, it is important to distinguish the product from its underlying technologies. The product may have failed for reasons other than the technology it uses, and the same technology may be used in other successful products – but then on the other hand, it may not.

It is important to also recognise the impact which technological disruption can have on the industry structure and hierarchy.

See also "[Instead of trying to see the future, start making it](#)".

##### 4.1 Digitalisation and digital transformation

###### Digital transformation

Digital transformation and digitalisation are very significant global trends which are affecting all segments of society globally, whether industry and commerce, the public sector, government and its agencies, education or individuals. No industry sector is left untouched. In many cases there are common elements of digitalisation which are driving change, transformation and disruption, but there are also industry-specific aspects.

**"Once it's digital, it's data"**

Digital transformation is an industry disruptor par excellence, as been has been demonstrated in many sectors as well as by a number of innovative companies in the construction sector which have digitised, and they have created substantial productivity benefits. Not only do digitalisation and digital transformation in themselves lead to higher productivity, they are also the catalysts for broader business transformation, which can in

<sup>95</sup><https://www.business.com/articles/construction-technology-software-guide/>

<sup>96</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

turn lead to a reshaping of business strategies and models.

A recent McKinsey study shows that there is a direct correlation between the degree to which an industry is digitalisation and the productivity growth in that industry (2005-2014).

McKinsey Global Institute  
February 2017

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McKinsey recommends the appointment of an chief digital/technology/innovation office and team<sup>97</sup> to champion the importance of digitalisation, develop a 'digital culture' and drive its implementation in the industry.

#### **Digitalisation of the construction industry**

It has been reported that more than half of all commercial construction firms have at least made some partial transition to the cloud, digitised their plans and are using tablets on the job site.<sup>98</sup> This is an encouraging trend. However, modern digital technology and tools should become the norm rather than exception. Digitalisation is an essential element of the digital transformation of the construction industry<sup>99</sup>. It is much more than just 'replacing paper with pdf'.

"A recent survey indicated that 90% of professionals in the construction industry are active on social media, whereas 43% use social media networks to obtain construction-related ideas and product information..."

Construction Index

advantage – but in general the industry suffers from a lack of digitalisation.

Of those industries analysed by McKinsey, the construction industry not only exhibits the least productivity growth, but is also the least digitised. In Europe the construction industry is in the last

position, and in the US, construction is second to last (ahead only with regard to agriculture).

IT spend in the construction industry is less than 1% of revenues<sup>100</sup>, compared to 3.5% for the automobile industry and 4.5% for the aerospace industry (2015).

In Germany, for example, the construction sector invested only 0.7% of its gross value between 1991 and 2007 in digital assets annually<sup>101</sup>. In comparison, financial intermediation invested 4.3% and manufacturing 1.8%. The average investment in Germany of all industries (2.3%) was three times that of the investment in construction. In the US, only 1.5% of gross value added was invested in the construction industry, compared with 5.7% in financial intermediation, 3.3% in manufacturing, and the all-sector average of 3.6%.

The underinvestment in digitalisation is one of the root causes of problems in the construction industry, according to the McKinsey studies. They suggest that there are particular deficiencies in the sector's ability to use digital tools to facilitate stakeholder interactions and in the rate of growth in digital tools available to the frontline labour force. A recent report indicated that less the 50% of respondents considered mobile technologies 'to be important when choosing software solutions

"New technologies in the digital space, for example, will not only improve productivity and reduce project delays, but can also enhance the quality of buildings and improve safety, working conditions and environmental compatibility"

World Economic Forum

<sup>97</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>98</sup> <http://www.conexpoconagg.com/news/february-2017/2017-construction-trends-in-technology/>

<sup>99</sup> <http://archinect.com/HCADDs/release/construction-industry-needs-digitized-project-management-work-flows>

<sup>100</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-construction-digital-future>

<sup>101</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

for their construction business<sup>102</sup>. This may be telling of the mindset.

Whilst the low level of digitalisation in the construction industry is problematic, it also offers great opportunities – digitising the industry will bring huge benefits (.....put another way, if it was already highly digitalised and still had major productivity issues, there would have been a really serious problem indeed).

#### **Future proofing designs**

Buildings and other infrastructural structures are required to last for decades. 50-year design life clauses will not be uncommon<sup>103</sup>. With the advent of smart buildings, buildings are increasingly populated with electronics of all types, including wifi and communications, security and the internet of things. The lifetime of electronics, however, is relatively short, given the rapid pace of digital development. From a design viewpoint, it is hence important to ‘future-proof’ smart buildings. The assumption should be that the structure of the

“eCommerce is having an effect as well – it was recently reported that the increasing impact from online traders have driven one of the large construction material vendors in the UK to reorganise...”

Construction Index

building will outlive the electronics, and will in fact see multiple generations of electronics. In addition for the need for continuous upgrading of what we have

now, many entirely new applications which are not even envisioned today will be common cause fifty years from now. Lifecycle management of infrastructure requires designs to be future-proofed.

“Construction design should incorporate strategies to upgrade, integrate and use different generations of technology throughout the lifecycle of structures....”

A range of emerging technologies directly relate to digitalisation, and are discussed below. Following this, a number of emerging technologies which can contribute towards the automation of the construction industry are then discussed. Many of

these are also digitally enabled, and it often difficult to decide whether a given technology should be considered part of the ‘digitalisation group’ or the ‘automation group’. The distinction is not really important – what is important is that the technologies are adopted and integrated with others.

#### **4.1.2 Data, software, mobile and the cloud**

Data is the driver of digitalisation. The gathering, processing, interpretation, reporting, communication as well as storing and archiving of data are central towards creating and embedding a digital transformation mindset and strategy.

In business, this should lead to enhanced decision-making – for the managers and employees of a company, but also for its customers, suppliers, shareholders and broader stakeholder community.

A number of emerging technologies are focused directly on data processing and interpretation, including analytics, big data, artificial intelligence, machine learning and digital imaging. These technologies find application in most industries, including construction, and are discussed in sections below.

“... the construction industry has yet to adopt an integrated platform that spans project planning, design, construction, operations, and maintenance. Instead, the industry still relies on bespoke software tools, and more often than not on paper-based procedures. And everybody on the same project uses different systems”

McKinsey

Systems integration, the integration of data originating from various sources and interoperability remain big challenges in data-driven environments.

Data inputs originating from different software programmes, IoT sensors, drones, 3D scanning, the weather, GPS and a host of other sources invariably have widely differing formats. They typically do not have the same or compatible data protocols or interfaces.

<sup>102</sup> <http://www.constructionworld.org/adoption-mobile-solutions-construction-industry/>

<sup>103</sup> <http://www.aurecongroup.com/en/markets/property-buildings-of-the-future/designs-that-make-sense.aspx>

There will be a rapid increase in the number and types of devices performing data collection, and subsequently also more companies offering services to transform and translate data into analytics and dashboards to support decision-making<sup>104</sup>. Programmes and platforms which perform integration and create ‘uniform’ interfaces can help to resolve this dilemma.

### **Mobile technologies and cloud-based applications**

Mobile and wireless technologies have become ubiquitous. In February 2017 it was reported that there was an estimated 5 billion+ (and growing) mobile telephones in the world<sup>105</sup>. In addition, billions of devices are being connected as part of the internet of things, many of them using wireless (wifi) technologies.

“...mobile technology will be a force multiplier in the digital transformation of the construction industry and its quest to improve productivity”

reporting, data transfer and collaborating ‘everywhere, anytime and in real-time’. Mobile data includes email, text messages as well as access to the internet. Its use is facilitated by the availability of mobile apps for phones and tablets, which provide user friendly interfaces to services and information. Not surprisingly, there is a global trend towards ‘mobile first’.

McKinsey recommends the use digital collaborating and mobility tools on portable devices as a mechanism for enhancing productivity and cutting costs in construction<sup>106</sup>.

Data storage is moving ‘into the cloud’ – transferred to storage devices ‘somewhere’, rather than on the device itself or local storage; but accessible (everywhere, anytime and in real-time) to any device connected to the internet, including mobile devices. As is the case with other industries,

mobile technology will be a force multiplier in the digital transformation of the construction industry and its quest to improve productivity<sup>107</sup>. Construction-specific applications such as project management, ERP and BIM can all be accessed via mobile, cloud-powered devices.

The nature of the construction industry is not always conducive to fixed IT infrastructure (including desktop computers and servers). There is often limited space in a physical site office and perhaps not adequate cooling and dust-free environments required by IT hardware. The use of mobile, web and cloud-based IT solve this problem.

Mobile communication technology empowers the individual, allowing voice communication, information availability, application programmes and data hosted on servers ‘in

“Very soon 5G mobile will be introduced, and will offer significant advantages over 4G, LTE and previous generations of mobile technologies. The coming of 5G will boost the benefits of mobile tremendously and will bring a step-change in its utility...”

the cloud’ (rather than physically on-site), can be accessed via wireless connection to the internet. This brings added advantages in that all staff can access the same data in real-time while ‘on the go’, and the data can securely stored. The application programmes (and data) on off-site servers (in the cloud) are centrally updated, so that all users simultaneously use the same, latest version.

Cloud-based computing is gaining more traction in construction<sup>108</sup>, and offers the advantages of scalability, mobility, collaborating and lower cost of ownership<sup>109</sup>. File sharing and synchronisation across the web using cloud-data storage services remove the need for project schedules, plans and other documents to be carried around in rolls of paper. The same information can also be shared with others in real-time.

Advances in mobile technology are enabling an entirely new generation of capabilities to become

<sup>104</sup><http://www.conexpoconagg.com/news/february-2017/2017-construction-trends-in-technology/>

<sup>105</sup><http://www.hindustantimes.com/tech/five-billion-mobile-phone-users-in-2017-study/story-zXhZeRKHv9u1C5WQ8fkK1K.html>

<sup>106</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>107</sup><http://www.constructionworld.org/why-construction-businesses-should-adopt-mobile-construction-software/>

<sup>108</sup><https://hbxl.co.uk/5-construction-trends-2017/>

<sup>109</sup><http://www.constructionworld.org/top-10-construction-technology-trends-look/>

'portable', many of them incorporation related emerging technologies such as augmented reality (AR) and virtual reality (VR). Mobile technologies also enable the use of advanced and real-time geolocation – the automatic identification and tracking of the location and movement of people, tools and equipment, vehicles as well as materials on a building site<sup>110</sup>. This ability can enhance on-site safety, logistics-related productivity increases and help to prevent theft and wastage.

The 'lack of internet availability' (and wireless signals) in remote sites has been mooted as one of the reasons why some in the construction industry are reluctant to adopt mobile solutions. To address this, some vendors are offering a self-contained high-speed internet trailer which can resolve this problem by creating a local wifi hotspot on a site<sup>111</sup>.

#### **Bring-your-own-device (BYOD)**

A Gartner survey in 2014 suggested that circa 40% of workers at large enterprises use their personally owned mobile device for work purposes. This number is increasing, with more workplaces encouraging smartphone use or allowing a BYOD (Bring Your Own Device) policy<sup>112</sup>. The 40% of respondents who use smartphones for work typically do so for email, phone calls and GPS tracking. Many of these functions are not specific to any company and have become convenient alternatives. In the future, we will see greater commitments by companies, including construction companies, to use smartphones beyond basic communication. This will lead to more integration of work-related functions through mobile.

#### **Enterprise Resource Planning (ERP)**

There is a growing market in Enterprise Resource Planning (ERP) solutions in construction<sup>113</sup>. ERP provides decision support for projects, particularly with regard to financial decisions, and forecasting inventory and materials requirements.

A number of related trends are reported to have an impact on construction through the ERP space, viz.

- Predictive capability.
- Mobile migration, which brings ERP functionality to staff on the site and can integrate data from wearables and IoT.
- Integration across platforms.
- Greater (BIM) functionality.
- Future-proofing to ensure that current systems are upgradeable and forward compatible.
- Channels for collaborating.

"Enterprise resource planning solutions are among the most significant progress benchmarks in terms of developments within the realm of software; they play a vital role in tech strategy of virtually every construction firm ...ERP systems serve to also reveal an organizations' technological savvy, since smaller trends in IT are quite often reflected in the deployment of the software..."

The Balance

#### **Software-as-a-Service**

The trend of 'software-as-a-service' (SaaS) is also impacting on construction, with a range of cloud-based products, aimed specifically at this industry. These include programmes which address construction bids, tracking environmental scoring (LEED), project management as well as document and plan handlers<sup>114</sup>.

"The trend of 'software-as-a-service' (SaaS) is also impacting on construction, with a range of cloud-based products, aimed specifically at this industry..."

A number of apps for mobile phones and tablets specifically aimed at the construction industry are becoming more readily available<sup>115</sup>. Many of the apps utilise the touch screen, camera, GPS and accelerometer capabilities of mobile devices. They

<sup>110</sup> ["People tracking technologies", DeltaHedron Innovation Insight, No 3/2017 \(May 2017\).](https://www.thebalance.com/people-tracking-technologies-deltahedron-innovation-insight-no-3-2017-may-2017)

<sup>111</sup> <http://www.windpowerengineering.com/construction/skycasters-brings-broadband-communications-remote-wind-farm-construction-sites/>

<sup>112</sup> <http://www.constructionworld.org/top-10-construction-technology-trends-look/>

<sup>113</sup> <https://www.thebalance.com/construction-erp-software-trends-845314>

<sup>114</sup> <https://www.thebalance.com/top-saas-construction-products-844902>

<sup>115</sup> <https://www.thebalance.com/top-construction-software-apps-for-ipad-845330>

include apps for CAD applications, virtual laser levels to determine slope and the recording of problems with images; as well as apps for multipurpose construction-related computing and BIM.

#### 4.1.3 Big data, advanced analytics and artificial intelligence

##### **Big data**

The digitalisation of the construction industry will lead to huge amounts of data being created from a variety of sources as indicated above. Some of the data will relate directly to the construction project, other data may be generated by the operation of a smart building, and other from external sources such as weather, markets and exchange rates. ‘Big data’ refers not only the large volume of data itself, but more specifically to actively analysing very large datasets to gain insights and support decision-making<sup>116</sup>. Big data can also be generated from aggregated time series of data accumulated over a period, which is useful to analyse patterns and trends.

Contractors as well as owners already possess vast amounts of data; analytics techniques can disaggregate budgets and schedules down to hours; and productivity and wage rates per trade provide practical predictive insights for use in bids, estimates, and plans. One US company is reported to have successfully implemented this approach on more than 40 project sites.

##### **Analytics**

Advanced analytics is the tool used to analyse the (big) data sets, often combined with artificial intelligence (AI). ‘Descriptive analytics’ produces an analysis of historic data – what happened in the past and why. Although useful, in a sense this is a reactive mechanism. ‘Predictive analytics’ can assist by predicting which conditions can develop in the future, given the current status. This feature can be very useful for simulations or alerting users to possible adverse events which may occur in the future. However, actionability is important in construction settings. Knowing what may happen in the future is not the same as knowing what to do about it. ‘Prescriptive analytics’ supports decision-makers by identifying and recommending options for action. When combined with mobile

applications, this information and recommendations can be provided in real-time to users on the site and in the field. The benefits of this powerful tool are obvious. In a maintenance setting for example, proactive action can be taken, rather than a reactive ‘find and fix’ approach.

McKinsey recommends the use of advanced analytics on project and firmwide data as a mechanism for enhancing productivity and cutting costs<sup>117</sup>. They estimate that on-site productivity can be increased up to 50% by using a cloud-based control tower which gathers data in near real-time, and uses the analytics modes referred to above<sup>118</sup>.

