WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

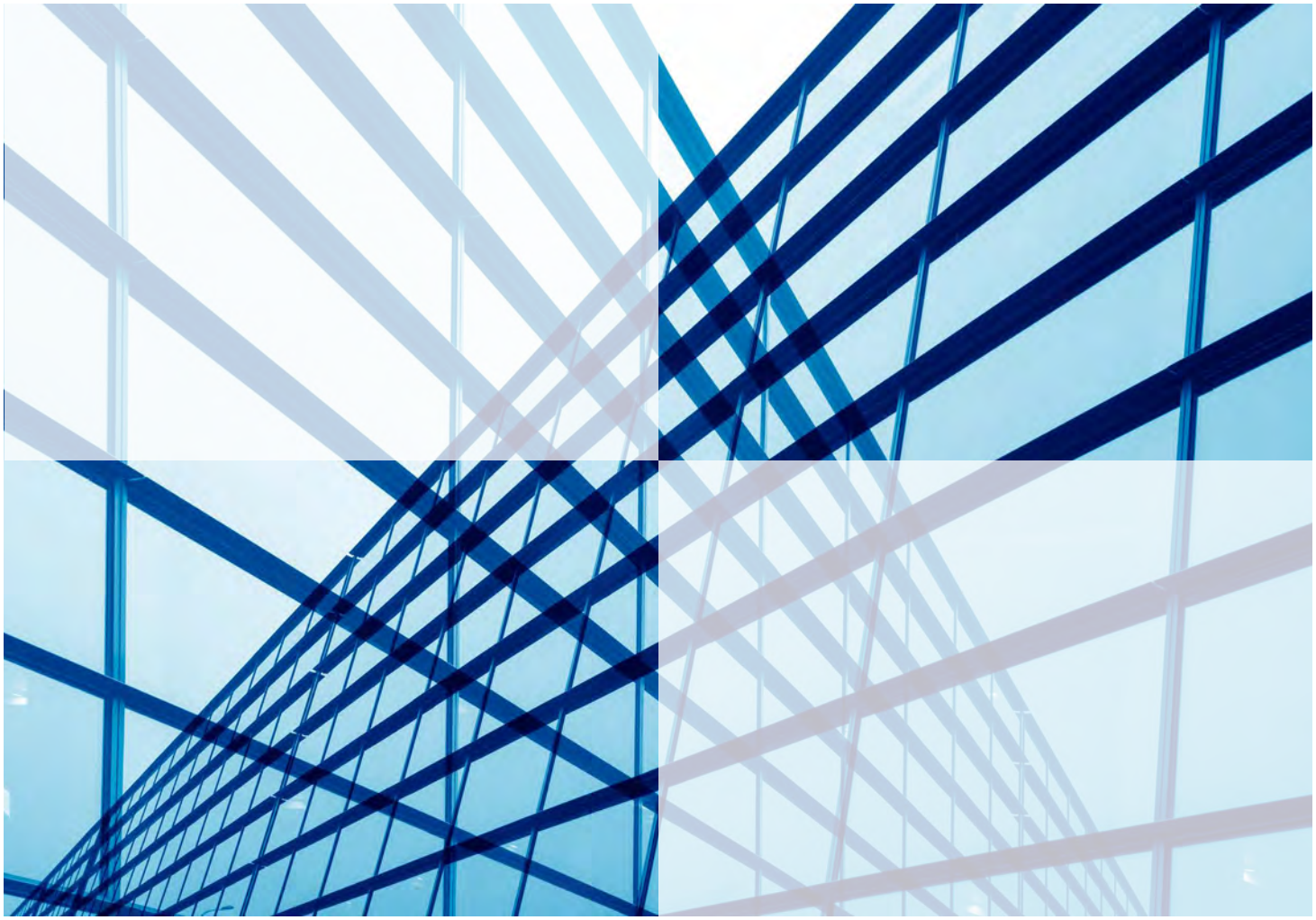
Industry Agenda

Shaping the Future of Construction

A Breakthrough in Mindset and Technology

Prepared in collaboration with The Boston Consulting Group

May 2016



Content

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Forewords

Foreword from the World Economic Forum

The world is changing faster than ever before. Consider just one of the global megatrends shaking up the construction industry: the population of the world's urban areas is increasing by 200,000 people per day, all of whom need affordable housing as well as social, transportation and utility infrastructure. In the face of such challenges, the industry is almost under a moral obligation to transform. Its transformation will have transformative effects elsewhere: on the wider society, by reducing construction costs; on the environment, by improving the use of scarce materials or by making buildings more eco-efficient over time; and on the economy, by narrowing the global infrastructure gap and boosting economic development in general.

While most other industries have undergone tremendous changes over the last few decades, and have reaped the benefits of process and product innovations, the Engineering & Construction sector has been hesitant about fully embracing the latest technological opportunities, and its labour productivity has stagnated accordingly. This unimpressive track record can be attributed to various internal and external challenges: the persistent fragmentation of the industry, inadequate collaboration with suppliers and contractors, the difficulties in recruiting a talented workforce, and insufficient knowledge transfer from project to project, to name just a few.

The industry has vast potential, however, for improving productivity and efficiency, thanks to digitalization, innovative technologies and new construction techniques. Consider the rapid emergence of augmented reality, drones, 3D scanning and printing, Building Information Modelling (BIM), autonomous equipment and advanced building materials – all of them have now reached market maturity. By adopting and exploiting these innovations, companies will boost productivity, streamline their project management and procedures, and enhance quality and safety. To capture all this potential will require a committed and concerted effort by the industry across many aspects, from technology, operations and strategy to personnel and regulation.

This report begins with an assessment of the industry's present state and the global trends that will impact on the industry. It then introduces a conceptual industry-transformation framework, listing a number of measures, grouped in eight topical areas, that would profoundly change the industry system. The measures are classified into three groups: measures taken by private companies on their own; measures taken by companies in collaboration with their peers – or by the industry as a whole; and measures taken by the government, acting both as the regulator and as a major project owner. For each of the topical areas, the report identifies current best practices, and provides illustrative case studies of innovative approaches, to prepare for the industry's transformation. The eight topical areas are:

- Technology, materials and tools
- Processes and operations
- Strategy and business model innovation
- People, organization and culture
- Industry collaboration
- Joint industry marketing
- Regulation and policies
- Public procurement

The World Economic Forum Future of Construction project is a collaborative endeavour, aimed at supporting the Engineering & Construction sector as it pursues its transformation. (Collaboration is, or should be, a hallmark of the construction industry itself: the industry's future success will rely heavily on effective collaboration among all stakeholders.) The project is planned as a multiyear effort. In its first year, the project is commencing with this wide-ranging report – a detailed map to help navigate the current industry transformation. Subsequently, the project will focus on specific topics; for example, the ways that new technologies, materials and processes will improve the project delivery and the life-cycle performance of buildings, and the ways of selecting relevant measures from the industry transformation framework.

The report involved input from a great many companies active along the construction value chain – suppliers of building materials, chemicals and construction equipment; contractors; and engineering, architecture and planning firms – as well as project owners and developers, academics, and leaders from government, civil society, and industry organizations. In this regard, we would like to express our gratitude to the World Economic Forum partner companies that served on the Future of Construction project Steering Committee: Acciona; Aecon; AkzoNobel; Amec Foster Wheeler; ArcelorMittal; Arup; BASF; Consolidated Contractors Company; Danfoss; Essar Group; Fluor; Lixil; Perot Group; SAP; Siemens; Skanska; SNC-Lavalin; Tarkett; and WS Atkins. And we extend a special acknowledgement and particular thanks to John M. Beck (Executive Chairman of Aecon Group Inc.), David T. Seaton (Chairman and Chief Executive Officer of Fluor Corporation) and Uwe Krüger (Chief Executive Officer of WS Atkins) for their unwavering interest in and commitment to the Future of Construction Initiative.

We would also like to thank the many experts who contributed to the report through their role on the Future of Construction project Advisory Committee: Victor Chen Chuan (Sichuan University), James Dalton (USACE), Juan Elizaga (ENCORD), Timothy Geer (WWF), Tiago Guerra (TG International Manager), Shervin Haghsheno (Karlsruhe Institute of Technology), Franziska Hasselmann (University of St Gallen), Markus Kraft (University of Cambridge), Fiona Murie (BWI), Ibrahim Odeh (Columbia University), Aristeidis Pantelias (University College London), Spiro Pollalis (Harvard Design School), Norbert Pralle (ENCORD), Bob Prieto (Strategic Program Management LLC), Aaron B. Schwarz (Plan A Architecture + Design), Douglas Stollery (Stollery Charitable Foundation), Jan Van Schoonhoven (Netherlands Government), Enrico Vink (FIDIC), Edmundo Werna, (ILO), and James X. Zhan (UNCTAD).

The experience, perspectives and guidance of all the above-mentioned people and organizations have informed and enriched a number of remarkable discussions, notably at the World Economic Forum Annual Meeting of the New Champions, Dalian, September 2015; the Future of Construction Initiative Steering Committee, New York, December 2016; and the World Economic Forum Annual Meeting 2016 in Davos-Klosters.

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Foreword from the Infrastructure and Urban Development Co-Chair

The digital revolution of the last half century has made the world a much smaller place – opening markets, creating new products and goods, and facilitating rapid industrialization in emerging economies. The pace of innovation, with improved communication and increased productivity, has been remarkable in many sectors, including health sciences, education and consumer goods. In the automobile industry, for example, robotics, computerized design and a host of other technical and work process innovations have helped to create a global industry that is now more productive and cost-effective, and increasingly environmentally friendly and sustainable.

The Engineering and Construction (E&C) sector has been slower to adopt and adapt to new technologies than other global sectors. While innovation has occurred to some extent on the enterprise or company level, overall productivity in the sector has remained nearly flat for the last 50 years. As an industry based on competitive procurement models, E&C has historically taken a conservative approach to product design and delivery, leading to silos in project management and a somewhat fragmented industry.

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

Our work at the World Economic Forum has focused on *how* the E&C industry can take advantage of new technologies and work processes to move the industry forward. It builds on the Forum's four-year initiative on strategic infrastructure. This report is the first in a multi-year series that will look at the supply side of E&C. It is a call to action for the modernization of the industry and a roadmap for achieving that goal. The report is the outcome of wide-ranging discussions across different sectors and locations; its recommendations derive from best practices not only of the E&C industry but of other industries as well. The report stresses collaboration, a holistic view of project management and information sharing – all critical elements for the future of the E&C industry. For many in the industry, especially in the private sector, this is a new and possibly radical approach, but these elements are the path to a more innovative, productive and socially responsible future. In this report alone, 30 such approaches are detailed, along with examples of supporting best practices.
I would like to acknowledge and thank my co-chair, Ajit Gulabchand (Chairman, Hindustan Construction Company, India) and the members of the Steering and Advisory Committee for their contributions and support.

The "Future of Construction Project" requires the commitment and encouragement of many active participants in our industry – people who believe in a modern E&C industry that will benefit all.

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Context and Objectives of the Report

Scope

This report is the first publication of a multi-year project for guiding and supporting the Engineering & Construction (E&C) industry during its current transformation. The report describes the industry's present state, assesses relevant global trends and their impact on the industry, and devises an industry-transformation framework with key areas for development and action. It also features many best practices and case studies of innovative approaches or solutions, and offers a view – at different levels, such as at the company-, industry- and sector-level – of how the future of construction might look. The project's subsequent phases and reports will deal with specific topics or will explore the subject in depth by geographical region.

The project as a whole, and this report specifically, builds on the findings of an earlier World Economic Forum project – the four-year Strategic Infrastructure Initiative. That initiative identified and described the key government measures needed to close the infrastructure gap, by such means as improving the prioritization of projects, enhancing public-private partnership (PPP) models, improving the operations and maintenance (O&M) of existing assets, and better mitigating risks.[1] During that research, it became evident that important contributions can also be made from the supply side – the E&C industry – in the form of improvements to and innovations in project delivery.

Audience

This report is aimed at all firms active along the construction value chain, including suppliers of building materials, chemicals and construction equipment; contractors; and engineering, architecture and planning firms, as well as project owners and developers. Governments are another target audience, as they not only have an impact on the industry via regulation but also act as the main procurer of most infrastructure projects. Finally, this report is also aimed at members of academia and civil society, in view of the socio-economic importance of the construction industry. The industry will rely on effective collaboration with all stakeholders for its future success.

Executive Summary

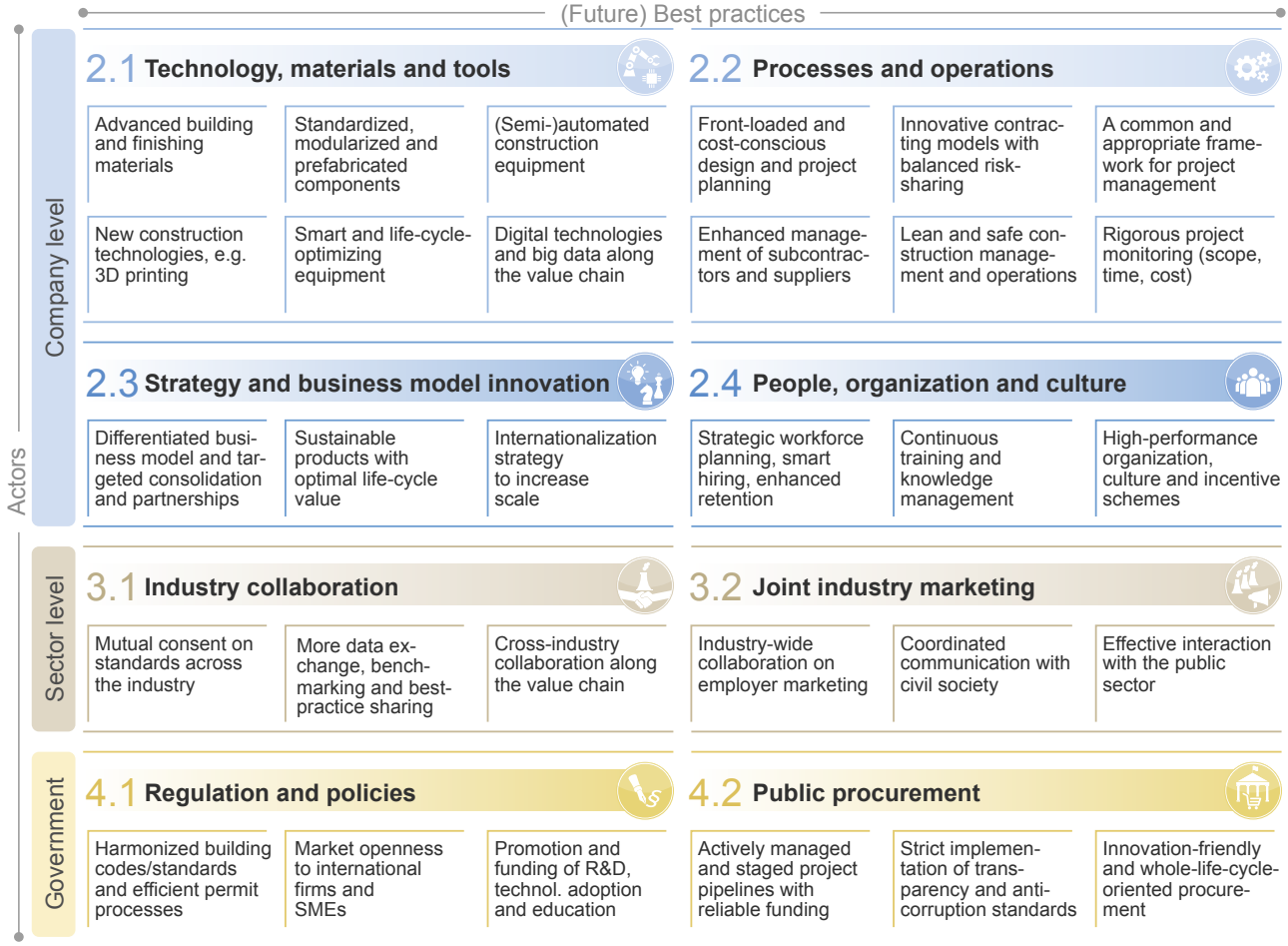
The Engineering & Construction (E&C) industry strongly affects the economy, the environment and society as a whole. It touches the daily lives of everyone, as quality of life is heavily influenced by the built environment surrounding people. The construction industry serves almost all other industries, as all economic value creation occurs within or by means of buildings or other "constructed assets". As an industry, moreover, it accounts for 6% of global GDP. It is also the largest global consumer of raw materials, and constructed objects account for 25-40% of the world's total carbon emissions.

Multiple global megatrends are shaping the future of construction. Consider just two developments: first, 30% of global greenhouse gas emissions are attributable to buildings (at the same time, the UK government has set a target for 2025 of 50% reduction in today's level of greenhouse gas emissions in the country's built environment); second, the population of the world's urban areas is increasing by 200,000 people per day, all of whom need affordable housing as well as social, transportation and utility infrastructure. Such trends pose challenges but also offer opportunities; either way, they require an adequate response from the industry as a whole.

Compared to many other industries, the construction industry has traditionally been slow at technological development. It has undergone no major disruptive changes; it has not widely applied advances in processes such as "lean". As a result, efficiency gains have been meagre. In the United States over the last 40 years, for example, labour productivity in the construction industry has actually fallen.

Given the sheer size of the E&C industry, even a small improvement would provide substantial benefits for society. To capture such potential, this report presents an industry transformation framework (Figure 1) listing 30 measures, supported by many best practices and case studies of innovative approaches. Some of the measures can be adopted by private companies on their own, while others require collaboration with their peers or with other companies along the construction value chain. In addition, some of the measures can be adopted by government, acting both as the regulator and as the major owner of infrastructure projects.

Figure 1: Industry Transformation Framework



Source: World Economic Forum; The Boston Consulting Group

Substantial improvements are already within reach for companies

Companies themselves should spearhead the industry transformation. Tremendous opportunities are available through the application of new technologies, materials and tools. 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.[2]

Building Information Modelling (BIM) plays a central role here, as it is the key enabler of and facilitator for many other technologies: the building of a bridge, for example, can be greatly facilitated by combining robotics and 3D printing via a parametrically designed 3D model.[3] Another extremely powerful lever for innovation is that of construction materials; the associated solutions are numerous and wide-ranging – from incremental innovation of traditional materials and existing characteristics to radically innovative materials with entirely new capabilities. Although many innovative solutions are already being applied on a small scale or in a few countries, the industry still needs a large-scale application or better adaptation of current technological developments. To unlock the potential inherent in new technologies, materials and tools, the industry also needs to adopt the relevant respective processes. For instance, the benefits of BIM are reinforced if companies exploit the new ancillary opportunities it offers – notably, a new way of collaborating and sharing information between stakeholders. Large productivity improvements can be achieved by optimizing existing processes: the broader use of "lean" principles and methods, for instance, could reduce completion times by 30% and cut costs by 15%.[4] Another core lever is early project planning. To improve such planning, companies should promptly draw on the knowledge of all stakeholders, and should explore new contracting models. A minimal increase in upfront costs of about 2% to support optimized design will lead on average to life-cycle savings of 20% on total costs.[5]

Every change has to be driven and supported by the people involved, so E&C companies must focus on attracting, retaining and developing talent, and establishing a company culture conducive to innovation and improved skills. This is all the more necessary as the industry is traditionally regarded as not particularly attractive to new talent and, at the same time, it is in increasing competition for talent with other industries. To compound matters, it has an ageing workforce.[6]

Cross-company collaboration is pivotal

E&C companies cannot realize their full potential on their own. The industry is one of the most fragmented in the world and relies on a seamless interplay of all participants along the value chain and throughout a project's life cycle. Companies need to enhance coordination and cooperation across the value chain, and jointly define standards and agree on common goals. Australia is duly pioneering the standardization of project alliance agreements and is adopting a model of cooperative partnership to reduce initial costs.