##### **Artificial intelligence**

Artificial intelligence (AI) in construction will power many of the emerging technologies, particularly robotics and automation. To an increasing extent, AI will also find application in BIM and related programmes to support strategic and real-time decision-making..

#### 4.1.4 Digital collaborating, workflow and project management

Many recent reports and commentators have emphasised that greater collaborative working in the construction industry can enhance productivity significantly. This includes collaboration among employees of the same company, but particularly also the enhancement of collaboration amongst the multitude of subcontractors working on a project, as well as designers, owners and funders.

“The construction industry’s ‘collaboration problem’ is at the root of its change inertia...”

Farmer Review of the UK Construction Labour Model,  
October 2016

Continued reliance on paper-based processes (including design, communication, procurement, equipment logs, progress reports) is contributing to the poor productivity in the construction sector and hampering collaboration and coordination. A lack of digitalisation also causes delays in information sharing and can lead to ‘confusion’ if everybody is not working from the same data set at any given time (“....everybody has a different

<sup>116</sup><https://www.thebalance.com/how-the-construction-industry-is-using-big-data-845322>

<sup>117</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>118</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

version of the truth"). Paper-based processes also makes it more difficult to capture and analyse data.

Digitalisation enables more real-time collaborating and data-sharing, particularly through mobile technology. When integrated as an element of enhancing workflow, ranging from project concept to commissioning, this can contribute significantly towards enhancing productivity.

Digital collaborating improves the transparency of processes and facilitates large-scale data mining. Mobile apps can be synced with sensors, wearable devices and fixed IT infrastructure (such as desktop machines). Typical uses include productivity tracking, report generation, document management, material logistics, and inventory management. Digital mobile collaborating tools will increasingly be used to create collaborative project development. These tools include mobile technology, integrated project management tools, BIM as well as virtual and augmented reality<sup>119</sup>.

**"Digital collaborating and mobility solutions have attracted close to 60% of all venture funding in the construction industry. This is the fastest-growing and most penetrated area for digital technology in construction, and it is attracting the majority of venture and growth capital funding..."**

McKinsey

A number of technologies are being used to develop tools which will enhance various aspects of collaboration. Building Information Modelling (BIM) is very prominent, but others include project management, logistics and inventory as well as geolocation systems. These systems typically rely on a number of the emerging technologies discussed below, including mobile, cloud, analytics, big data, internet of things and artificial intelligence.

The streamlining of workflow is a related problem. A number of emerging technologies are being applied to implement workflow programmes which can enhance efficiency, planning and coordination as well as data driven decision-

making. Other specialised software programmes aimed at the construction industry assist contractors with administration, ensuring that they are complying with relevant safety and other regulations<sup>120</sup> and document handling<sup>121</sup>.

#### 4.1.5 Building Information Modelling (BIM)

Computer-aided design and particularly 3D modelling were pioneered by aerospace companies in the 1970s. This transformed the design and manufacturing processes for aircraft, led to the development of more advanced and cost-effective aircraft and increased productivity significantly.

A similar approach was adopted in the construction industry, when Building Information Modelling

**"A recent survey indicated that between 70-80% of contractors perceive there to be a positive return on investment in BIM..."**

(BIM) was introduced around the turn of the century<sup>122</sup> as a process of developing a building's features digitally. A number of governments, including the UK, Singapore and Finland now mandate the use of BIM for public infrastructure projects. American construction companies are likely to increase their use of BIM following the success of the BIM mandate in the UK.

McKinsey recommends making BIM universal as a contributor towards enhancing productivity and cutting costs, and then to mobilise advanced BIM across the project life cycle with augmented and mixed reality interfaces<sup>123</sup> as ways of increasing productivity and cutting costs.

According to a 2014 Building Design Construction BIM survey<sup>124</sup>, more than 80% of all construction companies used one or other type of BIM system.

A recent survey indicated that between 70-80% of contractors perceive there to be a positive return on investment in BIM, and that on average they expect the percentage of their work involving BIM

<sup>119</sup><https://esub.com/construction-industry-trends-watch-2017/>

<sup>120</sup><https://hbxl.co.uk/5-construction-trends-2017/>

<sup>121</sup><https://www.skysite.com/tag/construction-industry-trends/>

<sup>122</sup><https://thebimhub.com/2017/06/30/aec-industry-trends-driving-toward-connection/#.WWXdjYjyvcs>

<sup>123</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>124</sup><https://www.thebalance.com/construction-erp-software-trends-845314>

to increase by 50%<sup>125</sup>. Contractors in all construction sectors were planning significant investments to enhance their BIM capabilities over the next two years, with more emphasis on internal and external collaborating, mobile hardware and BIM-related software. Among the top five benefits of BIM cited were fewer errors and omissions, less rework and lower costs. The survey also found that the companies with the greatest BIM engagement reported the highest return on their BIM investments.

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The digital BIM model can and should be used throughout the building's lifecycle<sup>126</sup>. To obtain the full benefit of BIM, owners, designers and contractors need to incorporate BIM from the design stage through construction and also while the building is in use. BIM models can also be developed retroactively for older buildings where it was not used in the design and construction phases. BIM models can be updated dynamically with real-time information obtained from various sensors, including those used for scanning and mapping, to track progress and monitor resources.



**Video clips showing BIM in construction can be seen [here](#) and [here](#)**

### **3D, 4D, 5D and 6D BIM**

Before BIM, architects and construction companies relied on detailed paper-based processes, with hand-drawn plans and 2D drawings<sup>127</sup>. That has now changed. BIM has become an industry best-practice for large and complex projects. It is equally useful for smaller projects. BIM implementations can range from fairly basic to highly sophisticated implementations. The original 3D BIM models were simply software models of buildings, enabling 3-dimensions projections of buildings to be viewed on computer screens. The 3D image of the building could be rotated, different cuts taken through various planes and certain features highlighted or isolated. Current and future

generations of BIM can, and will be able to, do much more.

3D BIM offers extensive 3D modelling combined with the use of intelligent data. Data is embedded into the BIM model and managed, which allows workers to run multiple scenarios, change processes and input functions to view the implications of these on the project, simulations.

The spatial data and information on materials, fixtures and fittings allow for calculation of space and volume. It also enables BIM to compile bills of quantity, to which cost estimates can be added.

Next-generation 4D, 5D and 6D BIM platforms of the future<sup>128</sup> will be capable of delivering insights that include both cost and scheduling functions. 4D BIM embeds time-related information into the model, while 5D BIM also incorporates schedule and costs. The addition of cost and schedule overlays enables 5D BIM to become a powerful visualisation and project-management platform through the life cycle of a project.

6D BIM refers to the system delivered to the owner when a construction project is completed. It is intended to aid facilities managers in the operation and maintenance of the facility, and also when alterations to buildings are required. The "As-Built" BIM model is typically populated with relevant building component information<sup>129</sup>.

Future generations of BIM will be integrated with [augmented and virtual reality](#) technology to create seamless interaction between back offices and the work site. The Microsoft Trimble HoloLens platform, for example, enables the interacting of a 3D hologram with a design, using a wearable holographic computer.

Virtual design tools such as BIM enable the 'virtual twinning' of buildings and structures. This involves the creation of a digital representation of the physical and spatial dimensions of a project, which in turn promotes the quality and speed of decision-making. It creates new ways to visualise the project and also enhances the ability to share ideas and manage change.

<sup>125</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>126</sup><http://archinect.com/firms/release/67343028/is-bim-more-beneficial-to-overall-construction-industry/150000521>

<sup>127</sup><https://www.morson.com/2016/08/technology-trends-that-are-transforming-the-construction-industry/>

<sup>128</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>129</sup>[https://en.wikipedia.org/wiki/6D\\_BIM](https://en.wikipedia.org/wiki/6D_BIM)

**"Virtual design tools such as BIM enable the 'virtual twinning' of buildings and structures..."**

building. These programmes can be used to simulate various operational effects, such as methods to enhance energy efficiency, before they are physically implemented. This can very useful to optimise energy consumption in the design phase and to forecast savings, for example<sup>130</sup>. The modelling allows pre-implementation optimisation, either in the design phase or once the building is in use. This approach can enhance productivity and contribute to cost savings – some claim savings of circa 30%.

#### **Mitigating risk with BIM**

BIM can contribute in a number of ways towards mitigating construction risks and reducing project liability, including safety, planning and execution risks<sup>131</sup>, viz.

- Planning for and operating safer buildings. BIM can facilitate planning processes to develop sequenced task schedules, where potential hazards can be spotted before they occur or eliminated in the design phase. It can also provide a safety risk analysis. A set of rules, based on compliance regulations and safety-related best practices can be formulated and coded into the BIM software. These rules can then operate on the digital model of the building to 'investigate and identify' possible safety problems. Similar techniques can be used to detect and eliminate design errors.
- Helping to limit the risks of negative project events. BIM systems, integrated with construction management software, can streamline cost and time estimation of jobs and reduce or eliminate delays. It can also help to reduce cost and time variability between projects.
- Contribute towards making construction projects more environmentally friendly. BIM can help construction planners forecast which LEED credits are attainable with a new project. Linked with green construction

Specialised software is available to simulate the effects of the internet-of-things (IoT) on a

software, BIM can assist with the identification and obtaining of bonus LEED credits for regional environmental priorities. Some BIM products can calculate a new building's effect on the environment. They can assist with choosing which materials are best for the environment, including cost comparisons of those with non-sustainable materials.

- Archiving a building's history. BIM creates a digital

**"BIM also creates a digital 'memory' of the building..."**

'memory' of the building. It can record all aspects of his history and operation, including problems which have occurred in the past and how they were resolved. When changes and alterations need to be made later in the lifecycle, the BIM model can guide the designers and contractors, who may not have been involved in the initial design and construction. This can facilitate and speed up the design and alterations, and help to prevent future design and safety problems.

#### **4.1.6 Internet of Things (IoT) and sensors**

The Internet of Things (IoT) refers to the connection of intelligent devices which allow them to communicate with one another as well as with humans, typically over the internet and often using wireless technology. IoT devices can be sensors as well as machines and computers.

IoT allows construction machinery, equipment, materials and structures (such as buildings, roads and bridges) to communicate with one another and also with humans. The data is typically routed through a central data platform where it is also analysed. The information can of course be accessible via mobile devices.

The construction and downstream industries such as facilities management and real estate operators of buildings will be some of the most significant markets for IoT.



**Video clips showing the IoT (internet of things) in smart buildings can be seen [here](#) and [here](#)**

<sup>130</sup><https://www.forbes.com/sites/bisnow/2017/03/09/how-brackets-building-model-tech-beats-everyone-else/#6ce268af5357>

<sup>131</sup><https://www.thebalance.com/how-can-bim-mitigate-construction-risks-845317>

### **Internet of Building Things (IoBT)**

McKinsey recommends leveraging IoT-enabled fully connected sites as a way of enhancing productivity and cutting costs<sup>132</sup>. Some refer to this niche of IoT as the “Internet of Building Things” (IoBT). IoT and specifically IoBT will be at the heart of smart buildings, smart roads and smart cities.

“IoT devices can generate data at a tremendous rate. Compare Facebook’s daily data production of 600 terabytes, with the 844 terabytes of data generated by a single twin-engine aircraft in just 12 hours...”

Huffington Post

Commercial real estate owners will be among the earliest adopters of widespread IoBT, to the extent that it will become a competitive requirement<sup>133</sup>.

IoBT will improve building

efficiency and also create greater customer value. It will increase market differentiation and uncover new revenue opportunities.

The adoption of IoBT is in an infancy stage, with just 9% of respondents to a Deloitte webcast poll in 2016 indicating that their organisations were planning portfolio-wide adoption of IoT, of which 22% were doing so in a piecemeal fashion; and 21% said they had no IoT plans yet<sup>134</sup>. However, it is estimated that smart commercial buildings will be the biggest users of Internet of Things (IoT) technology through 2017<sup>135</sup>, with the installed bases of IoT sensors in commercial buildings growing from 377.3 million in 2015 to more than a billion in 2018. The market for IoBT is forecasted to grow from \$46 billion in 2014 to \$155 billion in 2020.

Project sites are getting denser and generating vast amounts of data. A significant amount of this data is not captured and subsequently lost, let alone measured, processed or acted upon.

### **Smart homes**

The global smart home market is expected to grow 13.3% CAGR between 2017 and 2025 to reach a

value of \$16.3m by 2025, up from \$5.4m in 2016. However the market is fragmented because of the large number of vendors. The main market segmentations are energy and climate management (dominant segment, >25%), access and security control, home entertainment, lighting digital and telehealth devices<sup>136</sup>.

### **Asset tracking**

IoBT can be used to track asset utilisation and performance of construction assets and equipment. By capturing real-time data from construction crews, equipment and stores it enables contractors to optimise logistics and supply chains, and reconcile material plans with physical availability. IoT-enabled systems

can work with robots to increase the accuracy and speed of warehouse processes. In addition, IoT data can be fed into analytics processors and combined with business intelligence and BIM programmes. The information can then analyse productivity and generate predictive trends, estimates and recommendations to support decision-making and mitigate risks.

VergeSense developed an intelligent artificial intelligence-driven IoT sensor to assess room utilisation. The system requires no tags for individuals, and passively tracks how office space is used. The ‘sensor as a platform’ uses machine learning in pre-trained AI modules to perform all the processing in the device itself, rather than transmitting masses of ‘raw recordings’ for processing elsewhere...”

TechCrunch

### **IoT applications in construction**

Construction applications of IoBT include:

- Geolocation, including the tracking and identification of personnel. Monitoring of the health and wellbeing as well as accountability and performance of personnel.

<sup>132</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>133</sup> <http://deloitte.wsj.com/cio/2016/10/26/iot-poised-to-transform-building-management/?mod=WSJBlog>

<sup>134</sup> <http://deloitte.wsj.com/cio/2016/10/26/iot-poised-to-transform-building-management/?mod=WSJBlog>

<sup>135</sup> <http://www.gartner.com/newsroom/id/3175418>

<sup>136</sup> <http://www.sbwire.com/press-releases/smart-home-m2m-market-presence-of-many-prominent-players-makes-competition-stiff-843730.htm>

- Geolocation and tracking of equipment and tools, vehicles and materials with geofencing.
- Monitoring of equipment, maintenance and repairs. Breakage and maintenance interventions; and prevention of collisions.
- Inventory management and procurement. Supply replenishment forecasting and just-in-time (JIT) ordering. RFID tags can help to count items, trigger automatic replenishment and also pinpoint the location and movement of materials.
- Quality assessments.
- Energy efficiency.
- Sensors for measuring ambient conditions and fuel consumption, for example.
- Control of devices, including HVAC and other internal environmental parameters, entrance and security.
- Remote operation. Wearable computing such as Google Glass can provide on site access of instruction manuals in a hands-free mode, or benefit from remote support by 'seeing what they see'.

Adoption of new technologies typically bring new challenges. In the case of IoT, these include, technology integration and interoperability, analysing data generated by IoBT and smart buildings as well as cybersecurity and data privacy issues.

"EquipmentShare developed its own telematic platform for construction machinery and vehicles . It provides access to information like fluid levels, pressures and other data pertaining to machines' status. By enabling proactive maintenance, significant cost savings and lower down-time can be achieved. Telematics information can also determine whether a machine is underused, and indicate areas where the cost of ownership can be decreased by putting the machine to greater use..."

Huffington Post

### Sensors

IoT devices are typically equipped with one or more sensors, which measure operational variables. This data is then communicated to and shared with other devices, in addition to being used locally by the device itself.

A wide range of sensors is being connected to IoT devices in many industries. The sensors themselves rely on many different technologies, but their common IoT characteristic mandates that they all have the ability to communicate the information they are measuring.