To gain the support of society at large, the industry again needs to work collectively, along multiple dimensions. For example, it should promote itself as an attractive employer, and it should engage local communities by means of participatory planning and ongoing community-involvement initiatives during operations. A good example in that regard is the Considerate Constructors Scheme, a non-profit, independent organization founded by the United Kingdom's construction industry to improve its image, share best practices and strengthen public awareness of the impact of construction on the environment.[7]

The industry is also very much affected by politics and regulation and thus needs to optimize its interactions with the public sector. Here again, companies should cooperate in their efforts, to ensure constructive communication with public agencies, to monitor political developments accurately and to implement an effective advocacy strategy. In the German "National Initiative on Energy Transition", for instance, the construction industry coordinated well with the German government in developing a strategy on climate change.[8]

As both regulator and major client, the government too needs to take action

In any given country, the public sector, and in particular the national government, can enhance competition and productivity by simplifying and harmonizing building codes and standards. By setting and enforcing time limits for construction permits and environmental approvals, governments can greatly reduce project delays. Ideally, governments should also minimize barriers to competition at an international level. And they should provide appropriate support to academia and companies for developing technological innovations in construction. The British government, for example, recently put the construction industry on the national agenda, in the hope of eventually positioning Britain at the forefront of global construction: among the specific targets to reach, for instance, is a 33% reduction in both the initial cost of construction and the whole-life-cycle cost of assets.[9]

Governments can also shape the industry by their actions as key project owners. The Crossrail project in London, for instance, systematically generates, captures and replicates innovative ideas and eventually translates them into practical innovations and industry standards. It also aims to raise the bar for other construction projects by making these ideas, technologies and practices available to the industry as a whole. Finally, the issue of corruption on construction projects can only be resolved by creating a corruption-resilient procurement environment, by implementing fair and transparent procurement procedures, and by establishing clear practices regarding the prosecution of corruption – practices that address both the supply and demand sides of corruption.

1. Introduction: The Construction Industry – Time for a Transformation

1.1 The industry is crucial to society, the economy and the environment

Societal relevance

Construction is one of the first businesses that humankind developed, and it continues to shape our daily life in unique ways. Virtually all other businesses rely on the construction industry to provide and maintain their accommodation, plants and infrastructure, and construction is a determinant of where and how almost everyone lives, works and plays. For nearly the entire population of the world, the built environment heavily influences quality of life. In the United States, for instance, people on average spend nearly 90% of their time indoors.[10] So the building and the materials used in its construction and finishing have a major impact on the health and well-being of its occupants.[11]

> **We shape our buildings and, afterwards, our buildings shape us.**
>
> Winston Churchill, 1944

Economic relevance

With total annual revenues of almost $10 trillion and added value of $3.6 trillion, the construction industry accounts for about 6% of global GDP.[12] More specifically, it accounts for about 5% of total GDP in developed countries, while in developing countries it tends to account for more than 8% of GDP. The industry is expected to grow greatly in the coming years, to estimated revenues of $15 trillion by 2025. More than 100 million people are already employed today in construction worldwide.[13]

Construction is a “horizontal” industry (like the Financial Services industry), serving all industry verticals; in other words, construction has considerable interaction with numerous other sectors, since value creation almost always occurs within or by means of buildings or other constructed assets. To mention a few, residential housing accounts for 38% of global construction volume; transport, energy and water infrastructure for 32%; institutional and commercial buildings for 18%; and industrial sites (from cement to automotive manufacturing) for 13%.

For countries to enjoy inclusive and sustainable growth, modern and efficient infrastructure is essential. According to a 2014 estimate by the International Monetary Fund, if advanced economies invested an extra 1% of GDP into infrastructure construction, they would achieve a 1.5% increase in GDP after four years.[14]

Environmental relevance

The construction industry is the single largest global consumer of resources and raw materials. It consumes about 50% of global steel production and, each year, 3 billion tonnes of raw materials are used to manufacture building products worldwide.[15]

About 40% of solid waste in the United States derives from construction and demolition.[16] Throughout the world, such waste involves a significant loss of valuable minerals, metals and organic materials – so there is great opportunity to create closed material loops in a circular economy.[17]
As for energy use, buildings are responsible for 25-40% of the global total, thereby contributing hugely to the release of carbon dioxide.[18]

Value therefore lies in improving the quality of construction and the quality of materials used, in contributing to a healthier indoor environment, increasing its sustainability and reducing its cost. Any endeavour towards this goal will generate welcome benefits – whether for families investing in their first private home or governments embarking on a giant infrastructure project.

1.2 The industry's future will be shaped by a number of megatrends

The construction industry is affected by megatrends in four domains: markets and customers, sustainability and resilience, society and workforce, and politics and regulation (see Figure 2). The industry needs to identify and implement optimal responses to these megatrends – both with respect to the opportunities they offer and with respect to the challenges they pose.

Market and customer trends

As demand in emerging countries rises, the industry must identify how emerging and developing markets can benefit best from the technological advances and increased safety standards already being applied in developed countries, while still taking into account local market conditions.

The expected increase in global competition will produce winners and losers as strengths and strategies differ between companies and countries. Many Asian construction firms capitalize on their cost advantages and put great effort into securing construction contracts abroad. Most Western markets, such as the United Kingdom's, are characterized by a high degree of fragmentation, which impacts unfavourably on their level of innovation and their ability to access foreign markets. Eventually, the firms with strong processes in place and the ability to adapt their business models to new markets will prove to be the winners. Many of the others will disappear.

One particularly challenging area is that of infrastructure. Ageing infrastructure assets in developed countries demand proper maintenance, upgrading, replacing or newly built assets, and there is, of course, a fast-growing societal need for infrastructure assets in emerging markets. So overall, there is immense opportunity, and responsibility, for the construction industry. The vast "infrastructure gap" cannot be bridged by public-sector money alone. Private capital is needed, so the trend in infrastructure construction projects is for PPPs. One other notable development is the increasing number of infrastructure megaprojects; these projects, however, have a poor record historically in terms of on-time and on-budget delivery, environmental footprint and public support.[19]

Figure 2: Megatrends Shaping the Construction Industry's Future

Market and customers

Demand in developing countries
65% of the next decade's growth in construction will happen in emerging countries

Globalized markets
1 in 2 E&C companies plan to move into new geographies

Bigger, more complex projects
123km (76 miles) is the length of the Undersea tunnel that will connect Dalian and Yantai in China

Ageing infrastructure
1 in 3 German railway bridges are more than 100 years old

Massive financing need
$1tn annual investments are needed to close the global infrastructure gap

Sustainability and resilience

Resource scarcity
No. 1 consumer of global raw materials is the construction industry

Sustainability requirements
50% of the solid waste in the United States is produced by the construction industry

Energy and climate change
30% of global greenhouse gas emissions are attributable to buildings

Resilience challenges
3× as many disasters were reported last year as in 1980

Cyberthreats
90% of firms agree that information controls have an impact on front-line employees

Society and workforce

Urbanization and housing crisis
200k people are added daily to urban areas and need affordable and healthy housing

Health/comfort needs of citizens
2-5× higher than outside are the levels of volatile organic compounds found inside US homes

Talent and ageing workforce
50% of general contractors are concerned about finding experienced crafts workers for their workforce

Stakeholder pressure and organization
67k signatures were collected opposing the construction of the Stuttgart train station

Politicization of construction decisions
In 2011 the Portuguese government cancelled a 165km (103 mile) high-speed train line project as an austerity measure

Politics and regulation

Complex regulatory requirements
25 different procedures are required for a typical warehouse construction permit in India

Stricter HSE and labour laws
10% of the workforce in a public project in California had to come from the "otherwise unemployable"

Slow permit and approval process
$1.2tn of infrastructure could be added by 2030 if all countries committed to specific time limits for approvals

Geopolitical uncertainty
18 Turkish construction workers were kidnapped by militants in Baghdad in September 2015

Corruption
49% of survey respondents believe corruption is common in a Western European construction market

Source: Press reports; World Economic Forum; The Boston Consulting Group

Sustainability and resilience trends

Increasingly, sustainability is becoming a requirement rather than just a desirable characteristic, and its pursuit is bound to affect both the construction process and the built asset itself. The construction sector produces an enormous amount of waste, so the more efficient use and recycling of raw materials, even a small improvement, offer huge potential benefits. Other new priorities are emerging accordingly, including optimizing space, for example, and ensuring more efficient methods of heating, cooling and lighting. The industry is increasingly making use of off-grid or distributed power sources, such as wind power, geothermal energy and solar panels on roofs.

The industry also has to address the growing concerns over natural hazards (notably, flooding, hurricanes and earthquakes), and to enhance resilience. So new emphasis is being placed on devising risk-mitigating solutions, especially in urban areas with high population density. Finally, the industry must engage against the growing threats to cybersecurity. No doubt many important benefits will emerge from the convergence of Web, cloud and mobile platforms, as well as the Internet of Things (IoT), but vulnerability will increase, too – particularly in an industry as decentralized as the construction industry, with so many different stakeholders involved. So the imperative to protect the industry from threats without disrupting business innovation and growth has never been greater.[20]

Societal and workforce trends

The world's urban population is expected to exceed 6 billion by 2045, with about a quarter of that population living in slums if the current proportion remains unchanged.[21] Hence the need for a boost in affordable housing in urban areas – where the construction process is very complex, owing to the space constraints – and for increased infrastructure spending on water supply, sanitation, and so on. Another demographic trend, especially in developed countries, is the shifting age profile. The increasing proportion of elderly people in the population affects the construction industry in two main ways: first, it creates a need to construct or adapt buildings to accommodate ageing and convalescent citizens; second, it threatens to reduce the available supply of construction workers. That threat might seem less serious than in the past, since new technologies are now taking over many of the tasks that formerly required low-skilled workers.[22] However, the new technologies themselves require a highly skilled workforce, and the construction industry – traditionally perceived as less glamorous than other sectors – will struggle to recruit the requisite "digital" talent.[23]

The construction industry is concerned with the health and safety not only of workers but also of the people who actually live or work in the buildings. Employee health and productivity are linked to the quality of the indoor environment, and that quality is largely determined by decisions made during project development and construction. The construction sector's responsibility does not end with the delivery of the project: the entire operations or use phase is affected by the initial selection of materials. The safer the materials, the better for health and the environment. For instance, asbestos has been outlawed in many countries as a construction material, and construction companies are increasingly motivated to ensure that the living and work environments that they create are ergonomic and allergy-free. In addition, at the end of the building's life, safer materials can be more easily integrated in the circular economy.

A further challenge facing the construction industry concerns the rights or needs of local communities. Neighbourhood lobby groups, for instance, often influence permit decisions and might even be able to force the withdrawal of permits already granted. Communities are also becoming more organized and professional, partly thanks to new forms of communication and social media.

Political and regulatory trends

The various political challenges relate to regulation, bureaucracy, instability and corruption.

Regulation impacts on many aspects of the E&C industry. In a recent global survey, regulation was identified as the most important driver of increasing complexity.[24] The industry is especially affected by changes in health and safety requirements, financial and labour legislation, and environmental standards. New regulations in any of these areas can affect business operations adversely. If designed thoughtfully, however, regulation can actually prove advantageous to companies.[25] For instance, retrofit investments in response to Germany's new Energy Conservation Ordinance have been a major driver of innovation for the construction industry.[26] Going even further, one could think of regulation not as imposing a burden but as offering opportunities to stimulate an industry transformation and inspire innovations that would greatly benefit society and the environment.

Next is the issue of bureaucracy and political risk. Construction permits are, quite rightly, more and more subject to environmental and social-impact studies. If these studies are conducted inefficiently, however, or if there is a backlog in the granting of permits, projects are needlessly delayed and their prospects suffer: cash flows start later than anticipated, thereby compromising profitability. An appropriate balance is required: on the one hand, offering speedy approval processes; on the other, giving all stakeholders their due say. Even after the permits are granted, infrastructure projects remain vulnerable to cancellation, owing to the vagaries of national or local politics. Frequently, a new government will set different priorities from those of its predecessor.[27]

Another constant issue is that of political instability. The international community has arguably managed to reduce overall levels of violence in recent decades, but regional hotspots obviously persist and new ones flare up, at enormous human and economic cost. Contractors are wary of getting involved in such locations, even in post-crisis conditions – especially in long-term infrastructure programmes, where predictability is key – and need to find ways of mitigating the risks.

Finally, the challenge of corruption must be addressed. In many countries, corruption remains one of the greatest barriers to economic and social development. Although bribery and other forms of corruption afflict almost every industry sector, they are a particular concern for companies in the E&C and Real Estate sectors, given the nature of their business.

1.3 The industry must also confront internal challenges

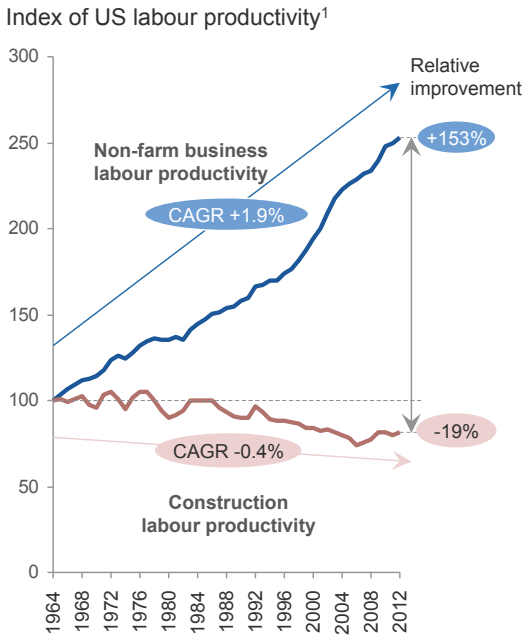
In most countries, over the past 50 years, productivity improvements in construction have been meagre, especially when compared to those in other industries (see Figure 3 for the respective historical trends in labour productivity in the United States). Some new technologies and tools have emerged, but the rate of innovation and innovation adoption has been very slow.
Why does the industry have such an unimpressive record? The underlying causes are many and varied.

– *Lack of innovation and delayed adoption.* The lifeblood of any industry is research and development (R&D). The benefits of R&D, however, are long term, whereas the costs arise in the present. This mismatch is ill-suited to the project-driven business in which the construction industry operates, so R&D has received less attention here than in other industries.[29]

– *Informal processes or insufficient rigour and consistency in process execution.* The processes typically adopted by construction companies regularly lack maturity. Companies often seem to put greater emphasis on defining the final product than on planning the actual construction process.
– *Insufficient knowledge transfer from project to project.* Although each construction project will have its own unique characteristics, the processes of construction itself are repeated in their essentials from project to project. Lessons learned from one project could therefore often be usefully applied to subsequent projects. Yet few companies have institutionalized such a process. Past experience is therefore often lost, and projects continue to rely heavily on the expertise of the individual project manager.
– *Weak project monitoring.* A related issue is the weak monitoring of projects, relative to other industries. In many manufacturing industries, for example, operations are continuously tracked and large quantities of data are collected. In that way, if something goes wrong, a car manufacturer, for instance, can quickly identify the root causes and implement remedies immediately and efficiently. Few construction companies are set up in this way.
– *Little cross-functional cooperation.* The conventional construction process is generally sequential, reflecting the input of the project owner, designers, constructors and key suppliers at different stages of the project. This set-up militates against sophisticated construction planning. Ideally, the knowledge of all stakeholders along the value chain should be fully exploited early on in the design and planning process, but that is seldom easy or even possible under current arrangements.
– *Little collaboration with suppliers.* For many large contractors, the purchasing strategy involves long-term relationships with key suppliers; nevertheless, the final decisions are often still made ad hoc, on a project-to-project basis. The problem is even more severe in smaller construction companies, where purchasing is almost exclusively project-based.
– *Conservative company culture.* The construction industry operates in a somewhat traditional environment and generally retains a conservative corporate culture. The widespread perception is, justifiably enough, that construction companies are not sufficiently progressive or forward-thinking.
– *Shortage of young talent and people development.* The image that people have of the construction industry as an employer is a relatively poor one, with inadequate gender diversity and little job security (owing to the cyclical nature of the business). As a result, E&C companies often struggle to attract talented recruits to their workforce. Relative to companies in other industries, construction companies engage less often and less effectively in internal people-development initiatives.

> **Looking at construction projects today, I do not see much difference in the execution of the work in comparison to 50 years ago.**
>
> John M. Beck, Executive Chairman, Aecon Group, Canada

Figure 3: US Industry Productivity and Performance, 1964-2012[28]



[1] Peer set based on US companies with Engineering, Construction and Services-related Standard Industrial Classification codes. Financials are inflation-adjusted and indexed to 1964; output per working hours.
CAGR = compound average growth rate
Source: Global Vantage; Compustat; Bloomberg; www.aecbytes.com/viewpoint/2013/issue_67.html; www.nber.org/papers/w1555.pdf; S&P Capital IQ; BCG ValueScience Center; World Economic Forum

In fairness, the construction industry does have some inherent characteristics that make it a structurally difficult business and that hinder attempts at reform. It also represents just one step out of several in the value chain, and relies on a large number of stakeholders. So the much-needed company and industry transformation is bound to be difficult. Figure 4 lists these unconducive characteristics in two categories: on the left, some of the industry's main peculiarities; on the right, the specific issues resulting from the special role of its clients.

1.4 The industry is ripe for and capable of transformation

> **Clients do not want to be guinea pigs.**
>
> Roger Smith, Executive Director, Corporate Strategy, Fluor Corporation, USA

Given the construction industry's societal, environmental and economic importance, even small improvements in performance will have a strong effect in all three domains:

- *Societal*. A mere 1% reduction in construction costs would save society about $100 billion annually[30] – a sum equal to the entire global cost of cancer drugs. In fact, the ambitions go far beyond that: the vision formulated by the UK government for 2025 is of a 33% reduction in the initial cost of construction and the whole-life-cycle costs of built assets.[31]
- *Economic*. The global shortfall in infrastructure capacity is expected to reach $15-20 trillion by 2030. Closing this gap could create up to 100 million additional jobs and generate $6 trillion a year in economic activity in the long run.[32] Up to 30% of this boost could come from improvements to construction projects and to asset operations.
- *Environmental*. By harnessing the capacity of the building sector, many countries can cut emission rates cost-effectively and achieve energy savings of more than 30%, according to the United Nations Environment Programme.[33] The target set by the United Kingdom's construction industry for 2025 is a full 50% reduction of today's level of greenhouse gas emissions in the overall built environment.[34]

Figure 4: Unique Construction Environment

The industry has unique characteristics …

Multiple stakeholders with diverse interests/needs
— Three different project owners are involved in the construction of the Berlin airport. Delays of 10 years and cost overruns of about €5 billion are expected.

Project business and on-site construction
— According to the corporate strategy director of a major global E&C firm:
"Our product output is in the unit of 1."

High industry fragmentation
— The United States has 710,000 E&C companies; only 2% of them have more than 100 workers and 80% have just 10 workers or fewer.

Low profitability and capitalization
— Global listed E&C companies have a weighted average total shareholder return of only 5% and are consistently outperformed by most S&P 500 companies.

Highly cyclical and volatile business
— The Spanish construction market declined from a peak of €151 billion in 2006 to just €70 billion in 2012, and has still not fully recovered.

Unstable workforce
— In Canada, about 25% of workers whose construction jobs are terminated find their next job in sectors outside construction.

Unique construction environment

… and operates in a complex client context

Immature project definition and technical assessment
— Construction costs of the Hamburg Elbphilharmonie increased from €241M to €789M. "Almost all the extra cost resulted from planning that was insufficiently progressed at tendering time."

Over-preference for lowest price bid
— The launch of a 17km (11 mile) highway segment in Germany was delayed by six months, as one bidder raised objections to the tendering process – the lowest bid had not been chosen.

Insufficient or incremental funding
— Many US government contracts have an Availability of Funds clause that limits the government's liability to pay the full amount claimed.

Conservative clients
— A minor problem with an innovative rapid-hardening concrete during a night shift almost brought a public road project to a halt, as the project owner lost faith in the new material.

Increased risk transfer to contractors
— Emerging-market infrastructure investments with private participation, which often involve a transfer of risk to contractors, have tripled since 1995 and totalled $108 billion in 2014.

Complexity of contracts and dispute resolution
— 25 years ago, a typical contract consisted of about 50 pages; today it can easily exceed 1,000 pages and is packed with legal complexities.