In the construction industry, useful sensors include devices which can measure:

- Motion, position and identification
  - Presence of people and identification of individuals.
  - Presence and identification of equipment and tools, vehicles and materials.
  - Geolocation, distance, direction, speed and acceleration.
  - Rotation speed.
- Bioinformation.
  - Physical health and emotional state of people, including pulse rate, body temperature, blood pressure and weight.

The smart home of the future will be configured for telehealth, including the ability to measure and communicate the health status of occupants.

- Fatigue, alertness and wellness. Remote usage monitoring, and automatic logging of hours. Limits can be monitored to prevent fatigue, stress and accidents.
- Substance use (and abuse) by personnel<sup>137</sup>.
- Environmental conditions.
  - Heat, temperature, light, moisture, fire, UV and the presence of toxins and gases.
- Images and sound, including infra-red for use in the dark.
- Telecommunications connectivity and usage.
- Resource efficiency.
  - Energy, water and waste.
- Stresses and strain of structures, pressure and fluid levels.

<sup>137</sup> <http://www.veritas-consulting.co.uk/blog/substance-misuse-and-drug-testing-in-the-construction-industry/>

### **Wearables**

**'Wearables'** are items worn by people, which incorporate IoT type sensors. These can include clothing, safety equipment, watches, fitness sensors and geotags.

### **Building automation systems**

Building automation systems<sup>138</sup> are being introduced to new and existing buildings<sup>139</sup> in order to automate various processes such as heating, ventilation and air conditioning (HVAC), lighting and similar functions.

**"...building automation can be retrofitted to existing buildings..."**

The fact that building automation can be retrofitted to existing

buildings is another factor fuelling their increasing adoption. The automation is enabled by the [Internet of Things](#).

### **4.1.7 Geolocation, tracking and spatial measurement**

Spatial information is an important data element in construction, as is the ability to measure distance, speed and location accurately.

Modern remote surveying technologies can be used to avoid geological surprises. Geological information can provide site overviews rather than just information (external and internal) of individual buildings.

#### **Distance measurement**

The industry has been using electronic distance measurement for surveying for some time. Photogrammetry and satellite positioning systems which produce high-resolution images are also used. However, these are costly and the post-processing time needed to convert the information into usable data makes it most useful for large sites. It remains highly labour-intensive.

**"....LiDAR laser scanning is a new technology which is proving to be very useful in construction applications"**

Light detection and ranging (LiDAR) laser scanning is a new technology which is proving to be very useful in construction

applications. LiDAR uses optical lasers to detect thousands of points per second, from which a 3D image can then be obtained.

LiDAR technology is much faster than conventional technologies and provides high-quality 3D imaging that can be integrated into project planning tools, such as BIM. These technologies enhance the accuracy and quality of surveys and reduce the labour and time needed to conduct them. It can be used in conjunction with drones or handheld scanners.

LiDAR can generate above-ground and underground 3D images of project sites, when used in conjunction with ground penetrating radar and magnetometers. Contractors are also able to update BIM models dynamically based on these surveys, allowing them to track progress and monitor resources in real-time. This can be complemented by GIS (Geographic Information Systems) which allow maps, images, distance measurements and GPS positions to be overlaid.

#### **Geolocation**

**Geolocation technologies** can be used to identify and track the position and movement of people, tools and equipment, vehicles and materials on site<sup>140</sup>. Technologies which are used in these applications include GPS, bluetooth as well as various nearfield devices, such as RFID sensors. Information from individual people, tools, equipment, vehicles and materials are transmitted wirelessly to a central server, where it is analysed, reported and displayed.

**"Geofencing is a technique which allows the user to set virtual boundaries in a geolocation device. If the objects being tracked cross the geofences, the user is alerted. This can also help to minimise theft from construction sites..."**

Geolocation technology can improve safety of personnel on site, particularly in the case of emergencies. Tracking technologies can also be linked to biosensors which can indicate the physical and emotional state of personnel, including whether equipment operators are

<sup>138</sup> <http://www.businessinsider.com/sc/autonomous-buildings-use-smart-technology-2017-7?IR=T>

<sup>139</sup> <http://www.sbwire.com/press-releases/research-offers-10-year-forecast-on-building-automation-systems-market-by-future-market-insights-802622.htm>

<sup>140</sup> ["People tracking technologies", DeltaHedron Innovation Insight, No 3/17 \(May 2017\)](#)

experiencing stress or fatigue. The technology can help with project management and scheduling, and can improve site security and prevent theft. Waste due to labour mistakes and fraud in the construction industry is considerable<sup>141</sup>.

The ability to track the availability and movement of materials on site can help with logistics, project management and scheduling. Replacement materials can be ordered in a just-in-time manner when stock is depleted. Tracking of vehicles can alert site personnel when a delivery truck is close to arrival, so that its content can be received.

#### 4.1.8 Logistics, supply chains and procurement

The construction sector ranks in the lower range of sophistication in the Global Purchasing Excellence Survey published by McKinsey's Procurement Practice<sup>142</sup>. McKinsey has also identified improvements in procurement and supply-chain management as one seven areas which can drastically improve productivity and cut costs in construction. It estimates that global productivity improvement from implementation of best practices in this area can be 7-8%, with cost savings of 3-5%<sup>143</sup>. Best practice in areas such as digitising procurement and supply-chain workflows will enable more sophisticated logistics management and just-in-time delivery.

In order to achieve this, McKinsey recommends the use of standard procurement tools and mechanisms, the creation of a central procurement organisation and 'clean sheeting' to improve supplier and subcontractor management. Once these basics are in place, they recommend an investment in supply-chain and inventory capabilities to address the recommended shift towards a [production system approach](#); as well as implementation of digitised procurement-management systems, which incorporate analytics as well as simulations and real-time predictive supply-chain practices.

Digital technologies, including the [Internet of Things](#) (IoT) and [advanced automation](#), will increasingly contribute towards automating logistics and the management of supply chains, and create more real-time flexibility. IoT enables

efficient tracking of inventory levels and automatic as well as anticipatory and predictive replenishment from suppliers. This allows products to be shipped before a construction firm even places an order. The 'order signal' is triggered automatically when the sensors detect that stock levels are dropping below a threshold level.

Shipments already en route can be rerouted in real-time to a new destination, if necessary. Timing of deliveries can respond to external factors such as weather conditions and market

trends in order

to optimise the price and the time of delivery.

By using advanced BIM with a supply-chain dimension, suppliers can continuously update the delivery schedule in real-time. This enables the contractor to

know where things are and if any delays are expected to optimise the just-in-time deliveries.

Relevant data on cost structures, supply availability, lead times, financial and operational risks as well as service and quality metrics can all be integrated into procurement systems. Two categories of digital applications are important in this regard, viz.

- Applications which identify and create value, including applications which create visibility and transparency regarding spending, by using historical data on invoices, material-cost indexes and other benchmarks to identify opportunities in sourcing and procurement<sup>144</sup>.
- Applications which prevent the leakage of value, including applications which create predictive order configurations automatically, and identify potential suppliers for categories

*"Kattera recently launched a data-enhanced global sourcing model to help develop a supply chain which reacts to potential disruptions and market dynamics with predictive replenishment of supplies informed by inventories connected to the IoT..."*

McKinsey

<sup>141</sup>

<http://www.constructiondive.com/news/construction-industry-trends-2017/433151/>

<sup>142</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>143</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>144</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

not covered by contracts or catalogues. This enables companies to track receipts and goods automatically and eliminates the need to match invoices<sup>145</sup>.

Advanced data-driven analytics can identify non-compliance in transaction-intensive purchases as well as large, high-value outsourced contracts. Contract conditions can be extracted with machine reading and compared with continuous streams of invoices, supplier activity and other performance data.

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### Digital market places

It is foreseen that there will be a growth in digital marketplaces — online platforms which match owners and contractors buying materials and services with contractors and suppliers who provide them. They can include, for example, markets for equipment sharing (largest application for markets) as well as for building materials, home improvement and jobs.

Digital marketplaces can enhance transparency, one of the root causes of low productivity growth. There will be an increase in the use of e-auctions (a one-time negotiation in which all suppliers can see the prices their rivals are offering, thus heightening competition) and using web-based online platforms, which can produce savings in the range of 10- 20%<sup>146</sup>.

#### 4.1.9 Virtual reality (VR) and augmented reality (AR)

Virtual reality (VR) is a technology which enables the user to view a virtual 3D environment through a special VR headset. Contemporary VR environments are expanding this capability to include sound, motion, tactile and other sensory experiences. The virtual environment simulates a real or digitally created environment, and the user experiences the VR environment as if he/she 'is there'. In the virtual environment, the user can perform acts as if he/she was in the real situation, and the environment engages in an interactive manner.

In the construction industry, VR can be used to create 3D representations of buildings before they are built, allowing the user to move around the

building to see and 'get the feeling' of the structure. VR is particularly powerful in allowing clients to interact with and better understand the unbuilt design. Changes can be made to the digital virtual building, and by 'walking around' virtually the user can 'see' the effect of the changes. VR environments are also very useful for training purposes, as they embed the trainee into a 3D environment where many scenarios, including hazardous situations, can be simulated. VR training is very effective for the training of operators of vehicles and equipment.

Designers are increasing using virtual reality as part of their regular design processes.

Mecanoo<sup>147</sup>, for example, provides its clients with a range of VR experiences, ranging from viewing spaces via a smartphone to fully immersive engagements through 3D headsets.

"The 3DEXPERIENCity 'Experience Room' is an example of how AR/VR tools work in construction. Stakeholders are projected into a collaborative workspace through which experts from government, business, urban planning, infrastructure design, and so on, can work together in harmony to define a city's future..."

The BimHub

Augmented reality (AR) is a technology which superimposes or overlays additional information onto the user's view of the real world. A heads-up display in the windshield of a car can, for example, overlay conditions on the road or the presence of animals or pedestrians at night on the windshield.

By wearing AR glasses, information about a tumour can be overlaid in real-time onto the area of a patient where a surgeon is operating. By pointing a smart phone at a building, the AR app will recognise the building and provide additional information, including images, audio and video information about the building.

An application was recently reported where AR allows construction workers to 'see through walls'<sup>148</sup>. Other potential applications can include

<sup>145</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>146</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>147</sup> <http://www.designboom.com/architecture/mecanoo-virtual-reality-johan-hanegraaf-interview-05-28-2017/>

<sup>148</sup> <https://redshift.autodesk.com/augmented-reality-in-construction/>

the modelling of buildings and the 3D mapping of archaeological excavations<sup>149</sup>.

The construction industry has so far only dabbled in the use of VR/AR to aid in construction practices, but as cheaper and higher quality options come to market, it is expected to take off rapidly.

"Buying furniture is often challenging because of the uncertainty of what an item will actually look like in the home. A new 3D tool allows the user to 'try furniture before buying it'. Houzz has developed an online platform, incorporating an augmented app, dedicated to interior design and home décor. The app allows the user to 'try out' furniture in the home in the same way one would clothing in a store. The user can preview up to 300,000 different pieces of furniture and other decor products in their home before they make a purchase. 3D models are 'placed' into the user's home, accurately representing materials and textures, and offering a realistic visualisation of how the physical item will look in the home...."

This is Insider



**Video clips showing augmented reality in construction can be seen [here](#) and [here](#)**



**Video clips showing virtual reality in construction can be seen [here](#) and [here](#)**

#### **Safety enhancement applications of VR/AR**

- Virtual and augmented reality allows costly mistakes to be identified and rectified before they occur by being able to visualise how something will work, without the costs and hazards of physical trial and error.
- Field conditions can be communicated in real-time to people who are not physically present on site.

- Possible dangerous situations can be explored without subjecting people to dangerous environments.
- Aid in safety training for new employees. Dangerous and hazardous situations can be simulated, and employees trained to deal with them, without having to do the training in a real environment.

#### **4.1.10 Cyber security and blockchain**

##### **Cyber risks**

A high degree of digitalisation is desirable, but brings its own risks. Cyber security and data protection are certainly amongst the highest of these. All companies need to ensure that they have taken adequate steps to protect their IT infrastructure – whether it be data, computers and digital devices, networks and servers, cloud and mobile applications or IoT-enabled devices – are secure from unauthorised access, data theft and manipulation. Business continuity and disaster recovery are also high priorities.

Once hackers have gained access to a company's IT assets, they have the ability to steal, manipulate or erase data, steal money and identities, and disrupt and disable systems and machines. Cyber security poses huge risks, which include financial, liability and reputational damage. External denial-of-service attacks, for example, can cause tremendous strategic and operational disruption<sup>150</sup>, as can viruses and ransomware.

As digitalisation becomes more embedded, the volumes of data transmitted, processed and stored increase. Data leaks, whether maliciously or unintentionally and by accident,

can be hugely damaging. Not only could there be a transgression of data privacy laws (with resultant fines), but sensitive commercial information could be compromised. Companies need to balance the

"The increased risk of a sensitive information breach through cyber-intrusion was the biggest concern for those polled during Deloitte webcast on IoT in buildings ..."

<sup>149</sup> <https://3dprint.com/179081/palmyra-arch-in-italy/>

<sup>150</sup> <https://www.forbes.com/sites/patrickmoorhead/2017/05/31/denial-of-service-is-a-growing-threat-how-can-you-better-protect-your-business/#1ebacaf94f41>

benefits of increasing the amount of data they gather and use with privacy concerns<sup>151</sup>.

A proliferation of mobile devices and access complicates the cyber security problem, specifically with growing concerns regarding the cyber safety of IoT devices<sup>152,153</sup> and [bring-your-own-device \(BYOD\)](#) policies.

### **Blockchain**

Blockchain is well known as the technology driver of the bitcoin cryptocurrency. It is a technology which is used to ensure and verify the integrity of records of transactions in a secure manner. It is a very powerful technology in own right, and has a vast range of applications in many industries beyond cryptocurrencies<sup>154</sup>.

"... BimSense is working on a blockchain backed BIM data idea at the moment. This will mean an immutable record of who added what to the digital asset"

Blockchain is a distributed ledger system, meaning that a copy of all the records of all transactions are continuously updated on a

vast number of computers across the world. This makes it impossible for a single user to tamper with any given record, because all the other computers where the records are kept will cry foul. Blockchain allows the direct transacting of business between parties and eliminates the middleman.

Blockchain will increasingly find applications in the construction industry, including digital payments, self-executing contracts, verifiable digital identification, workflow applications and records of procurement and inventories<sup>155</sup>.

It has been suggested that blockchain can be at the core of the next generation of collaboration tools in construction, when combined with BIM, by providing enhanced transparency and incentives<sup>156</sup>.

<sup>151</sup> <http://www.bbc.co.uk/news/business-40441434>

<sup>152</sup>

<https://www.recode.net/2017/8/1/16070996/congress-internet-of-things-cybersecurity-laws>

<sup>153</sup> <http://www.mobihealthnews.com/content/tactics-defending-iot-devices-hackers-often-overlooked-experts-say>

<sup>154</sup> <http://www.itproportal.com/features/what-is-blockchain-everything-you-need-to-know/>

<sup>155</sup> <https://futureofconstruction.org/blog/will-blockchain-transform-the-construction-industry/>

## **4.2 Automation technologies**

Emerging technologies will contribute significantly towards automation in the construction industry, and enhance productivity. McKinsey recommends the implementation of automation on construction sites as a mechanism to enhance productivity and cut costs<sup>157</sup>. Estimates suggest that the construction industry could automate 68% of on-site tasks, one of the highest of any sector. Areas where it will impact include design and contracting, workflow as well as on-site execution. Automation will necessarily also have an [impact on employment](#) and the nature of work in the industry.