Source: World Economic Forum; The Boston Consulting Group

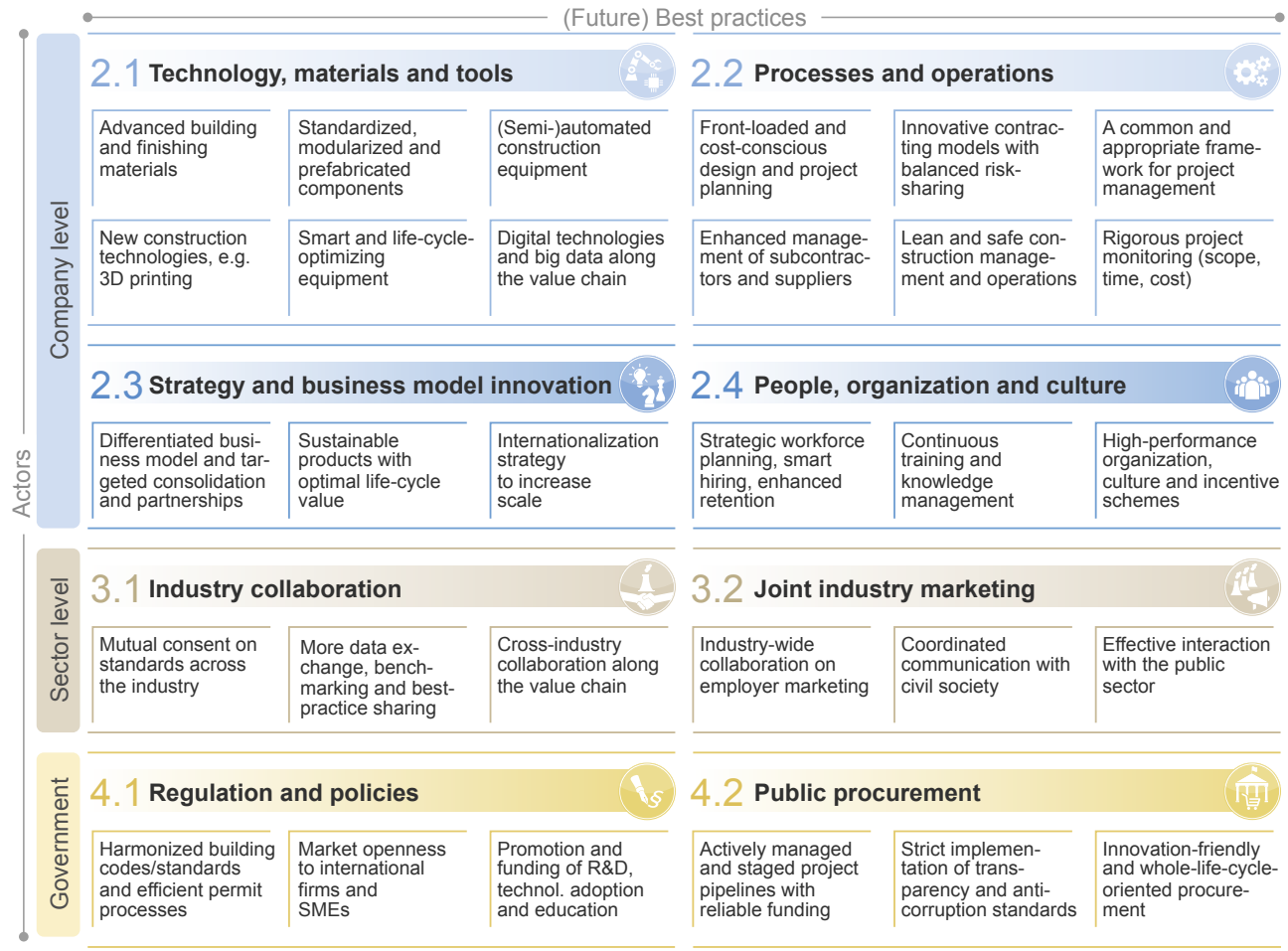
All of this significant potential is ready to be unlocked. New opportunities are emerging as transformative developments reshape the E&C industry – from innovative technologies to revolutionary construction techniques. Productivity and efficiency will surge. It is up to the industry to embrace these new opportunities more vigorously and change the way it has traditionally operated.

Other industries, such as the automotive industry, have already undergone radical and disruptive changes, and their digital transformation is now well under way. Construction companies need to act quickly and decisively: lucrative rewards await nimble companies, while the risks are serious for hesitant companies.[35] Given all the megatrends and internal challenges, the construction industry should take action in several areas. A comprehensive approach is outlined in the industry transformation framework shown in Figure 5.

The framework structures the various areas of action according to responsibility. Initially, the transformation relies on the initiatives of *individual companies* – the adoption of new technologies and processes, business-model innovation, refinements to the corporate culture and organization, and so on. Individual action is not enough, however, in such a highly fragmented and horizontal industry: many of the challenges need to be tackled *collectively* – the *industry as a whole* has a responsibility. It needs to establish new forms of collaboration, or to improve existing forms. Finally, *governments,* too, have a large part to play, in their dual role as regulators and clients.

The following sections discuss the steps all those involved must take.

Figure 5: Industry Transformation Framework



Source: World Economic Forum; The Boston Consulting Group

2. Companies as the Spearhead of Transformation

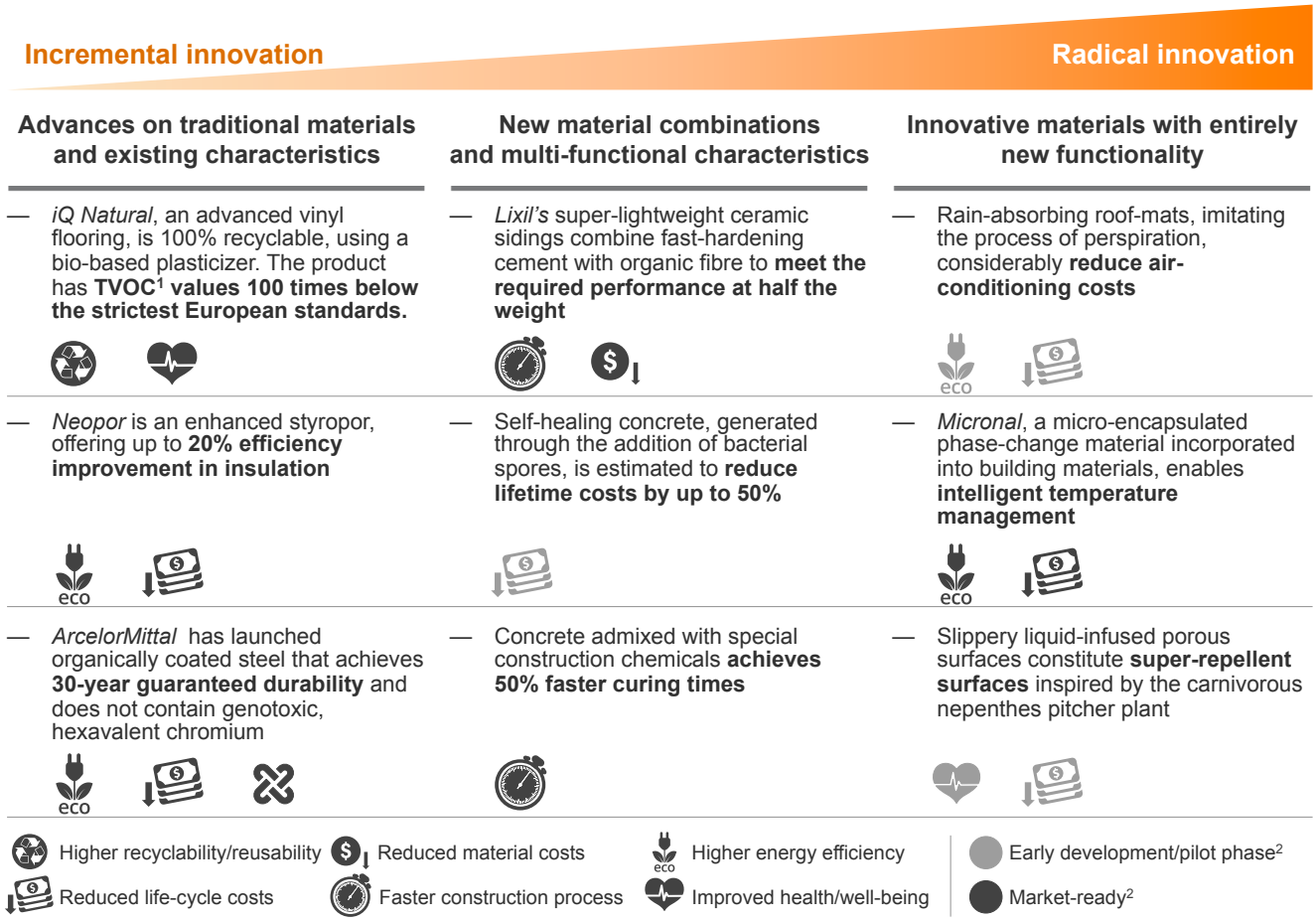
2.1 Technology, materials and tools

Advanced building and finishing materials

Materials constitute an extremely powerful lever for innovation. The European Commission estimates that 70% of product innovation across all industries is derived from new or improved materials. With approximately one-third of construction cost attributed to building materials, the scope for applying advanced building materials (ABMs) is considerable.[36]

The solutions emerging from the building material industry are numerous and wide-ranging – from the incremental innovation of traditional materials and existing characteristics, to the generation of new material combinations with additional multifunctional characteristics, to radically innovative materials with entirely new functionalities. A few examples appear in Figure 6.

Figure 6: Examples of Advanced Building and Finishing Materials



[1] Total volatile organic compound
[2] Shading of the symbols indicates technology maturity (market-ready versus early development/pilot phase)
Source: World Economic Forum; The Boston Consulting Group

A large variety of innovative ABMs are market-ready or close-to-market. Yet despite their great potential, they very often fail to penetrate the market, let alone achieve widespread acceptance. That is particularly true for emerging countries. One reason is that ABMs often require a higher initial investment, with the benefits generally realized over the entire life cycle. Other reasons are that the new materials still lack a track record of success, and that project owners and E&C company decision-makers may not be up-to-date on the latest developments, or may lack the information needed for making difficult trade-offs (on such issues as price vs quality, durability and ecological merit). All of that points to another serious impediment to the introduction of new materials: the liability risks that engineers, contractors and suppliers would face if they recommend a new material.[37] To remedy this unsatisfactory state of affairs, it is crucial for stakeholders along the value chain to take action.

E&C companies should build up relevant competencies in-house, and create a database of evidence on the applicability and benefits of ABMs, to be able to provide clients with a convincing quantitative case for using ABMs. Afterwards, contractors should institutionalize the knowledge transfer to local project teams, so the decision-makers at a project level have all the relevant up-to-date information and can thereby optimize their decisions on materials.

EXAMPLE: *Fluor* has built up an internal team of experts on concrete to advise the client at an early planning stage, to develop a foundation of data based on experience and to create a convincing business case for greater use of innovations (such as 50%-faster-curing concrete) in the market.

EXAMPLE: The *United States Army Corps of Engineers (USACE)* validates new technologies (such as cross-laminated timber), whether in its own research labs, in demonstration projects or in collaboration with academia. Once a new technology has met *USACE* requirements, its value can be communicated internally in multiple ways to ensure broad awareness. Additionally, when appropriate, such technologies can be specifically incorporated into design guides or specifications.

It is also essential to inform and convince architects, engineers and clients of the advantages of ABMs. For instance, by showing how ABMs, despite their price premium, have an improved total-cost-of-ownership (TCO) performance relative to traditional materials, the industry can win risk-averse clients who would normally favour the lowest-price options.