### **4.2.1 3D printing and scanning**

3D printing, also referred to as 'additive manufacturing', is a manufacturing process<sup>158</sup> which creates a three-dimensional object by laying down layers of thin horizontal cross-sections until the entire project is completed. 3D Printing is used in many industries and its use is steadily growing in construction. 4D printing is a process whereby objects are 3D printed, but then alter their shape after having been printed. These changes can, for example, allow objects to self-transform as they respond to heat, sound or moisture levels.

Models of buildings, prototypes and smaller parts can be 3D printed. They can also be easily changed and reprinted. Large construction structures require super-size printers and specialised materials. 3D printing allows the production of all sorts of twisted construction forms, which were previously difficult or impossible to create through other methods<sup>159</sup>.

3D printers for construction applications typically use cement as the 'ink'<sup>160</sup>. Cement used in 3D printing is composed of additives from construction waste, sand, fibre and other materials. Manufacturers claim that this new technology can save 90% on labour-related costs.

<sup>156</sup> <https://www.linkedin.com/pulse/future-collaboration-construction-trust-backed-david-hughes>

<sup>157</sup> <http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>158</sup> <http://www.constructionworld.org/impact-3d-printing-construction-industry/>

<sup>159</sup> <http://www.aurecongroup.com/en/markets/property-buildings-of-the-future/designs-that-make-sense.aspx>

<sup>160</sup> <http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

"The London Crossrail, to be named the 'Elizabeth Line', is claiming to be the world's first commercial 3D printed construction project ('not a purely conceptual demo'). Precise wax moulds rather than concrete itself is printed. It is claimed that this method has several advantages, including structural integrity and strength, less waste and cost..."

3ders

few days of assembly requiring just three human workers.

3D printers are also creating construction modules in off-site factories which are shipped to the construction site for assembly. This relatively fast and inexpensive alternative has many implications on the way construction is done now, and more importantly, how it will alter the industry in the future. As in the case of other automation-related technologies, its adoption will also [impact of the labour force](#) and nature or work in the construction industry<sup>161</sup>.

Advantages of 3D printing in the construction industry include<sup>162,163</sup>:

- Increased speed, accuracy and efficiency<sup>164</sup>. 3D printing ensures that each subsequent piece is uniform and consistent.
- Significantly lowering labour costs and cost savings on supplies.
- Greatly reduce the amount of waste.
- Creating safer work environments and reducing health and safety risks.
- 'Contour crafting' enables large projects to be 3D printed.

3D printing is proving to result in shorter project times and less waste.

Some of the buildings now being built with 3D printers are completed within 24 hours, and fast drying materials allow structures to be finished in a matter of days. A two-story 1,200 m<sup>2</sup> house can be printed in one day with a

- Greener construction.
- Speedier project planning and mock ups, identification of flaws and pain points before construction starts, and clearer client expectation.
- Global development, creating homes for people in developing countries and destitute areas.

"Printed buildings will be the future within 10 years.... this is a potential disruptor to the construction industry and designers..."

Aurecon

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Although 3D printing is still in the early stages of adoption in construction, it is possible to print submodules as well as complete concrete structures. Illustrative examples of ongoing research are often useful signals and precursors of what has already been achieved, what we can expect and the emergence of trends:

- The European Space Agency (ESA) is using 3D printing to address the challenges of transporting materials to the moon in order to construct lunar habitations. Their study is investigating the use of lunar soil, known as regolith, as a building material to be used by a robot-operated 3D printer<sup>165</sup>.

NASA also supports 3D printing technology, inter alia to build houses in space where astronauts can live. It is claimed that 90% of materials needed for construction are already on the moon, so that it would be feasible to transport the remaining 10% from earth in a spaceship<sup>166</sup>. It is anticipated that the 3D printed technologies which are being developed for space exploration could also be used on earth, for example for building shelters in regions where construction supplies are low.

NASA has awarded \$100,000 to two winning teams in the first segment of the agency's 3D Printed Habitat Challenge in May 2017<sup>167</sup>. The aim of the challenge was to "foster the

<sup>161</sup><http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

<sup>162</sup><http://www.constructionworld.org/impact-3d-printing-construction-industry/>

<sup>163</sup><https://www.thebalance.com/a-guide-to-the-future-3d-printing-and-construction-3960242>

<sup>164</sup><http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

<sup>165</sup>

<http://www.aurecongroup.com/en/markets/property/buildings-of-the-future/designs-that-make-sense.aspx>

<sup>166</sup><https://viterbi.usc.edu/news/news/2014/3d-printing-a.htm>

<sup>167</sup><http://trendintech.com/2017/05/19/success-so-far-nasas-100k-awarded-3d-printed-habitat-challenge/>

development of technologies to manufacture a habitat using local indigenous materials with, or without, recyclable materials”.

- In March 2014, the Chinese company WinSun claimed to have printed 10 houses in 24 hours, using a proprietary 3D printer which uses a mixture of ground construction and industrial waste, such as glass and tailings, around a base of quick-drying cement mixed with a special hardening agent. The 3D printer was reported to be 6.6 metres high, 10 metres wide and 40 metres long. Large sections were prefabricated with the printer and then assembled on-site, complete with steel reinforcements and insulation. It is claimed the this process saved 30-60% of construction waste and decreased production times by 50-70% and labour costs by 50-80%. Using recycled materials, the buildings reduced the need for quarried stone and other materials, resulting in a construction process that is environmentally advanced and cost effective. The ‘ink’ used was made of recycled construction materials, industrial waste and tailings. Each of these homes were reported to cost circa \$4,800. This project represented the first of an entirely new wave of housing, which is inexpensive, durable and can be produced in only a few hours.

WinSun printed its own headquarters building, a 10,000 m<sup>2</sup> facility, in a period of 30 days. In January 2015 it was reported that the company had successfully 3D printed a five-storey apartment building and a 1,100 m<sup>2</sup> villa in Suzhou Industrial Park, using a special print material. In July 2017 it was reported that Winsun had signed a \$1.5 billion contract with Saudi Arabia to print 2.8 million m<sup>2</sup> of 3D printed projects<sup>168</sup>.

- Dubai, the largest city in the United Arab Emirates, recently launched the Dubai 3D Printing Strategy<sup>169</sup>. The objective is to make Dubai a global leader in additive manufacturing technology. It is a unique and wide-reaching initiative aiming to exploit the

power of 3D printing to add value to the national economy and to humanity as a whole. The strategy will cover three key economic sectors, viz. 3D printed construction, 3D printed medical products and 3D printed consumer products.

The goal is to ensure that 25% of buildings in Dubai are constructed with 3D printing technology by 2030, with the percentage to be raised progressively with the development of global technology and growth of market demand. The value of Dubai’s 3D printing construction sector is expected to reach Dhs3 billion (circa US\$800 million) by 2025.

**“The Dubai Clean Energy Strategy 2050 was announced in 2015, in which 3D printing will play an important role in helping Dubai become the most sustainable city in the world....”**

In July 2015, Dubai announced plans to build an office that would be “the most advanced 3D printed structure ever built at this scale” and the first to be put into actual use<sup>170</sup>. The project was to be the first major initiative of the ‘Museum of the Future’ and part of a larger partnership between Dubai and the Chinese company WinSun Global. The one-story prototype was to have circa 186m<sup>2</sup> of space. The building and furniture were to be printed using a mixture of reinforced concrete, gypsum and plastic, using a 6m tall 3D printer. It was estimated that labour costs would be reduced by 50-80% and construction waste by 30-60%.

In January 2017 is was reported that an office building of 251m<sup>2</sup> had been 3D printed in Dubai. It required 17 days of off-site construction, with only two days of on-site assembly<sup>171</sup>. The cost was estimated to be \$140,000<sup>172</sup>. In July 2017 it was reported that WinSun had constructed 17 office buildings in Dubai<sup>173</sup>.

<sup>168</sup><http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

<sup>169</sup><http://www.impactlab.net/2016/12/20/25-of-dubais-buildings-to-be-3d-printed-by-2030/>

<sup>170</sup><https://wtvox.com/3d-printing-in-wearable-tech/the-worlds-first-3d-printed-building-to-be-built-in-dubai/>

<sup>171</sup><http://jbknowledge.com/top-10-construction-tech-trends-2017>

<sup>172</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>173</sup><http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

The Institute for Digital Archaeology (IDA), a collaborating between the University of Oxford, Harvard University and Dubai's

**"The future will depend on 3D printing technologies in all aspects of our life, starting from houses we live in, the streets we use, the cars we drive, the clothes we wear and the food we eat..."**

Vice President and Prime Minister of the UAE and Ruler of Dubai, His Highness Sheikh Mohammed Bin Rashid Al Maktoum

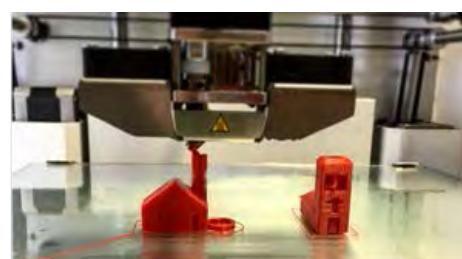
Museum of the Future, distribute 5,000 3D cameras to citizens in ISIS-stricken war zones so that people could document ancient buildings, such as the Temple of Bel in Palmyra in Syria, and other artefacts before they are lost forever in the conflict. The Million Image Database Project is under the partnership of the United Arab Emirates, the IDA, and the United Nations Educational, Scientific and Cultural Organization (UNESCO). The project aims to document historic and archaeological locations around the globe, using 3D photography to capture dimensions and specifications. The data will then be used to recreate the artefacts and structures through 3D printing and other advanced technologies. More than half a million images have already been published on an electronic portal.

- In June 2017, it was reported that the Dutch 3D printing company CyBe Construction had completed its role in 3D printing a drone Research and Development laboratory for the Dubai Electricity and Water Authority (DEWA). The 168 m<sup>2</sup> building was 3D printed on-site in just three weeks with the CyBe RC 3Dp 3D printer. It features rubber wheel tracks, which allow it to roam freely around the construction site.

CyBe will be involved in the 3D printing of 'De Vergaderfabriek' in the Dutch town of Teuge<sup>174</sup>. The intention is to construct the building in just ten days. As a result, carbon

emissions will be reduced by 40% and waste by 70%, compared to conventional techniques.

- In March 2017 it was reported that Apis Corporation had built its first ever 3D-printed home in Stupino, near Moscow<sup>175</sup>. Construction took only 24 hours during December 2016, through temperatures of minus 35°C. The home is equipped with a living room, kitchen, bathroom and a hallway. It was printed on-site with mobile 3D printer and is claimed to be a world-first for a 3D-printed building constructed in that amount of time. The total cost of construction for the 38m<sup>2</sup> home was \$10,134 (\$275/m<sup>2</sup>), including the expenses of work, materials for the construction and furnishing. The company claims that a square house with a simpler design and averagely priced material would cost only \$223/m<sup>2</sup>; and that its method of 3D printing homes cuts 70% of costs compared to traditional methods.
- A giant 3D printer that can print an entire house of 232 m<sup>2</sup>, including electricity and plumbing, in less than 24 hours was being tested by the University of Southern California<sup>176</sup>.
- Amsterdam-based MX3D has reported that it is developing a technique to print a bridge made of steel<sup>177</sup>.



3D printing of a model

### ***The permanency dilemma – exploring the viability of disposable housing<sup>178</sup>***

Whereas there is a view that durability and 50-year lifecycle contracts will be gather momentum<sup>179</sup>, there is also an alternative view that the future

<sup>174</sup> <https://3dprintingindustry.com/news/cybe-construction-3d-prints-concrete-drone-labouratory-site-dubai-114869/>

<sup>175</sup> <https://futurism.com/this-home-was-3d-printed-in-only-24-hours-and-for-just-10000/>

<sup>176</sup> <https://viterbi.usc.edu/news/news/2014/3d-printing-a.htm>

<sup>177</sup> <http://mx3d.com/projects/bridge/>

<sup>178</sup> <https://futureofconstruction.org/blog/disposable-houses/>

<sup>179</sup>

<http://www.aurecongroup.com/en/markets/property-buildings-of-the-future/designs-that-make-sense.aspx>

**"With an ability to reprint houses in less than a day, the question can be posed whether an expected lifespan of 10-20 years is appropriate or even preferable for residential homes..."**

may be in disposable 3D printed homes. With an ability to reprint houses in less than a day, the question can be posed whether an expected lifespan of 10-20 years is

appropriate or even preferable for residential homes. Arguments in favour of disposable home approach include:

- When moving to another location, it may be preferable to reprint one's home rather than settling for what is available in the new neighbourhood.
- Housing needs change as people move through different stages in life. When the children leave the home, a smaller one may be desirable. On the other hand, it can also be easy to add extensions to a house if it needs to be larger.
- When weather, fire or termites cause significant damage to a home, it may be easier and cheaper to reprint a house than to repair it, with reworked design features if necessary.
- When autonomous cars make [owning of cars obsolete](#), garages can be eliminated and reformed into other kinds of usable spaces.

### 3D Scanning and mapping

3D scanning is a process whereby digital 3-dimensional data of an object is obtained. The 3D digital models are used for inputs to 3D printing, but also to visualise structures in [BIM](#) and [CAD](#). The ability to create digital 3D images of buildings and structures is an essential component of the digitalisation of the construction industry. There have been significant recent advances in this area, many of them using mobile technologies.

A tablet-sized mobile device uses a laser range finder to make digital models of building sites or interiors undergoing renovation, in real-time<sup>180</sup>

has been reported. As an architect or contractor walks through a space, the device gathers thousands of measurements per second at a range of up to 15 metres. A similar mobile device which can be used for the 3D mapping of buildings in real-time has been developed at the Institute for Visual Computing at ETH<sup>181</sup>. The system has the advantage that it can be used outdoors in sunlight.

[Drones](#) are also increasingly also being used for 3D scanning and mapping.

Innovative 3D laser scanning<sup>182</sup> can be used to digitally capture the exact measurements

**"Innovative 3D laser scanning can be used to digitally capture the exact measurements of a building...."**

of a building. This data can then be embedded into BIM software to establish the exact size and shape of a structure. Determining the exact dimensions of a project using this form of construction technology means that no reliance on human measurements is necessary, hence reducing human error.



Video clips showing 3D printing in construction can be seen [here](#) and [here](#)

### 4.2.2 Robotics

Robotics has had a dramatic impact on productivity in manufacturing and will do the same in construction. In fact, there has been a suggestion that construction sites will be run by robots by 2050<sup>183</sup>. The use of robotics in construction will no doubt also have an effect on the [labour market](#)<sup>184</sup>.

Robotic technology provides the construction industry with numerous advantages.<sup>185</sup> Robots do their work with precision and accuracy throughout all construction processes, which can lead to significant time and financial savings. With many robotic systems completely automated, the manufacturing of parts and materials will be much

<sup>180</sup><https://www.bloomberg.com/news/articles/2017-03-09/this-mobile-device-can-map-your-future-home>

<sup>181</sup><https://phys.org/news/2016-01-d-entire-mobile-devices.html>

<sup>182</sup><https://www.morson.com/2016/08/technology-trends-that-are-transforming-the-construction-industry/>

<sup>183</sup><https://www.balfourbeatty.com/2050>

<sup>184</sup><http://www.cornwalllive.com/this-bricklaying-robot-could-put-thousands-of-workers-in-cornwall-out-of-jobs/story-30282827-detail/story.html>

<sup>185</sup><http://www.constructionworld.org/6-ways-robotics-transforming-construction-industry/>

more consistent. By removing human error and inconsistency, robots take advantage of speed, efficiency and repeatability to ensure better overall quality. The ability to ensure accuracy and precision also contributes towards reducing the amount of waste.