EXAMPLE: *BASF and Arup* have jointly developed an app for architects, engineers and project owners to calculate the energy savings achievable from the latent-heat storage system *Micronal.*

Given the multiple-stakeholder nature of construction projects, it is essential to improve collaboration and knowledge transfer among contractors, subcontractors and building material suppliers – both strategically and on a project basis. For optimal innovation and better uptake of ABMs, what's needed is a concerted effort on the part of the industry as a whole – for instance, via industry-wide standards and certifications (see section 3.1) – as well as an active role by governments, in establishing innovation-friendly policies and procurement processes (see section 4). Proper risk sharing is crucial in this context. (See section 2.2 for a discussion of innovative contracting models with improved risk sharing.)

Standardized, modularized or prefabricated components

Productivity in construction could receive a substantial boost from standardization, modularization and prefabrication. The standardization of components brings many benefits, including a reduction in construction costs, fewer interface and tolerance problems, greater certainty over outcomes, reduced maintenance costs for end-users, and more scope for recycling. Modularization adds to the advantages of standardization, by increasing the possibilities for customization and flexibility, and helping to realize the potential of prefabrication in a factory-like environment. Prefabrication would increase construction efficiency, enable better sequencing in the construction process and reduce weather-related holdups; by such means, it becomes possible to reduce a project's delivery times and construction costs relative to traditional construction methods, and also to create safer working environments.[38] Prefabrication can be applied in a wide variety of project types, ranging from residential housing to large-scale industrial plants. The various systems can be distinguished by their degree of prefabrication: at the simpler end are the mostly two-dimensional building components, such as walls, ceilings or truss elements; then there are modular structures, comprising larger volumetric elements like entire rooms or storeys; and, finally, there are entirely prefabricated assets. The degree of prefabrication is based not just on these physical dimensions, but on a further factor as well: the integration and complexity of mechanical, electrical and plumbing systems.

How widely and to what degree prefabrication is accepted in the construction industry depends on the segment and country. Prefabrication is very common in offshore oil and gas facilities, for instance, and in residential projects in Scandinavia, whereas it has made little headway in the residential market in Germany. It is used very widely in the construction of prisons, and is becoming more important in transportation infrastructure, such as bridges and elevated highways.[39] Among the typical obstacles to its acceptance are:

- Poor image, due to misconceptions about quality, price and the potential for individualization
- Client demand for individual solutions, which discourages the use of standardized processes and components
- Limited experience of the application of prefabrication – in high-rise projects, for instance

- The increased risk involved in committing to particular off-site suppliers, especially since the market is not yet well developed and alternatives are not instantly available
- Underutilization of the prefabrication factory space, due to the customized and irregular nature of construction demand
- The high cost of transportation, especially in cases where the distance between the factory and site is large or where the transport links are inadequate, as well as community opposition to the transportation of oversized components
- Problems in handling large prefabricated components in space-constrained construction sites
- Technical specifications from project owners: in Spain, for example, public projects forbid the use of prefabricated bridge foundations

Various mitigation strategies are available. The increased risk involved in committing to a particular supplier, for instance, could be mitigated by developing industry-wide standards on component dimensions or connections, and so on. Additional steps that individual companies along the value chain should take include:

- *Further develop modular construction systems*, working jointly with suppliers – to improve applicability, for instance, and generate systems to meet the demand for affordable high-density housing in urban areas

  EXAMPLE: *Fluor* has applied modular concepts from offshore construction to onshore projects such as chemical plants, and has thereby achieved capital-expenditure reductions of 20-40%. In collaboration with the supplier, it has included cable harness in its modular systems, resulting in further productivity improvements.

- *Introduce an economic and logistical assessment* of these technologies in the planning process and *tailor on-site construction processes* to the use of prefabrication components or modular systems; work of this kind can help greatly in realizing the full productivity potential of prefabrication

  EXAMPLE: *Broad Group China,* in cooperation with *ArcelorMittal*, is using a system of modular building components that enables very speedy construction: a 57-storey building was built in only 19 days by moving 90% of the construction work to the factory.[40]

- *Collaborate with customers* and educate them on the advantages of prefabrication; take into account the opportunities for repurposing or post-installation adjustments, to meet society's future needs

  EXAMPLE: *MQ Real Estate* developed, in collaboration with hotel operators, a scalable modular apartment system that enables firms to build non-permanent housing or hotels within weeks in dense urban areas, to cope with seasonal peaks in demand and exploit temporarily vacant areas much more efficiently

- *Apply new construction concepts*

  EXAMPLE: *Skanska* has developed a new construction concept known as "Flying Factories", which are temporary factories set up close to construction sites; they apply "lean" manufacturing techniques and employ local semi-skilled labour. The advantages include a reduction in construction time of up to 65%, a halving of labour costs and a 44% improvement in productivity relative to on-site assembly, while still upholding the construction industry's importance as a local employer.

(Semi-)automated construction equipment

As more and more processes in the construction industry are mechanized, machinery has acquired a central role and has proved to be a strong driver of productivity gains. Excavators and bulldozers make it quick and easy to move large amounts of earth; drilling rigs and piledrivers facilitate underground engineering; conveyers and pumps optimize concreting work; and mobile cranes lift and position heavy loads.

But while other industrial sectors, such as the automotive industry, have already reached the tipping point to Industry 4.0,[41] the construction industry still has generally low levels of automation. That looks set to change, however, as technological advances – in robotics, for instance – open up enormous new possibilities. New technologies in the digital space (such as unmanned aerial vehicles, low-cost sensors, remote operations and autonomous control systems) could become significant enablers of innovation in construction equipment.[42] Semi-autonomous equipment is capable of carrying out complex tasks, though it still requires considerable human controlling. Autonomous equipment makes use of sophisticated digital tools and new technologies such as out-of-sight drones, leaving only "monitoring roles" for the human worker.

(Semi-)automated equipment offers great potential along multiple dimensions – reduced construction costs, thanks to shorter delivery time and increased productivity; higher quality, due to higher accuracy and fewer workmanship errors; improved safety, by keeping workers out of danger zones, and so on.

Companies along the value chain can take several steps to increase the use of automation where beneficial:

– *Leverage new technologies* by integrating physical and digital systems

  EXAMPLE: *Komatsu,* a Japanese manufacturer of construction equipment, is developing automated bulldozers incorporating various digital systems. Drones, 3D scanners and stereo cameras gather terrain data, which is then transmitted to the bulldozers; these are equipped with intelligent machine-control systems that enable them to carry out their work autonomously and thereby speed up the pre-foundation work on construction sites, while human operators monitor the process. On mining sites, autonomous haul trucks are already in common use.

Figure 7: New Deployment Models for Construction Equipment[43]

Improve availability of individual equipment	**Continuous monitoring** and preventive maintenance and repair of construction equipment result in **better availability of individual equipment**		Volvo Construction Equipment has launched a programme based on a machine-tracking information system that **aims to identify problems before they occur, improving equipment uptime**
Enhance utilization of a company's entire fleet	Central fleet management systems and the tracking of vehicle use **increase the utilization of equipment across the firm**, e.g. by identifying ways to save fuel costs		Teletrac provides GPS fleet-tracking software with a real-time view and analytics, resulting in **reduced fuel consumption of up to 30%** – for instance, by avoiding unauthorized vehicle use
Use equipment better across companies	Various forms of equipment leasing and sharing help to **distribute capacity more efficiently** across the industry, e.g. — traditional leasing — "power by the hour" — "pay by intensity" — B2B sharing platforms		A large construction equipment manufacturer has invested in the start-up Yard Club, which helps owners of heavy equipment to rent out idle machines to other businesses, thereby **reducing the cost of owning equipment**

Source: World Economic Forum; The Boston Consulting Group

– *Create preconditions for automation early* – as early as the design and project planning phase. That can be done by increasing the proportion of prefabrication and modular systems, since automation works best with standardized components and processes. Better upfront planning and technical preparation in setting up construction sites is also needed.
– *Establish industry standards* – for communication protocols, for instance – so that automated and interoperable equipment can be applied widely to overcome the fragmented and multistakeholder nature of construction processes
– *Make better use of existing equipment* – for example, by adopting new business models (as described in Figure 7)

New construction technologies

The development of 3D printing is expected to have a disruptive impact on the construction industry. The technology enables the production of purpose-built shapes that cannot be produced by any other method; it promises productivity gains of up to 80% for some applications, together with an important reduction in waste. Construction time for some buildings could shrink from weeks to hours, and customized components could be provided at much lower cost.

However, 3D printing in the construction industry is still at an early stage of development. Several issues persist, including resolution problems (large-scale printing often produces rough, chunky results), a trade-off between scale and speed (big printing remains slow – standard 3D printers are constrained by their size), and high costs. At present, 3D printing is still mostly applicable to low-volume, high-value parts. It remains to be seen how quickly companies will overcome the main technological challenges, and whether they will be able to bring down costs and achieve economies of scale.

Many companies are optimistic in this regard and point to other industries, such as aviation, where mass production of 3D-printed components is already common practice. The following are some examples of pilot schemes within the construction industry itself, with steel and concrete components now being 3D-printed for purposes ranging from bridges to complete homes:

EXAMPLE: In a project on 3D-printed steel components, *Arup* achieved a 75% weight reduction and 40% reduction in materials compared with traditional production methods

EXAMPLE: *The Skanska* 3D Concrete Printing project aims to demonstrate that 3D printing can be used to manufacture concrete objects in shapes that were unfeasible through traditional casting methods.

EXAMPLE: *MX3D*, a Dutch start-up working with partners such as *ArcelorMittal, ABB* and *Autodesk,* has developed an external sixaxis 3D printing robot capable of printing lines in mid-air, and has used it to print a footbridge across an canal in Amsterdam.

EXAMPLE: *WinSun (China)* has been building 10 houses a day by using 3D-printed building components, and has concluded a deal with the Egyptian government for 20,000 single-storey dwellings leveraging this technology.[44]
Few other new construction technologies look capable of making a comparable impact, but structural bonding is worth mentioning. It offers certain advantages over conventional welding, such as greater design freedom, a more uniform stress distribution and lower heat input; so far, however, its applications in construction are limited, owing to ongoing concerns about structural integrity and fire safety. One other new construction technology has considerable potential: instead of constructing immoveable concrete buildings, companies could create lightweight block-like structures that can be relocated.