Traditional construction, particularly repetitive and predictable activities such as bricklaying, tiling, spool fabrication, welding, material handling, packing, dispensing, concrete recycling, cutting and packing can be either fully automated or automated to a significant extent by using robots.

**"The PipeGuard team at MIT has developed a robot which can find the smallest leaks in pipes, irrespective of the material from which the pipe is made. The robot is inserted into the water supply, and then either floats passively in the pipe or is controlled. A small robotic shuttlecock device gathers data on divergent pressures using sensitive detectors on its rubber skirt. At the same time it monitors its position. This enables the robot to discover the position of 'anomalies', i.e. leaks..."**

MIT

**"SAM (Semi-Automated Mason) is a bricklaying robot, produced by Construction Robotics. It can lay 3,000 bricks per day, compared with the average construction worker who can lay 400-500 per day..."**

New York Post

Companies in Australia and the United States have achieved a masonry productivity gain of more than 100% through the use of bricklaying robots. A proof-of-concept paving robot called RoadPrinter is claimed to be 20% more productive than comparable human paving teams<sup>186</sup>. Construction robots can also include robotic cranes and diggers, for example<sup>187</sup>. As the machinery dig holes and level land, they can use on-board sensors to collect data to indicate how the site's layout is changing.

One of the earliest uses of robotics in construction has been in demolition, including breaking down walls, crushing concrete and gathering debris.

<sup>186</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>187</sup><http://www.cornwalllive.com/this-bricklaying-robot-could-put-thousands-of-workers-in-cornwall-out-of-jobs/story-30282827-detail/story.html>

Speeding up the demolition process can provide large savings of time and cost.

**"ETH in Switzerland are building the 'next generation of construction robots'. The DFAB House integrates the use of a range of emerging construction technologies, and exploits the strengths and synergies of all. The technologies include robots and 3D printers, and can accommodate real-time changes to designs..."**

Digital Trends

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#### 4.2.3 Drones

A drone is a vehicle controlled remotely by a human operator or a computer. The term generally refers to remotely controlled aircraft, also known as unmanned aerial vehicles (UAV)<sup>188</sup>, but it is also sometimes used to refer to remotely controlled ships. Remotely controlled and autonomous vehicles and robots operating on land are being used extensively as well, but are not typically referred to as drones. In this document, the term 'drone' is used to refer to UAVs.

Drones can provide value at every step in the building process. They have a multitude of applications in the construction industry. McKinsey recommends the use of drones and UAVs for scanning, monitoring and mapping as a way of increasing productivity and cutting costs<sup>189</sup>.



A drone on a construction site

It is estimated that the construction industry will acquire more than 6 million drones by 2025<sup>190</sup>,

<sup>188</sup><http://www.constructionworld.org/5-reasons-drones-will-save-business-money/>

<sup>189</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>190</sup><https://www.inc.com/kate-l-harrison/b4-cool-technologies-driving-the-construction-si.html>

worth \$45 billion (as opposed to drones for delivery, which is estimated to be worth \$13 billion)<sup>191</sup>. Drones is one of the technologies which will contribute significantly to the disruption of the construction industry<sup>192, 193, 194, 195</sup>, including:

- Pre-project assessments and project survey data. Before breaking ground, drones can be used to survey the topography. Drones can offer unprecedented aerial images of a project site much more accurately and realistically than aerial photographs<sup>196</sup>.
- Conducting aerial surveys. They can also provide real-time aerial views of key project areas, allowing management and construction staff to monitor operations and performance, which in turn supports decision-making.
- Site mapping<sup>197</sup>, documenting project evaluation and progress for costing, remote project management and related applications, where surveyors were previously required. Recording the actual progress on a site can also be used as a marketing tool, as conditions of a project developments are recorded in real-time. This information, including images and video, can be presented to clients, investors and funding institutions.
- Building surveillance and inspections, including of roofs, high tension electric wires, remote sites and other areas which are difficult to access.
- Asset tracking, including movement of machines and equipment, tools, vehicles and people. They can also be used to keep attendance records and monitor workers on site and is a convenient tool to keep track of how many employees are working in sensitive or hazardous areas.

- Monitoring the movement of materials, stockpile reporting and inventory management. Drones can be used to keep record of linear metres of material being installed, for example.
- Transporting items from one site to another or across sites.
- Enhanced safety. Drones can provide real-time data of safety violations or situations which might have a negative safety impact during the construction process.
- Physical and cybersecurity. Real-time visibility, including at night with the use of infrared cameras and adverse weather conditions.
- Reduced energy costs.
- Data can be acquired instantly and integrated with mapping and BIM programmes.

It was mentioned above that emerging technologies often bring new risks. This is also the case with drones. A number of countries are introducing various types of regulations, which will also affect the construction industry<sup>198</sup>. In addition, there a number of other legal risks to consider as well<sup>199</sup>.

“Komatsu have been developing a drone-based program to overcome shortage of construction workers. The drones scan job sites from the air and send images to computers to build 3D models of the terrain. Komatsu’s unmanned bulldozers and excavators could then use the models to execute out designs, dig holes and move earth...”

The Balance

<sup>191</sup>

<https://www.recode.net/2017/6/6/15701186/robots-construction-homes-technology-drones-building-automation-productivity>

<sup>192</sup><https://www.suasnews.com/2017/01/challenges-avoid-launching-drone-ops-construction-company/>

<sup>193</sup><http://www.constructionworld.org/drones-benefiting-construction-industry/>

<sup>194</sup><http://www.constructionworld.org/5-reasons-drones-will-save-business-money/>

<sup>195</sup><http://www.digitaljournal.com/tech-and-science/technology/drones-are-helping-the-construction-industry-to-reach-new-heights/article/497382>

<sup>196</sup><https://www.thebalance.com/how-drones-could-change-the-construction-industry-845041>

<sup>197</sup>

[https://www.insight.com/en\\_US/learn/content/2017/05162017-top-manufacturing-and-construction-tech-trends.html](https://www.insight.com/en_US/learn/content/2017/05162017-top-manufacturing-and-construction-tech-trends.html)

<sup>198</sup>

<http://www.theconstructionindex.co.uk/news/view/government-to-clamp-down-on-drones>

<sup>199</sup><http://www.enr.com/articles/41910-legal-risks-of-using-automated-drones-in-construction>

"Companies in India have used drones to string transmission lines spanning towers..."

McKinsey

Drones as a service. "Drone SmartX™ offers a hub which can be used with almost any commercial drone and convert it into 'smart drones' configured for use in the construction industry. The drone-based hub can connect to smart sensors such as RFID and bluetooth devices on the field, which are capable of capturing data and storing it in the cloud platform. Existing drones can be used without having to acquire new equipment or other drones..."

The Balance

"The Swiss Federal Institute of Technology is exploring the use of drones to rapidly string cable bridges remotely and autonomously..."

ScienceDirect



VIDEO

**Video clips showing the use of drones in construction can be seen [here](#) and [here](#)**



VIDEO

**Video clips showing autonomous vehicles in construction can be seen [here](#) and [here](#)**

#### 4.2.4 Autonomous vehicles

The trend in driverless cars will spill over into industrial sectors. Buses, trains, lorries and even entire fleets will become autonomous. Autonomous vehicles are already being used in mining and will also gain traction in construction.

Autonomous heavy machinery has many benefits, including higher utilisation ratios and reduction in operator costs. The autonomous construction vehicles rely on a range of technologies, including GPS and LiDAR.

Manufacturers such as Komatsu and Volvo CE continue to release new models of heavy construction equipment. Komatsu offers

autonomous and automated dozers, backhoes, excavators and dump trucks which remove the need for manual labour and the time it takes to complete projects. Caterpillar and John Deere are developing dozers with automatic blades, with the aim of producing fully autonomous and driverless versions.

#### 4.2.5 Wearables in construction

Wearables refer to textiles and other devices worn by a person, which can send (and receive) information gained from IoT sensors. The information can reflect the person's physical and emotional state, movement or position<sup>200,201</sup> as well as other environmental variables. Typical wearables include items of clothing and textiles, footwear, hard hats and helmets, safety equipment such as high visibility vests and safety harnesses, glasses and headsets, gloves, watches and related wrist-worn devices as well as geotags.

Wearables find many applications in the construction industry and can contribute towards enhanced safety, security and productivity<sup>202</sup>.

They can, for example, be used for the identification, tracking and geolocation of people as well as the monitoring of their health status. Monitoring of heat stress, emotional stress and fatigue as well as substance use (and abuse) are relevant for the construction industry<sup>203</sup>, particularly also for operators of equipment and vehicles.

Applications of wearables in construction include:<sup>204</sup>

- Smart helmets, which incorporate a clear visor that displays augmented reality (AR) and 3D visual overlays in the wearer's field of vision. A 360° view allows workers to see all of their surroundings. Advanced features include

"Wearable computing such as Google Glass can provide on site access of instruction manuals in a hands-free mode, or benefit from remote support in order to 'see what they see'...."

<sup>200</sup> ["People tracking technologies", DeltaHedron Innovation Insight, No 3/17 \(May 2017\)](#)

<sup>201</sup> ["Developments in emerging health technologies", DeltaHedron Innovation Insight, No 1.2/17 \(April 2017\)](#)

<sup>202</sup>

[https://motherboard.vice.com/en\\_us/article/gvkaa4/c](https://motherboard.vice.com/en_us/article/gvkaa4/c)

[onsumers-may-be-ignoring-wearables-but-the-construction-industry-isnt](#)

<sup>203</sup> See also <http://www.veritas-consulting.co.uk/blog/substance-misuse-and-drug-testing-in-the-construction-industry/>

<sup>204</sup> <http://www.constructionworld.org/4-wearable-technology-innovations-construction/>

augmented work instructions, direct communication to remote workers and thermal vision. The AR capability can also help to increase safety.

- Bionic suits and exoskeletons. Many of the health and safety issues which arise on a construction site involve arduous physical labour, which can cause long-term problems. Bionic suits (also referred to as exoskeletons) provide the ability to pick up and operate heavy machinery with ease. It also increases the speed at which a worker can do manual tasks and contribute to greater efficiencies.
- Location-enabling and tracking capabilities can be embedded in smart safety vests, harnesses, boots and other clothing. Monitoring can include a worker's activities, distance walked, temperature and hours worked, as well as the health parameters referred to above. Linked with GPS, the worker can be warned if predefined hazardous zones are entered or when vehicles are approaching or are dangerously close. Panic buttons can be included to alert co-workers in emergency situations. The wearable can transmit the location of the injured worker as well as health related information.

**"Prolonged use of power tools can lead to various musculoskeletal, neurological and vascular disorders. Gloves embedded with tiny sensors are being developed by Nottingham Trent University to help protect construction workers from exposure to vibration. It will alert wearers when they experience vibrations likely to cause conditions such as vibration white finger and carpal tunnel syndrome"** Phys.org

**"SolePower is a manufacturer of industrial boots, which contain a variety of sensors, including temperature detection, GPS, wifi, electronics as well as inertial measurement units for tracking location and motion. Each sensor is powered by a kinetic charger that harnesses the untapped energy produced by walking"**

**"An innovative smart vest has been developed by RMIT in Melbourne to monitor the health of construction workers in real time. The vest uses sensors to measure a worker's body temperature and heart rate and sends the data wirelessly to a smartphone app, which instantly alerts users to any anomalies. The innovation comes amid concern at the growing number of heat-related accidents on construction sites..."**

Phys.org



A video clip showing wearables in construction can be seen [here](#)

### 4.3 Construction materials

The materials used in construction have a big impact on the productivity of the industry as well as the cost, durability and safety of buildings and infrastructure. Trends in materials of the future will redefine how projects are conceptualised, designed and executed as well as the life cycle trajectories of the projects.

McKinsey recommends the development of alternative and innovative materials as a mechanism for enhancing productivity and cutting costs<sup>205</sup>.

Whereas there are continuous improvements in traditional construction materials such as concrete and steel, many new materials and new types of materials are being developed. They are light, strong, cheap, durable, environmentally friendly and can include characteristics such as self-healing.

There is also an increasing trend in demand for green materials. Following the [Grenfell Tower tragedy](#) in London in June 2017, an increased focus on safe materials, design codes and building regulations pertaining to fire safety is expected. In addition, factors such as supply-chain agility and ease of off-site construction are also playing a role in advancing the use of new materials.

The [cost of materials](#) in the construction industry is rising<sup>206</sup>. Costs of iron and steel increased 5% - 6% in recent years, with the cost of materials such as plumbing fixtures, asphalt, roofing and siding

<sup>205</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>206</sup><http://www.constructionworld.org/forecasting-construction-trends/>

products as well as copper, aluminium and diesel fuel also rising.

The rising costs may well push construction companies to seek cheaper, eco-friendly, reusable or recycled materials as alternative construction materials. The adoption of new types of materials has been slow due to lack of awareness and familiarity within the design and engineering community, limited supply chain and lack of availability at scale as well as risk awareness among project owners and contractors<sup>207</sup>.

#### **4.3.1 Improvements in concrete and steel**

Concrete is the most widely produced and consumed material in the construction industry. It was used as the primary material for 46 of the world's 100 tallest buildings in 2013, with an additional 36 using concrete in combination with steel construction<sup>208</sup>. It is estimated that by 2030, urban growth in China and India will place global cement output at 5 billion metric tons per year<sup>209</sup>.

Given the wide use of concrete, even marginal improvements in its performance can have a major impact on the industry. Recent advances have seen the emergence of lighter, more flexible and more versatile forms of concrete, including self-consolidating, self-healing and self-compacting concrete<sup>210</sup>.

**"Work at Delft University is focused on developing a process to embed self-activating limestone-producing bacteria within concrete. This is aimed at decreasing the amount of new concrete produced and also to lower the costs for maintenance and repairs..."**

Construction World

Concrete is of course not without its own problems. It is estimated that current concrete output is responsible for circa 8% of the total global emissions<sup>211</sup>, and hence there is a need to reduce its environmental impact. Much of this effort is

directed at developing self-healing concrete and extending concrete's lifespan.

Continuous improvements are also being made in steel, another material pervasively used in construction. New technologies could slash the cost of steel production<sup>212</sup>. Con-X-Tech<sup>213</sup>, for example, is creating modular structural steel systems which eliminate the need for riveting or welding. The product relies on gravity connectors to create a rigid frame. Innovations like these can also save considerable on-site time.

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**"Research at the University of Wisconsin in Milwaukee is focused on the development of '100-year concrete'. The product contains a new water repellent concrete mix and is claimed to hold up with little or no maintenance for well over a century. This is achieved by adding super-hydrophobic elements which prevent the normally porous concrete from absorbing water and developing cracks. Unwoven polyvinyl alcohol fibres are also added, which allows the concrete to bend without breaking and withstand four times the compression of traditional concrete..."**

#### **4.3.2 Alternative materials**

Work is continuing to develop a range of alternative construction materials for use in structural and non-structural applications in high-end as well as affordable projects. Interesting new trends include:

- Ethylene tetrafluoroethylene (ETFE) is 99% lighter and also stronger, eco-friendlier, better at light transmission and more flexible than glass. This material was first employed on a large scale at the 'Water Cube' swimming venue at the 2008 Beijing Olympics. It is reported to have cut energy costs by 30%. The use of ETFE has since increased five fold<sup>214</sup>.

<sup>207</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/imagining-constructions-digital-future>

<sup>208</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>209</sup><http://www.constructionworld.org/top-10-construction-technology-trends-look/>

<sup>210</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>211</sup><http://www.constructionworld.org/top-10-construction-technology-trends-look/>

<sup>212</sup><http://www.economist.com/news/business/21718545-150-year-old-idea-finally-looks-working-new-technologies-could-slash-cost-steel>

<sup>213</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>214</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

- A pilot project in Rotterdam uses recycled plastics to replace traditional asphalt construction for modular road sections. The objective is for this solution to last more than 50 years.
- A number of brick substitutes made of natural materials are being developed, including:
  - Fly-ash bricks made from volcanic ash, sand, lime and gypsum.
  - Compressed earth blocks made of soil with a small amount of cement.
  - Ferro-cement wall panels made of cement, sand, aggregates, fibre and welded mesh.
- Roofs are being constructed from micro-concrete tiles formed from cement, aggregates and sand. Ferro-cement roofing channels have 60-75% lower deadweight and can reduce costs by 30% compared with traditional concrete roofing.
- Nanomaterials can be super-strong and ultra lightweight. Research is continuing to develop carbon nanotubes as a strong, very lightweight alternative to steel reinforcement. This could boost on-site productivity significantly, by eliminating the need for reinforcement fixing times<sup>215</sup>.
- Photovoltaic glazing and solar polymers, which can turn a multitude of surfaces into energy generating areas.
- It is claimed that photocatalytic technology in building materials can cut nitrogen dioxide levels. The technologies can be installed in roof tiles and on roads, for example. It is being used in the US, Netherlands and Japan<sup>216</sup>. In the Netherlands it was found that photocatalytic concrete reduced NOx levels by 25% (and up to 45% in ideal weather conditions) on a busy road.
- Topmix is permeable cement alternative, which can absorb 4,000 litres of water per minute.
- Aerogel is a super-transparent, super-insulating material, consisting of 99.98% air.

- Kinetic technologies are particularly interesting and useful. Pavegen and Lybra, enable flooring to harness the energy of vehicles or people moving on the surface<sup>217</sup>.

#### 4.3.3 Green materials

Green construction, also called sustainable building, refers to buildings which are environment-friendly and energy efficient throughout their lifecycle, including the designing, construction, maintenance, renovation, operation, and demolition phases<sup>218,219</sup>.

Demand momentum is stimulated by an increasing public awareness and concern regarding environmental sustainability and governmental regulations.

“The drive to enhance eco-friendliness, reduce carbon emissions and create a greener environment will increase the demand for green buildings and construction materials as well as the greening of construction processes...”

Business is also recognising the value of ‘going green’, which is reflected in their corporate responsibility activities. Health benefits of greening buildings are become ever more apparent<sup>220</sup>.

The global green construction materials market is expected to reach circa US\$ 255 billion in 2020<sup>221</sup>. The global green construction materials market was estimated to be worth \$127.5 million in 2014 and is expected to grow to \$225 million in 2020 (CAGR of circa 12.5% from 2015-2020)<sup>222</sup>.

Green construction materials is one of the fastest growing industries worldwide. North America was the largest regional market for green building materials market in 2014, and accounted for more than 40% share in total green building materials volume consumed in that year. In addition to requirements for new buildings, retrofitting,

<sup>215</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

<sup>216</sup>

<http://www.theconstructionindex.co.uk/news/view/air-quality-plan-ignores-photocatalytic-technology>

<sup>217</sup> <https://www.balfourbeatty.com/2050>

<sup>218</sup> <http://www.mynewsdesk.com/us/pressreleases/green-building-materials-market-industry-trends-outlook-and-opportunity-analysis-2016-2024-2005633>

<sup>219</sup><http://www.constructionworld.org/benefits-of-green-technology-in-construction-today/>

<sup>220</sup>

<https://www.theguardian.com/news/2017/jun/15/green-streets-way-to-go-weatherwatch-pollution>

<sup>221</sup><http://www.sbwire.com/press-releases/green-building-materials-market-will-reach-255-bn-in-2020-776113.htm>

<sup>222</sup><http://www.sbwire.com/press-releases/green-building-materials/release-840568.htm>

renovation and maintenance will increasingly also require green materials. Product innovation is one of the key strategies adopted by the leading players in the green building materials market.<sup>223</sup>

Green roofs and walls<sup>224</sup> can insulate buildings, leading to energy savings, reduced temperatures outside by absorbing sunlight and mitigation of the urban heat island effect. They also contribute to storm water management by soaking up the rain, reducing noise and increasing urban biodiversity. They contribute towards removing air pollution, in that they can reduce nitrogen dioxide by up to 35% and 50% in the small particulates which damage lungs. Popular green building materials include straw bales, grasscrete, rammed earth, hempcrete, bamboo, recycled plastic and wood as well as mycelium, ferrock, ashcrete, and timbercrete<sup>225</sup>.

#### **Green credentials**

'Green credentials' for construction materials include requirements for energy and resource-efficiency as well as sustainability. Green certification, such as Building Research Establishment Environmental Assessment Method (BREEAM)<sup>226</sup>, Leadership in Energy and Environmental Design (LEED)<sup>227</sup>, the ICC 700 National Green Building Standard<sup>228</sup>, Green Building Evaluation Labeling (GBEL)<sup>229</sup> and the Green Rating for Integrated Habitat Assessment (GRIHA)<sup>230</sup>, an environmental safety regulatory tool used by the United Nations to encourage the use of renewable materials in the construction sector. They will contribute to stimulate the demand for green construction and green materials.

We are likely to see similar requirements for recycling and the need to show that construction

materials were 'green sourced'. The latter will also be tied to the requirement to show that the material was ethically sourced. LCA-based Environmental Product Declarations are now recognised by USGBC LEED<sup>231</sup>.

#### **4.3.4 Wood and timber**

There is a resurgence in the use of wood and timber as construction materials. Until the late 19<sup>th</sup> century, wood was widely used in building construction. Following a number of major fires, it was replaced by other materials such as concrete, brick and steel<sup>232</sup>. However, a number of new innovations have now made wood a viable construction material again, including for use in high-rise buildings. The renewed interest in wood as a construction material is driven in part by advances in wood-binding technologies<sup>233</sup>, which are enabling new types of timber products and processing technologies.

Life Cycle Assessment (LCA) anticipates the environmental and human health impacts at each stage of the product life cycle. It is increasingly being used in green building to evaluate the environmental performance of building materials and products.

Wood has a number of benefits over traditional construction materials. Carbon dioxide is a major by-product in the creation of iron, steel and also the non-metallic minerals which are the raw components in concrete, contributing significantly to climate change. This is not the case with wood.

<sup>223</sup><http://www.mynewsdesk.com/us/pressreleases/green-building-materials-market-industry-trends-outlook-and-opportunity-analysis-2016-2024-2005633>

<sup>224</sup>

<https://www.theguardian.com/news/2017/jun/15/green-streets-way-to-go-weatherwatch-pollution>

<sup>225</sup><http://www.mynewsdesk.com/us/pressreleases/green-building-materials-market-industry-trends-outlook-and-opportunity-analysis-2016-2024-2005633>

<sup>226</sup> <http://www.breeam.com/>

<sup>227</sup>

[https://en.wikipedia.org/wiki/Leadership\\_in\\_Energy\\_and\\_Environmental\\_Design](https://en.wikipedia.org/wiki/Leadership_in_Energy_and_Environmental_Design)

<sup>228</sup><http://www.sbwire.com/press-releases/green-building-materials-market-will-reach-255-bn-in-2020-776113.htm>

<sup>229</sup><http://www.sbwire.com/press-releases/green-building-materials/release-840568.htm>

<sup>230</sup>

<http://www.mynewsdesk.com/us/pressreleases/green-building-materials-market-industry-trends-outlook-and-opportunity-analysis-2016-2024-2005633>

<sup>231</sup><http://3blmedia.com/News/Surprise-What-LCA-Reveals-about-Built-Environment-and-Circular-Economy>

<sup>232</sup>[https://www.wired.com/2017/05/wood-skyscrapers/?mbid=nl\\_53017\\_p4&CNDID=49148020](https://www.wired.com/2017/05/wood-skyscrapers/?mbid=nl_53017_p4&CNDID=49148020)

<sup>233</sup><https://www.digitaltrends.com/cool-tech/wood-skyscraper-approved-in-portland/>

It was reported in May 2015 that:

- A new kind of high-rise structure of 80 storeys ('River Beech Tower') built entirely from timber was being explored in Chicago.
- An 80 storey wooden skyscraper in London ('Oakwood Tower') has been proposed.
- In Stockholm, plans for a 133 metre high residential building, the tallest in the city, were being prepared.
- An undulating, all-timber football stadium in England had been commissioned.
- A 133 metre high tower in the Netherlands ('The Lodge'), a glass hyperboloid wrapped in a series of wooden beams, was being constructed.

At the time (May 2015) it was mentioned that projects such as River Beech Tower, Oakwood Towers and The Lodge were technically feasible, although perhaps not entirely practical, to build. Further research regarding safety and cost was required. The tallest timber building in the world (in May 2015) was an 18-storey dormitory in Vancouver ('Brock Commons').

"....a number of new innovations have now made wood a viable construction material again, including for use in high-rise buildings"

building<sup>234</sup>. Construction of the 11-storey building (called the 'Framework') is set to commence in the autumn of 2017. The building will utilise a technology known as cross-laminated timber (CLT). It has been extensively tested by Portland State University and Oregon State University. The material passed tests for fire safety<sup>235</sup>, and tests have also shown that CLT designs can withstand large-scale earthquakes<sup>236</sup>.

CLT is a light yet very strong type of plywood, rivalling steel. CLT panels are constructed from small wooden planks bound to one another by a polyurethane adhesive, giving them the strength of traditional construction materials such as concrete

and steel. It can be processed using precision digital manufacturing techniques, such as CNC milling. CLT has a number of benefits, including its environmental properties. CLT panels are claimed to be lighter and less energy-intensive than concrete and steel and much faster to assemble on-site than regular timber.

The grain in each layer is at a right angle to the one below and above it, creating a counter-tension

"CLT panels are claimed to be lighter and less energy-intensive than concrete and steel and much faster to assemble on-site than regular timber..."

built into the panels, which makes CLT strong enough to build tall skyscrapers<sup>237</sup>.

#### **Mass Plywood Panels**

Another new type of panel, known as 'Mass Plywood Panel' (MPP) is set to rival plywood. MPP can be as much 12' wide, 48' long and 2' thick<sup>238</sup>, compared with standard plywood sheets which measure 4' wide, 8' long and between  $\frac{1}{4}$ " - 1" thick. MPP panels are claimed to be very versatile and can be customised for different applications. As a result of their good compression qualities, MPPs can also be used for columns. It is claimed that MPPs can achieve performance characteristics similar to CLT panels, but with 20-30% percent less wood.

#### **4.3.5 Fireproofing and cladding**

The Grenfell Tower fire tragedy in London in June 2017<sup>239</sup>, in which at least 80 people were killed, will place renewed emphasis on safety, particularly regarding fire hazards and fire retardant materials. At the time of writing (August 2017), investigations are ongoing. However, a number of reports suggest that cladding on the building contributed significantly to disaster. Questions will no doubt also be raised with regard to design, building regulations, approval and inspection processes as well as fire-related equipment. Calls will also intensify for the universal retrofitting of more fire protection in tall buildings.

<sup>234</sup><https://www.digitaltrends.com/cool-tech/wood-skyscraper-approved-in-portland/>

<sup>235</sup><https://phys.org/news/2017-06-oregon-city-all-wood-high-rise.html>

<sup>236</sup><https://www.treehugger.com/modular-design/katerra-shaking-construction-industry-literally-and-figuratively.html>

<sup>237</sup><https://phys.org/news/2016-12-wood-technology-struggling-timber.html#nRlv>

<sup>238</sup><https://phys.org/news/2016-11-prototype-plywood-panels-world-largest.html#nRlv>

<sup>239</sup><http://www.theconstructionindex.co.uk/news/view/grenfell-tower-blaze-puts-cladding-system-in-the-dock>

Cladding is used in part to insulate buildings as well as to improve their appearance. However, it has been suggested that cladding can also act like a 'chimney' for flames by allowing the fire to spread upwards through the gaps between the cladding and the building walls<sup>240</sup>.

Grenfell Tower was designed in 1967. Construction commenced in 1972 and was completed in 1974 by Kensington and Chelsea London Borough Council. The building underwent an £8.6m refurbishment, which was completed in May 2016. It had 24 storeys and 127 flats, and was used as social housing in June 2017, when it was destroyed by a fire.

In 1968 a gas explosion caused the collapse of the 22-story Ronan Point building in the UK. Building regulations were reviewed following the Ronan Point incident. A number of people were killed when a fire occurred in the 14-storey Lakanal House in Camberwell in the UK in 2009. At the time, there were renewed calls for another review of building regulations.

Two other large tower blocks were also ablaze recently. At least three people died when a fire erupted in 39-storey condominium in Honolulu, Hawaii in July 2017. It was reported that the building did not have a sprinkler system. The Dubai Torch, one of the tallest residential skyscrapers in the world (86 storeys, 335m) caught fire early in August 2017, the second time in two years. No injuries or fatalities were reported.

Metro, The Times, BBC

The cladding used on London's Grenfell Tower was supplied by the US firm Arconic. It ceased global sales of the product for use in high-rise blocks soon after the disaster<sup>241</sup>, and was quoted as saying, "We believe this is the right decision because of the inconsistency of building codes across the

world and issues that have arisen in the wake of the Grenfell Tower tragedy regarding code compliance of cladding systems in the context of buildings' overall designs". The company confirmed that Reynobond PE (polyethylene), an aluminium composite material, was "used as one component in the overall cladding system" of the block.<sup>242</sup>

On 26 June 2017 it was reported that Arconic's share price had fallen<sup>243</sup> after the Grenfell tragedy, and on 14 July 2017 it was reported that Arconic was being sued by one of its shareholders for losses he claimed he suffered because of the drop in share price<sup>244</sup>.

Towards the end of July 2017 it was reported that tests of the types of materials used in the Grenfell Tower suggest "that designs like that used in the tower's cladding are fundamentally flawed" and that "the cladding was the critical component that spread the fire".<sup>245</sup>

On 3 July 2017 it was reported that of 181 tower blocks tested for flammability, all had failed<sup>246</sup>. On 27 July 2017 it was reported that the largest provider of student accommodation in the UK may need to close 600 rooms as a fire precaution, and spend up to £2 million to replace cladding<sup>247</sup>. An initiative to install more sprinklers in council blocks was also announced<sup>248</sup>. On 28 July 2017 it was reported that 82 buildings had failed a fire safety test, set up after the Grenfell Tower tragedy. Of these, 47 were local authority or housing association-owned or managed. On 2 August 2017 it was reported that 111 buildings in the UK had failed the latest fire test<sup>249</sup>.

It was reported on 27 July 2017 that the UK government had begun work on a review of building standards<sup>250</sup>. At the time, it was estimated that there are circa 30,000 buildings in the UK fitted with cladding similar to that on Grenfell Tower<sup>251</sup>.