EXAMPLE: An army of robot-crane hybrids (called "crabots") will be assembled to build *Google*'s new headquarters in California. They will lift prefabricated components such as walls and heavy furniture into place beneath vast glass canopies.[45]

Smart and life-cycle-optimizing equipment

The concept of smart building is gaining in popularity. This is in part due to technological advances, which are driving down the cost of sensors, data storage and computing services. At the same time, potential customers are showing increased interest, attracted by the widening adoption of connected devices, and are demanding greater energy efficiency in buildings and improved safety and convenience. As for the owners or end-users of buildings, they stand to gain several benefits: reduced operating costs, through a likely 20-40% reduction in energy usage; greater comfort, thanks to improved lighting and temperature controls, for instance; and increased operational efficiency, partly by means of remote servicing.

This development affects all built assets and sectors. In the Energy sector, for instance, smart meters and demand response are emerging.[46] In Transportation, smart technology enables smart transport and parking. In Housing, connected and smart devices are gaining popularity. And by interconnecting people, machines and data, smart-building equipment is contributing powerfully to the optimization of the O&M of buildings and other constructed objects.

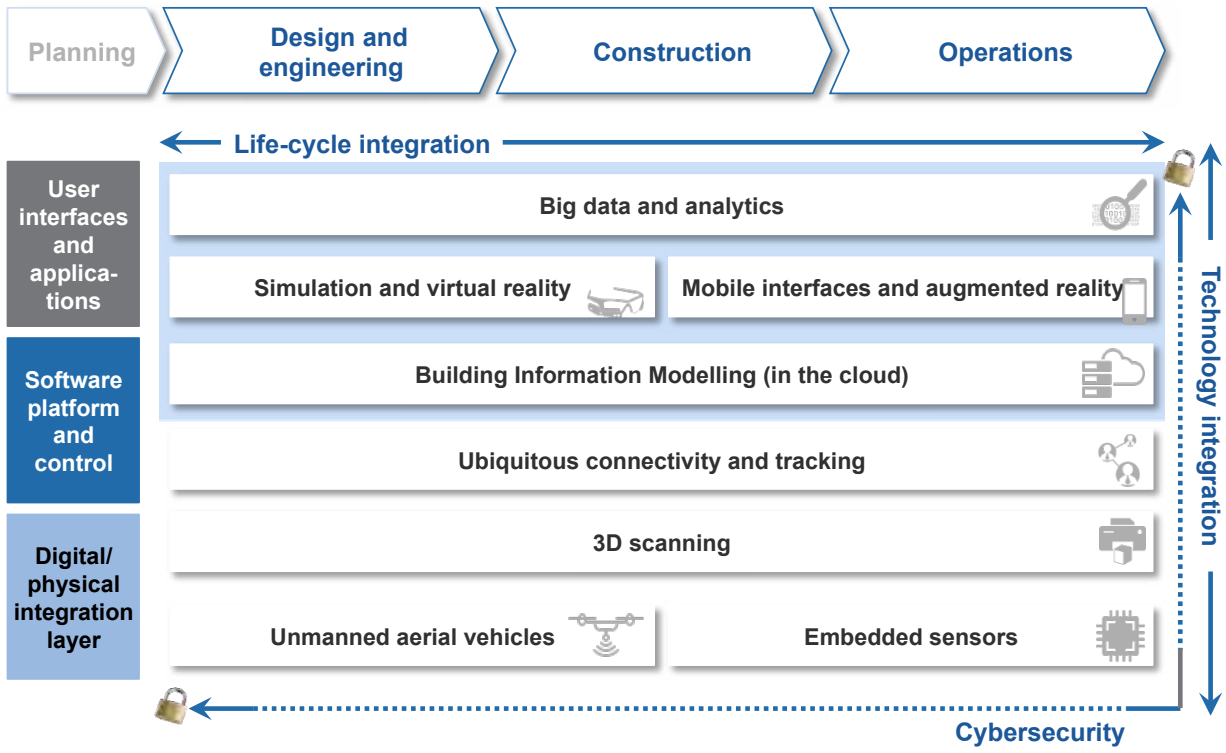
The adoption of smart-building equipment is also a prerequisite for smarter cities and an increasingly powerful influence on people's quality of life.

EXAMPLE: *The South Korean city of Songdo* – which claims to be the largest private real-estate investment in history – is a greenfield initiative, combining "smart" technologies across all sectors to create an environmentally sustainable, economically viable and liveable city.

A number of issues persist, however, which restrict the uptake of these smart technologies: the lack of a TCO perspective, a shortage of city-related information technology (IT) standards, heterogeneous starting points and low-quality legacy infrastructure, concerns about privacy and data protection, and so on. Until uptake increases, the industry as a whole cannot hope to reap the full benefits. Various initiatives could help to increase the uptake: for example, building up the relevant internal capacities; improving collaboration along the value chain; convincing customers of the long-term advantages of adopting smart equipment; and, if necessary, persuading governments and other project owners to take the initiative. A sensible first step would be to conduct pilot schemes with selected clients, and thereby gain practical experience.

EXAMPLE: *Skanska* and its partners are pioneering the wireless monitoring of buildings, using sensors to record data (such as temperature and vibration), and wireless equipment to store and transmit this data. Data analytics are applied to determine the implications of any changes in the sensor readings. These smart-equipment technologies have the potential to reduce unexpected failure by 50%, improve building-management productivity by 20-30% thanks to less need for inspections, and improve the building's energy performance by 10% over its lifetime.

Figure 8: Digital Technologies Applied in the E&C Value Chain[48]



Note: The figure displays the main application areas of the respective digital technologies along the E&C value chain.
Source: World Economic Forum; The Boston Consulting Group

Digital technologies and big data along the value chain

Digitalization – the development and deployment of digital technologies and processes – is central to the required transformation of the construction industry. Innovations of this kind enable new functionalities along the entire value chain, from the early design phase to the very end of an asset's life cycle at the demolition phase.

According to a recent study, full-scale digitalization in non-residential construction would, within 10 years, be capable of producing annual global cost savings of $0.7-1.2 trillion (13-21%) on E&C and $0.3-0.5 trillion (10-17%) in the Operations phase.[47] The core technologies enabling this transformation are listed in Figure 8 and described below.

First, the use of big data and analytics: algorithms generate new insights from the huge data pools created both on construction projects and during the operations phase of existing assets. New methods of simulation and virtual reality help to identify interdependencies and clashes (clash detection) during the design and engineering stages, and enable a virtual experience of the building even in the early design phase. By exploiting mobile connectivity and augmented reality, companies can engage in real-time communication and provide workers with additional on-site information.

EXAMPLE: *Atkins* has implemented advanced parametric design techniques for detailed design "optioneering" in the water infrastructure industry. That has made it possible to provide 22 design options in one day, a 95% time improvement on traditional design methods for similar results.

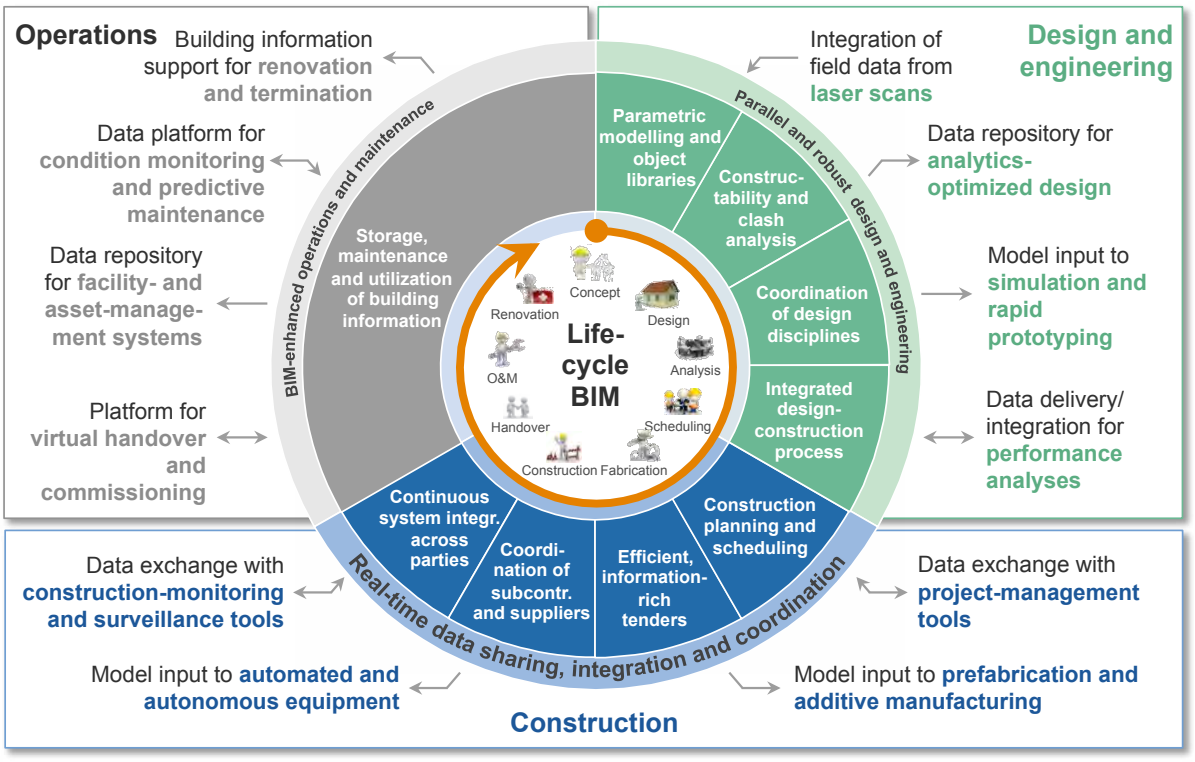
EXAMPLE: *Arup* combines various data-collection methods, including mobile surveys, security-camera footage and traffic-flow reports, for improved decision-making in the design of residential projects.

Companies can refine their monitoring of projects by using drones and embedded sensors to enable real-time communication and to track people, machines, components and the construction process itself.[49] 3D scanners build digital models of existing buildings; they can also detect any deviations very quickly during the construction process, and can enable deformation monitoring.

EXAMPLE: *Skanska* is developing a Tag & Tack system, pioneering the use of radio frequency identification (RFID) tags and barcodes on products and components in construction projects. By facilitating real-time monitoring of delivery, storage and installation in this way, the new system is achieving reductions of up to 10% in construction costs.

These digital technologies also facilitate the adoption or enhanced application of many of the other innovations, such as prefabrication, automation and 3D printing, and should help to improve various processes in the industry, such as front-loaded design and planning or project management in general. For instance, advanced project planning tools use complex mathematical modelling to optimize the allocation of construction staff and individual roll-out functions for infrastructure projects.