<sup>240</sup> <http://www.telegraph.co.uk/news/0/cladding-fire-risk-grenfell-tower/>

<sup>241</sup> <http://www.bbc.co.uk/news/uk-40409981>

<sup>242</sup> <http://abcnews.go.com/International/manufacturer-arconic-end-sales-paneling-grenfell-tower/story?id=48286188>

<sup>243</sup> <http://abcnews.go.com/International/manufacturer-arconic-end-sales-paneling-grenfell-tower/story?id=48286188>

<sup>244</sup> <https://www.thetimes.co.uk/article/8edd9e14-680d-11e7-9755-334d14a02d15>

<sup>245</sup> <http://www.bbc.co.uk/news/uk-40735851>

<sup>246</sup> <http://www.mirror.co.uk/news/politics/181-tower-blocks-tested-flammability-10731319>

<sup>247</sup> <https://www.thetimes.co.uk/article/00bcc32e-723c-11e7-83f1-667fdd1d78f>

<sup>248</sup>

<http://www.theconstructionindex.co.uk/news/view/croydon-plans-sprinkler-programme-in-response-to-grenfell>

<sup>249</sup> <http://www.bbc.co.uk/news/uk-40809206>

<sup>250</sup> <http://www.bbc.co.uk/news/uk-40735851>

<sup>251</sup>

<http://www.theconstructionindex.co.uk/news/view/cr>

### **Investigating other building failures**

The Chartered Institute of Building (CIOB) announced in June 2017 that a commission to investigate build quality was to be set up. The CIOB investigation was prompted by the Cole Report which was published in the wake of a wall failure at Osgangs Primary School in Edinburgh in January 2016. The report had taken on a new significance following the Grenfell Tower tragedy.

The Royal Incorporation of Architects in Scotland (RIAS) noted in its evidence to the Cole inquiry that the core issue behind the wall collapse was lack of independent supervision. It has been suggested that at both Osgangs and Grenfell Tower, any build quality issues were not readily apparent after project completion; and that they would have only come to light through independent inspection during construction when wall tie fixings (in Osgangs' case) and materials (during Grenfell's recent refurbishment) were evident<sup>252</sup>.

#### **4.4 Interesting innovations and innovators - lifting the limits**

In this section we describe two interesting innovations in construction. The first regards the Golden Gate Bridge in San Francisco, the longest suspended bridge span in the world when it opened in 1937. The question is posed: If the bridge had to be designed and built today, would new technologies enable us to do better?

The answer to this question provides an important lesson - new technologies enable inherent design constraints posed by older technologies to be lifted. Rather than merely trying to incrementally improve the performance of the old design, new technologies enable an entirely new design solution, with significantly enhanced benefits. The second case illustrates a very recent demonstration of the same principle. It describes a new type of lift, which has the potential to revolutionise the way people move vertically and horizontally in buildings.

Perhaps more significantly, it also has the potential to lift<sup>253</sup> design constraints inherently imposed by current lift technology, particularly limitations to the height of buildings – at least with regard to limits imposed by lifts. This

development now allows new 'blue sky thinking' about how high buildings can be built.

“...an important lesson - new technologies enable inherent design constraints posed by older technologies to be lifted. Rather than merely trying to incrementally improve the performance of the old design, new technologies enable an entirely new design solution, with significantly enhanced benefits”

##### **4.4.1 If you had to design the Golden gate bridge today.....<sup>254</sup>**

When the Golden Gate Bridge opened in 1937, it was the longest suspended bridge span in the world with a span of 1,280 m<sup>255</sup>. The suspension bridge has no intermediate supports or pillars, and cables hold up the roadway between two towers over its entire span. The cost of the bridge at the time was US\$37 million, about US\$1 billion in today's money. It is interesting to pose the question: If the bridge had to be designed and built today, would new technologies enable us to do better?

Reducing the weight of bridge would be one of the major design aims. The self-weight of a bridge is typically responsible for 70–80% of the maximum load it can bear before it breaks. If this can be reduced, the bridge's structure would need less strength, allowing for cheaper and simpler design choices. What is very important, though, is the fact that if the self-weight can be reduced enough, entirely different types of bridges, other than a suspension bridge, could be considered. Another type of bridge could, in turn, bring many benefits (including the elimination of the suspenders).

<sup>252</sup> [oydon-plans-sprinkler-programme-in-response-to-grenfell](http://www.theconstructionindex.co.uk/news/view/ciob-launches-investigation-into-build-quality)

<sup>253</sup>

<sup>254</sup> [http://www.theconstructionindex.co.uk/news/view/ciob-launches-investigation-into-build-quality](https://theconversation.com/how-would-engineers-build-the-golden-gate-bridge-today-77846)

<sup>255</sup> ... pardon the pun

<sup>256</sup> [https://en.wikipedia.org/wiki/Golden\\_Gate\\_Bridge](https://en.wikipedia.org/wiki/Golden_Gate_Bridge)



San Francisco Golden Gate bridge

Modern materials are light, strong and durable in addition to having other desirable characteristics. This would be major focus of our approach to the set problem. The use of fibre reinforced polymers (FRPs), for example, rather than steel or concrete

can reduce the weight of a large structure. The steel cables in use on the bridge are corrosive and four times

heavier than newer materials. They can also fail in harsh moisture and temperature environments (as is prevalent in that part of California). Carbon cables are now commonly used and are more inert. Other lighter materials could also be used in other elements of the bridge. For example, plastic composite decking could bring the bridge's deck self-weight down by a factor of five. In addition, a modern damping system could be used, which will be more effective to resist seismic, traffic and wind forces. And BIM would definitely be used in the design and construction of the bridge.

 A video clip showing the building of the Golden Gate bridge can be seen [here](#)

#### 4.4.2 A cable-free, horizontal-vertical lift

The lift<sup>256</sup>, which is used to move people and goods vertically in buildings, was invented more than 160 years ago. There are currently circa 12 million lifts in use in buildings across the world. It is also

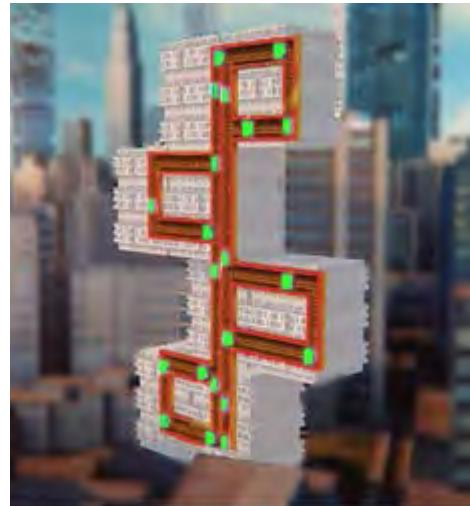
<sup>256</sup> Also referred to as the 'elevator' in some parts of the world...

<sup>257</sup>

<http://www.theconstructionindex.co.uk/news/view/trailblazing-elevator-makes-world-debut>

interesting to note that the number of buildings taller than 200m has tripled since 2000. More than 180 buildings currently being built will be more than 250m high.

A new innovation, the Multi lift, was recently announced by ThyssenKrupp<sup>257,258</sup>. This innovation has the ability to transform the industry at large and change the way tall buildings are conceived. Importantly, it allows for much more efficient core designs, as well as better connectivity in buildings. The new Multi lift is currently being installed in a building in Berlin. It may be possible to retrofit the Multi to existing buildings.



The ThyssenKrupp 'Multi' lift system  
(after ThyssenKrupp schematic)

The Multi allows multiple lift cabins to run in a loop<sup>259</sup>, with no cables or ropes necessary. The cabins use a magnet-based drive system similar to that used in Maglev trains. A number of cabins travel simultaneously. They can move vertically as well as horizontally, since no cables are required. The cabins can also overtake one another and move out of the way to let another pass.

The weight of the cables is of the greatest limiting factors in traditional lifts, in addition to restricting the movement of the lift to vertical movement in a linear manner. In very tall buildings, this mandates that more than one lift must be used to reach the upper floors. By eliminating the cables (and their

<sup>258</sup><https://eandt.theiet.org/content/articles/2017/06/multi-cabin-german-ropeless-lift-could-revolutionise-design-of-tall-buildings/>

<sup>259</sup> <http://inhabitat.com/thyssenkrupp-unveils-worlds-first-cable-free-horizontal-vertical-elevator/>

self-weight), the Multi eliminates a fundamental constraint (weight) previously imposed by lifts on the design and height of buildings.

The Multi has a smaller physical footprint than traditional lifts. It also has a reduced carbon footprint and uses as much as 60% less peak energy than traditional lifts. The cabin is made of carbon composites, which reduces its weight by 50%.

Lifts also tend to become time bottlenecks. It is estimated that in New York City, workers wasted circa 16.6 years waiting for lifts just in 2011. Because of the multiple cabins moving around the system, passengers will only need to wait 15-30 seconds for the next lift.



**Video clips showing the ThyssenKrupp 'Multi' lift can be seen [here](#) and [here](#)**

## 5. 'Construction workforce, skills, training and education'

The emerging technologies discussed in this report will have a profound effect on the future of the construction workforce and labour market, skills requirements as well as training and education. Automation and robotics in particular, will impact on employment and careers in construction.

Several countries are reporting labour shortages in the construction industry, including the US, UK and Australia.

The Farmer Review<sup>260</sup> (2016) notes that the "real ticking 'time bomb' in the UK is that of the industry's workforce size and demographics. Based purely on existing workforce age and current levels of new entrant attraction, we could see a 20-25% decline in the available labour force in the next decade. This scenario has never been faced by UK construction before and would be a capacity shrinkage that would render the industry incapable of delivering the levels of GDP historically seen. Just as importantly, it would undermine the UK's ability to deliver critical social and physical

infrastructure, homes and build assets required by other industries to perform their core functions".

The Chartered Institute of Building in the UK reports that the number of workers over 60 is rising<sup>261</sup>. A third of the UK's construction workers is older than 50 and it is estimated that circa 620,000 will retire within the next decade<sup>262</sup>. At the same time the number of workers under 30 is decreasing faster than any other segment.

The National Association of Homebuilders in the US reports that 82% of construction companies consider their main concern to be a shortage of construction workers.

"It has been estimated that circa 40% of construction jobs [in the US] were eliminated between April 2006 and January 2011. Those workers have moved elsewhere and have not returned to construction. The safety hazards of working in construction may also be one of the factors contributing to the labour shortages in construction in some countries. An increased focus on safety, aided by emerging technologies, can contribute towards relieving this pressure...."

Siemens

Emerging technologies and the adoption of new technologies require new skills sets and competences, creating new jobs in the process. However, other skills become obsolete as the technologies they match become obsolete or are replaced by newer technologies. As the new technologies and their skills requirements phase in, this creates a dilemma for workers currently in the labour market.

In order for the construction sector to enhance its productivity, it will require a more agile workforce with new skills. McKinsey<sup>263</sup> identifies reskilling of the workforce as another one of the seven important ways in which construction productivity can be improved. They estimate that global construction productivity can improve by 5-7% if best-practices in on-site execution are adopted,

<sup>260</sup>

[http://www.theconstructionindex.co.uk/news/vie\\_w/farmer-review-government-response](http://www.theconstructionindex.co.uk/news/vie_w/farmer-review-government-response)

<sup>261</sup>

<https://www.weforum.org/agenda/2017/05/construction-industry-recruit-talent/>

<sup>262</sup><http://nypost.com/2017/03/27/this-bricklaying-robot-is-going-to-destroy-construction-jobs/>

<sup>263</sup><http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/reinventing-construction-through-a-productivity-revolution>

with potential cost savings of 3-5%. They recommend building an apprenticeship model,

**"By 2050 construction sites will be mainly populated by robots working in teams using 'dynamic new materials', with many components self-assembling. The only humans working there will be wearing 'robotically enhanced exoskeletons' controlling machinery..."**

Balfour Beatty

developing frontline training and ensuring knowledge retention and management.

Once the basics are in place, the focus should shift to the introduction of e-enabled micro-training for frontline workers, a mix

robots, for example, will have an impact on the labour requirement for bricklayers<sup>266</sup>, but at the same time creates jobs for operators and maintenance people.

- A new training and education ecosystem needs to be developed, so that a new generation of workers can be trained for the new types of jobs. Very often, workers currently in the sector require additional training to update and upskill, so that they can use new technologies effectively. It is not uncommon for new technologies to be branded as 'not delivering on expectations', when in reality the technologies were not deployed and used in ways which optimise their ability and contribution.

of classroom and field-based training, and the creation of internal academies to institutionalise best practices.

Labour shortages may also speed up the adoption of new technologies, particularly with regard to automation<sup>264</sup>.

The adoption of new technologies will no doubt enhance the productivity of the construction industry significantly. In order for these innovations to be effective, a number of other things also need to change, such as business models and ways of working. This often implies significant changes in the affected sector's labour market.

When an industry is disrupted by a new technology, it is very typical to find that:

- New types of skills are required, and at the same time current and skills associated with mature technologies and business models become redundant. The World Economic Forum (WEF) predicts that over 400,000 jobs in architecture and engineering will be required in the future<sup>265</sup>.
- Automation often means that less people are required for jobs that can be done with machines. At the same time, new types of jobs become available, albeit jobs which require new types of skills. The use of bricklaying

"Germany's automotive sector has the highest robot density in Europe (circa 1,150 industrial robots/10,000 employees). 'As a result... employment in the German car industry rose by about 93,000 jobs in the period 2010 to 2015.' Similar trends can be observed in the UK and in America..."

Siemens

### **Generational preferences**

Generational and social trends will also have an effect on the labour market. We can anticipate that the influx of 'digital natives' will accelerate the digitalisation of the construction industry<sup>267</sup>. Digital natives are people who were born into the digital age and who embrace digital and mobile technology – in fact, they expect its prevalence and cannot imagine another world. They will soon represent the largest part of the total global workforce.

In contrast, many of the current generation are 'digital immigrants', who are not always comfortable adopting digital technologies, particularly not at a rapid pace at which it is developing. If these people are senior decision-makers, their biases and digital-scepticism may prevent or slow down the adoption of new and emerging technologies, and have a negative impact on the fortunes of the companies they manage.

<sup>264</sup><http://www.industrytap.com/3d-printed-construction-saves-80-overall-building-costs/43156>

<sup>265</sup><http://www.constructionworld.org/6-ways-robotics-transforming-construction-industry/>

<sup>266</sup><http://www.cornwalllive.com/this-bricklaying-robot-could-put-thousands-of-workers-in-cornwall-out-of-jobs/story-30282827-detail/story.html>

<sup>267</sup><https://www.thebalance.com/what-influx-of-digital-natives-means-for-construction-845300>

In addition to their affinity for digital and mobile technology, digital natives also seem to have other characteristics by virtue of also being members of the Millennial Generation or Generation Z. It is believed that these generations also value time more than money, enjoy flexibility and remote working, and like collaborating, for example. They shop online, would rarely (if ever) physically go to a bank and defer to an app on their smartphone rather than a 'hardcopy manual'.

Reflecting on discussions at the World Economic Forum on the 'Future of Construction', one commentator noted that "Technology featured prominently throughout the discussions, with the war for talent focused on a millennial generation with different work goals and expectations. Technology was viewed as not just necessary for bridging the skills divide and improving productivity, but for defining the relevance of our industry and profession in a world of digitalisation"<sup>268</sup>.

"It is estimated that 65% of children at school today will work in jobs that do not yet exist..."

The Balance

### ***Education and training requirements for the future***

Indications are that there is a lack of the right sort of education and training programmes to provide the next generation of people in a 'reinvented construction industry', particularly one where new and emerging technologies are prevalent.

Programmes focused on the use and implementation of digitalisation and new technologies are required, but it is also necessary

"SkillsPlanner is an industry-led collaborative project to develop a Linked Data construction skills platform in the UK. It will allow employers, skills providers and other stakeholders to share past, present and future skills data, and support stakeholders to plan for and meet current and future employment requirements"

Farmer Review of the UK Construction Labour Model,  
October 2016

<sup>268</sup><http://www.rics.org/uk/news/news-insight/news/how-to-solve-the-construction-and-engineering-talent-gap/>

to infuse a new mindset and new ways of doing things. Educational and training programmes should be aimed not only at new entrants, but also on upskilling current workers as well as workers in other sectors who may wish to enter the construction industry.

It is important for educational institutions, including universities, further education colleges, technical colleges as well as institutions for younger learners to prepare the next generation construction workforce<sup>269</sup>. The next generation must be able and eager to embrace the new technologies and leverage their potential to the fullest, if the productivity improvements that are so critically important are to be achieved. In order to do so, the educational institutions themselves must champion the new technologies, focus their research on the next generation of emerging technologies and their applications, and proactively develop curricula and learning materials for the next generation of constructors. If not, they will a priori be designing and creating an obsolete workforce.

## **6. Discussion**

This report focuses on the impact of emerging technologies on the construction industry, with an emphasis on recent trends.

The vantage point of DeltaHedron's approach is one of exploring the impact and the strategic business opportunities, risks and threats presented by emerging technologies and technological change. These insights support decision-making and underpin the development and implementation of corporate innovation strategies, informed by an assessment of companies' own technological capabilities and dependencies.

### **6.1 A strategically important industry, ripe for disruption**

Construction is a large industry which is of strategic importance on the regional, national and global levels. It is also an industry which has been suffering from a number of problems for many

<sup>269</sup><http://www.constructiondive.com/news/how-colleges-companies-can-work-together-to-develop-future-construction-le/440368/>

decades, including low productivity, low profit margins, waste and safety concerns.

A number of forces are pressuring for change and there are calls for a ‘reinvention of construction’. Many agree that the construction industry is indeed ripe not just for change, but for a much more serious disruption.

A range of emerging technologies, including those which will enhance digitalisation and automation of the industry as well as new materials, will be catalysts and accelerators for the disruption.

## **6.2 Embracing innovation**

The construction industry’s general risk averseness, resistance to change and ‘lack of innovativeness’ are fundamental to many of its other woes.

**The key is for the construction industry, as well as individual companies, to embrace innovation in its broadest sense. An innovation mindset and culture must be developed and the pursuit of a quest for innovation and the ‘innovation premium’ should be fundamental objectives.**

Technological innovation is important, but it should be blended with other types of innovation such as business model and organisational innovation to achieve ultimate business success.

Equally important is the recognition of the importance of different innovation modes. Focusing on incremental innovations alone is a flawed and unsustainable strategy. They are important elements to achieve continuous improvement, but this should not become a comfort zone and a cover for resistance to fundamental change when that becomes necessary. The impact of incremental innovations have a tendency to run their course, and their further pursuit then becomes one of diminishing returns. Very often this is the time when radical and disruptions are required to bring renewal and stimulate growth. The construction industry seems to have reached that point.

## **6.3 Opportunities, risks and threats**

The disruption of an industry brings huge opportunities for those who seize them. This is true for the construction industry as well. A number of progressive companies in the industry are already riding the next wave. They have digitalised and are

adopting innovative business practices and emerging technologies.

As is often the case when industries are disrupted, there will also be successful new entrants. The new entrants will leverage new technologies and typically also bring new organisational cultures and industry dynamics, new business models and new best-practices, some of which were developed in other industries. In fact, some of the new entrants will no doubt come from other sectors – such as manufacturing.

‘Constructech’ start-ups, analogous to the fintechs and insurtechs which are disrupting the financial and insurance

industries, will also contribute to the disruption of construction and fill industry niches where they have competitive advantages.

At the same time, the impact of the emerging technologies also pose risks and threats for industry laggards who fumble the future. This is not a time for companies in the construction industry, governments for that matter or those who are considering entering the industry, to be complacent.

It is also not uncommon for the industry hierarchy to change, with new companies emerging as industry leaders.

## **6.4 Technology-related trends**

A number of trends in the construction industry are technology-related, either driven to a large extent by digitalisation and other emerging technologies, or impacted by technology. These include the greening of construction, smart buildings, modularisation and off-site manufacturing.

## **6.5 The impact of emerging technologies**

A number of emerging technologies are collectively driving change in the construction industry. They will have a transformative impact on the industry and contribute towards addressing the challenges it faces.

### **6.5.1 Digital transformation and digitalisation**

Digital transformation is one of the most significant global trends. It impacts every sector of

**‘Constructech’ start-ups... will also contribute to the disruption of construction and fill industry niches where they have competitive advantages.**

society, driving progress, economic growth and quality of life. No industry is left untouched.

The construction sector has exhibited very little productivity growth during the last two decades. Mindful that there is a direct correlation between the extent to which an industry is digitalised and productivity growth, it is not surprising to note that construction is one of the least digitalised industries.

**“Digitalisation of the construction industry is one of the forces which will accelerate disruption....”**

Digitalisation of the construction industry is one of the forces which will accelerate disruption. Digital-related technologies such as mobile and cloud-based applications will underpin a number of other emerging digital and data technologies. These will in turn enhance the quality of data driven decision-making and productivity.

As part of the digitalisation process, the construction industry will increasingly adopt practices which are common cause in other industries, such as software-as-a-service (SaaS), Enterprise Resource Planning (ERP) and bring-your-own-device (BYOD). Emerging data technologies such as big data, analytics and artificial intelligence (AI) all have applications in the construction industry, and will multiply the impact of digital transformation as they have done in other industries; as will virtual reality (VR) and augmented reality (AR), Building Information Modelling (BIM), the Internet of Things (IoT), geolocation and blockchain.

Collectively, digital emerging technologies will enhance logistics, supply chains and procurement. An interesting development is the emergence of digital markets in building materials, in which constructechs have taken the lead. Similarly, the market for peer-to-peer rental of equipment, which is enabled by data sharing platforms.

Increased digitalisation brings with it greater cyber security risks, posed not only by viruses, malware and ransomware which can disable and disrupt systems, but also criminal cyber activity which include the theft of commercially sensitive and personal data. These incidents carry significant legal, financial, reputation and operational risks.

### 6.5.2 Automation technologies

A number of emerging technologies are contributing to the automation of construction, lending weight to the notion of ‘construction as a manufacturing process’. They will contribute significantly to productivity enhancement.

3D printing is finding increasing applications in construction, including the printing of parts and models, but also modular panels and even entire buildings. There are many reports of buildings being 3D printed in a matter of days, often combined with modular off-site manufacturing. Large 3D printers specifically designed for construction use a technique known as ‘contour crafting’, with cement as the ‘ink’.

Robotics is also set to impact on construction, ranging from robots involved in site preparation and waste clearance to brick laying and welding.

Drones and autonomous vehicles have many construction applications. Drones can be fitted with a range of image, video and related sensors. This enables them to conduct aerial mappings and surveys, safety inspections as well as recordings of project progress. In addition, they also find application in data relay, site security and safety.

Wearables refer to textiles and other devices worn by a person, which can send (and receive) information gained from IoT sensors. The information can reflect the person’s physical and emotional state, movement or position as well as other environmental variables.

### 6.5.3 New materials

By their very nature, new builds and retrofitting consume vast amounts of construction materials. Trends in materials of the future will redefine how projects are conceptualised, designed and executed as well as the life cycle trajectories of the projects. Given the volumes, even small improvements in performance can have significant impact productivity, durability and safety; and similarly for reductions in cost.

Concrete and steel remain widely used, with work continuing to improve the performance of both.

Recent advances have seen the emergence of lighter, more flexible and versatile forms of concrete, including self-consolidating, self-healing and self-compacting concrete.

A number of innovative alternative materials with promising construction applications are emerging. These include, for example, ETFE which is 99% lighter and also stronger, eco-friendlier, better at

light transmission and more flexible than glass; permeable concrete replacements which can absorb significant amounts of water and insulating materials as well as adhesives. Kinetic materials have the ability to convert movement to energy, and can be used in flooring and roads.

There are signs of a resurgence in the use of wood and timber, fuelled by the emergence of cross laminated timber (CLT) panels and related products. CLT panels are strong, light and durable, and their use has been approved for use in high rise buildings.

Following the Grenfell Tower fire tragedy in London in June 2017, there will be a renewed focus on the use (or not) of cladding and fire retardant materials as well as building codes, planning and inspection to prevent and contain fires.

Green construction materials will no doubt become increasingly prevalent, driven in part by regulations, demand from customers who are more environmentally sensitive as well as economic benefits. We will probably also see the need for suppliers of green construction materials to prove that the materials have procured from green and eco-friendly sources, in a manner similar to which there is a requirement for consumer products to be ethically sourced. These may be tied to existing green credentials such as BREEAM and LEED.

## **6.6 Workforce, skills, training and education**

A number of countries are experiencing labour shortages in construction, including the UK, US and Australia. It is also not easy to attract new talent. The global financial crash of a decade ago is still reverberating, but the industry's image, safety record and other challenges are not helpful either.

Disruption of the construction industry will necessarily have an impact on the labour market, driven in part by the emerging technologies and the dynamics of technological change.

As new technologies emerge, the nature of work and jobs change. It is typical for disrupted industries to experience technology-related labour upheavals, particularly during transitional periods. New types of jobs requiring new types of skills emerge. As mature technologies become obsolete, the jobs and skills they require, phase out.

The construction industry desperately needs to improve its productivity. This will provide further impetus for the increasing prominence of

productivity enhancing technologies and practices, such as off-site modular construction, 3D printing, robotics and drones. The adoption of these technologies will lessen the demand for some skills currently required in construction, but will also precipitate the creation of new jobs, requiring new skills.

The use of data driven technologies such as big data, analytics, machine learning and artificial intelligence will similarly also change the nature of work in construction-related professions such as architecture, quantity surveying, building management and perhaps also structural engineering.

The next generation of construction workforce will work in a industry which differs in many respects from the industry we know today. Many of the young people entering the industry will be 'digital natives', who will naturally accept, if not demand, digitalisation. They need to be prepared for the new types of jobs which will be required in the new digitalised and automated construction world – many of which don't even exist today.

### ***Education and training***

Universities and other training institutions need to embrace the emerging new technological regime in construction. They need to focus research and enterprise on the development and enhancement of the new technologies and related business practices and ensure that their curricula are designed to train constructors who can create the future. Perhaps we should also consider the notion of disruption when thinking about construction education.

It is also necessary to ensure that the current workforce understands the new technologies and the benefits and opportunities they bring; as well as the risks and threats of ignoring them. Senior decision-makers in particular need to take note – it is very much in their gift to embrace innovation and benefit from the innovation premium, and to adopt emerging technologies and lead the disruption charge.

The question is not so much "what will it cost?", but rather "what will it cost if we don't do it?".

## **6.7 Recommendations**

From a strategy viewpoint, decision-makers in construction companies as well a governments need to consider the broader evolving landscape and the drivers which will contribute to the disruption of the construction industry.

The impact of emerging technologies is one those drivers, albeit a very important one. They will be catalysts and accelerators for change.

It is important for companies to recognise the strategic importance of a structured approach to the management of innovation, and particularly technological innovation. An innovation strategy should be an integral part of the corporate strategic plan.

The dynamics of technological change will always impact on the fortunes of companies and countries. Emerging technologies will continue to substitute and replace mature technologies, and disrupt industries.

Companies should consider the importance of formally assessing their 'technology dependencies' as part of the risk management process. They should gain an understanding of which technologies they critically depend on and rely, whether it be technologies which constitute their (current) competitive advantages, underlie the products they make, services they render, are used

in their operations or on which their logistics and supply chain and customers rely. At the same time, they should be mindful that the same applies for their competitors.

Assessing the impact and the strategic business opportunities, risks and threats presented by emerging technologies and the dynamics of technological change should be integral elements of the innovation strategy of companies in the construction industry.

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Does your company have an innovation strategy – and if so, can you describe it and determine whether it is working? If not, do you sometimes find yourself wondering what happened.... not even to speak of what can happen and which interventions should be made to shape the future?



DeltaHedron's business offices are located in the **Centre for Digital Innovation (C4DI)** - a vibrant private technology business incubator located in the centre of Hull.

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[www.c4di.technology](http://www.c4di.technology)

## Appendix: 'Instead of trying to see the future, start making it'

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# Instead of trying to see the future, start making it

**Dr Calie Pistorius,  
chief executive of  
DeltaHedron, says  
that companies  
must stay abreast  
of the latest  
technologies in  
order to remain  
competitive**

**A**nticipating an actionable future enables a proactive shaping of the future, rather than merely reacting to a world predetermined by others. The fate and fortunes of companies, irrespective of the business they are in, are closely linked to the technologies on which they rely to conduct their business.

It is the dynamics of technological change, whether incrementally or disruptive, in products, processes and services, which drive innovation and progress. Emerging technologies present great opportunities, but also strategic business risks and threats to companies' and industries' products, operations, supply chains, logistics, business and manufacturing processes. The strategic business risk here is as much about failing to exploit the opportunities as it is about the threat of an adverse event.

Technologies are continuously being improved, leading to "better, faster and cheaper". At the same time "last year's hot model" becomes obsolete. Some technologies evolve at a gentle and incremental pace, whereas others change rapidly. From time to time the technological, business and societal landscapes are disrupted by radical innovations, often coming from unexpected and different industries to the one in which they impact.

The disruptions typically result from the interaction of a combination of emerging technologies blending with innovations from other fields, be it finance, fashion or fitness. Many emerging technologies are IT-based, including big data and analytics.

However, the disruption can just as easily come from new materials, drones, robotics, 3D printing, virtual and augmented reality, biometrics or the Internet of Things.

Technological innovations spawn new opportunities, jobs and careers, business models, companies and industries; new ways of doing things and new sources of prosperity. When a new technological order is established, expect the industry hierarchy to change. New companies, in fact new types of companies, become the new industry leaders, often those that had no position in the old technology. The "wave of creative destruction" tends to destroy the established structure, triggering the demise of old technologies, labour markets, jobs and skills and eventually also companies and industries based on the old and obsolete technologies.

There are many examples of those who have created successful new futures underpinned by new technologies. Similarly, there are many who have perished whilst fumbling the future, who have been in denial and steadfastly clung to the obsolete, ignored the precursor indicators signalled by emerging technologies or deployed ineffective innovation strategies to deal with them. It is not unusual to find that their organisational cultures just could not embrace the technological change, often causing the transition to a new technology to, if it made, to be bungled.

Anticipating what can happen in the future is one thing, knowing what to do about it is quite another. As is the case with all business risks, the process of technological innovation and the associated opportunities and strategic business risks – especially those presented by emerging technologies – should be managed, and managed within the context of an innovation strategy which is an integral part of the corporate strategy. Vigilant and continuous tracking of emerging technologies and assessing their impact are essential elements of this process.

**For more information, visit:  
[www.deltahedron.co.uk](http://www.deltahedron.co.uk)**

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# DeltaHedron Innovation Insight

## *The impact of emerging technologies on the construction industry*

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**Dr Calie Pistorius** is the Chief Executive and Principal Consultant of DeltaHedron Ltd, and has extensive experience of consulting and research in the management of technological innovation. He is a former Chair of the *National Advisory Council on Innovation* in South Africa, former Vice-Chancellor of the University of Hull in the UK and Emeritus Vice-Chancellor and Principal of the University of Pretoria in South Africa, where was also the Director of the *Institute of Technological Innovation*. He is registered as a Chartered Engineer in the UK and holds a PhD degree in electrical engineering from the Ohio State University, a masters degree in the management of technology from the Massachusetts Institute of Technology, a bachelors degree in electronics engineering from the University of Pretoria and is an alumnus of Harvard Business School.



DeltaHedron Ltd is a UK-based business consulting firm specialising in the management of technological innovation. We support our clients with the development and implementation of innovation strategies, underpinned by an assessment of the strategic business opportunities, risks and threats presented by emerging technologies and the dynamics of technological change.

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