Figure 9: Applications of BIM along the E&C Value Chain[50]



Source: The Boston Consulting Group

To elaborate on one further digital tool: Building Information Modelling (BIM) is gaining currency as a platform for central integrated design, modelling, planning and collaboration. BIM provides all stakeholders with a digital representation of a building's characteristics – not just in the design phase but throughout its life cycle. It presents several important opportunities, as shown in Figure 9.

Above all, BIM facilitates collaboration among all stakeholders – from early design through to O&M and even to the decommissioning phase – and thereby holds out the promise of large efficiency gains. All stakeholders can contribute information to and extract information from the central model. By providing a lifelong view of construction projects, including the TCO, it offers owners great benefits in the commissioning and operations phase, and enables new business models, particularly in asset management. Such a life-cycle BIM eventually produces a continuous build-up of know-how, by enabling a seamless flow of information across different construction phases and stakeholders. By providing a neutral and unbiased view, BIM can also contribute greatly to creating a level playing field in this regard, and more effective dispute resolution.

EXAMPLE: *Atkins* is applying advanced digital and high-tech solutions to high-hazard operations, such as the retrieval of radioactive waste or the transport of spent nuclear fuel.[51] It uses 3D laser scanning and 3D cameras to provide an accurate as-built status of the asset profile up front, and thereby increases confidence in the design and facilitates delivery. Virtual reality and augmented reality help to engage stakeholders, by clarifying the design and indicating progress throughout the project's life cycle; they also help to reduce the time that operators and surveyors have to spend in high-hazard or high-dose areas. 3D BIM facilitates clash detection and – by also incorporating programme details, cost constraints and asset-management information – it optimizes the use of data throughout the project's life cycle without loss, contradiction or misinterpretation. By learning from experience and implementing its solutions adeptly across the full life cycle of the project, Atkins can achieve as much as a 20% reduction in the time needed for completing a project, and up to 16% in cost savings.

Prior to achieving large-scale implementation and all the potential benefits of BIM, however, various obstacles must be overcome:[52]

- Implementing BIM, within a company and industry-wide, requires a considerable build-up of expertise, especially appropriate employee training and substantial IT upgrading. Small companies will find that especially challenging, as they might struggle to afford the upfront investments.
- Technological standards have to be in place and interoperability must be ensured, so that the various stakeholders can share information and cooperate on planning.
- Project owners will be slow to adopt the technology until they acquire a greater understanding of the benefits of BIM for them.
- In BIM, data is created and shared in a more collaborative way, which leads to further issues regarding data ownership and liability.
- The benefits of large-scale BIM can only be realized when all participants along the value chain get involved; without this interlinking effect, there is little benefit for the first movers.

The uptake and sophistication of BIM vary considerably from country to country, and from company to company – according to their size and position in the value chain. For some large engineering companies, BIM is already part of business as usual, but most small companies across the value chain have little BIM experience. In fact, even some of the major contractors have never used BIM on any of their projects. The difference in adoption rates within Europe is considerable; for example, 16% of E&C companies in the United Kingdom have never used BIM, while in Austria the figure is 49%.[53] What the industry needs is "big and open" BIM, which integrates the entire value chain and is characterized by full interoperability of software and open access to it. The technical challenges are likely to be overcome in the near future, but it might prove more difficult to change existing processes and to increase collaboration, including data sharing. Here are some potentially helpful steps in that regard.

For large companies:

- *Build up the digital expertise and spread it across the company.* E&C companies have not exactly been a magnet for "digital natives" up to now, and they really need to attract a critical mass of such talent. Companies should set up a central innovation department and/or a BIM department to institutionalize digital endeavours and to expand the digital knowledge base more quickly. Larger companies should appoint a chief technology officer. Make sure that all regionally dispersed divisions and teams are part of the transformation.

  EXAMPLE: *Skanska* established a robust network of BIM and Virtual Design and Construction professionals, who are committed to enhancing project planning, execution and delivery through the implementation of new technologies and innovative processes. Within this network is a core group of experts who are responsible for developing standards, training staff, providing project support, sharing best practices and improving the way the company works.
- *Establish the technological foundation and complement digital capabilities* through third parties where needed. Identify and prioritize the most relevant digital technologies according to their maturity level as well as business and market needs. Invest in the requisite software and hardware tools and IT infrastructure. Make sure to gain access to and/or ownership of relevant data generated along the building life cycle.
- *Take on pioneering roles and share expertise* to encourage the adoption of BIM among smaller companies, though without overstraining them or expecting equivalent commitment from them

EXAMPLE: *Arup* set itself the goal of using BIM on more than 80% of its design projects by April 2015, and has developed a diagnostic tool measuring the degree and success of a project's use of BIM. The company has made the tool available to other companies.[54]

For technology suppliers:

- *Strengthen the core and seek to overcome interoperability issues* and improve interface definitions. Strengthen the product offering for the traditional target group of designers and engineers, by adding functionalities and modelling dimensions, improving usability and simplifying reuse of the vast amount of data from past projects. Agree on standards to improve the interoperability of different BIM systems and integrate all disciplines. Eventually, get the 3D models connected to the Enterprise Resource Planning systems also, in order to create a single source of authoritative data across all relevant systems.

  EXAMPLE: *Autodesk* and *Bentley Systems* are working together to enhance interoperability between their portfolios of construction software.[55]
- *Educate project owners on the advantages* of using BIM, and encourage them to use it early in the planning process. Launch initiatives, such as value proofs, joint pilots and digital-skills training courses for clients, to speed up the adoption of new digital technologies.
- *Expand into construction and underserved markets* by adapting to the specific needs of construction companies. Address new links in the value chain and/or new market segments. Offer operators a clearer value proposition for their use of the BIM model after handover. Ensure that everything is working smoothly at the interfaces between BIM and adjacent facility- and asset-management systems and building-automation systems. Provide holistic solutions for the entire design-build-operate life cycle.

Ultimately, digital technologies will realize their full potential only if they are widely adopted as an industry norm. It is crucial to create a fertile environment for the digitalization of the E&C sector. In any given country, that is the task of the government, as regulator and incubator, and often as a key project owner. (see Chapter 4)

The ongoing transformation of the construction industry will rely increasingly on BIM and the other digital tools. The potential is there – both for coordinating all the stakeholders of construction projects and for facilitating construction processes on-site. The latter aspect needs to be tackled from two sides: suppliers of digital tools have to create products relevant to construction; and contractors have to rethink their approach to construction processes and operations, so these become amenable to digital tools like BIM. This rethinking is the theme of the next section.

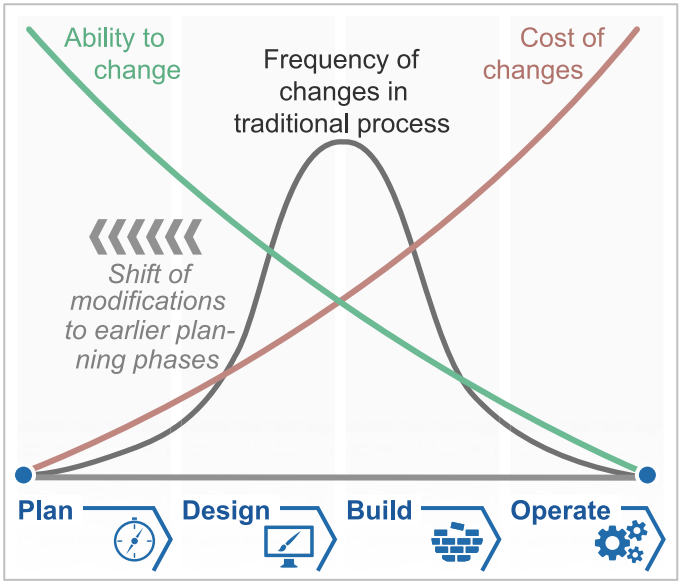
2.2 Processes and operations

Front-loaded and cost-conscious design and project planning

From a TCO perspective, construction's share of the total cost over the lifetime of the asset can be as high as 10-50%, while the O&M costs may account for 40-80%.[56] These two major cost components are largely determined early on, during the design and engineering phase. At this early stage, it is still relatively easy and inexpensive to make changes: hence the case for smart front-loaded design and engineering, as highlighted in Figure 10. By making whole-life-cycle-conscious decisions and finding the right innovative solutions, project planners can create significant value.

To achieve substantial improvements in construction productivity and to reduce O&M costs, companies need to ensure that, during the design and engineering phase, they keep the actual construction process in mind, as well as the final operations phase. This early phase should ideally incorporate the knowledge of all companies along the value chain – the main contractor, subcontractors, suppliers, and later on the asset's operator, owner and maintenance firms. From the outset, stakeholders, especially of large and complex construction projects, should give prominence to project planning and scoping – for instance, by conducting sophisticated needs assessments and feasibility analyses. Alarmingly, projects sometimes go to tender and even begin construction *before* detailed scoping and planning have taken place.

Figure 10: Cost of Changes in the Construction Life Cycle



Source: World Economic Forum; The Boston Consulting Group

Companies across the value chain can enhance front-loaded design and project planning by adopting the following procedures:

– *Highlight and plan adequately the construction and O&M phases* (do so during the design and engineering phase) and continuously analyse the impact of all design and planning decisions. Apply Design for Manufacture and Assembly (DfMA) – that is, design that facilitates the manufacture and assembly of components. And consider, as soon as possible, what the optimal O&M regime might be, and how that might influence the asset's requirements, the design and the eventual handover of information to the operators.

  EXAMPLE: *Fluor* has achieved a noticeable reduction in direct scaffolding costs by starting its pre-planning of the construction process very early, in the early design and engineering phase.

  EXAMPLE: *Atkins* embraced the opportunities offered by DfMA in a Priority Schools Building Programme in the United Kingdom. The measures included investing in off-site manufacturing capability, using BIM to speed up and coordinate aspects of design, using common specifications and details across projects, and adjusting the business model to produce more detailed information earlier in the process. As a consequence of these innovative measures, construction time decreased considerably and safety on the construction site improved greatly; the project cost and lifetime cost (such as energy consumption) were reduced and became more predictable; and the project as a whole proved much more environmentally and socially sustainable (causing less neighbourhood disruption, for example) than if more traditional approaches had been adopted.

– *Ensure successful know-how transfer across phases.* This could be achieved by transferring construction experts temporarily to the engineering team, or by using the same project manager across both the engineering and the construction sub-phases. It usually entails new delivery methods with early involvement of the contractor, or an approach where a single company is responsible for design, engineering and construction. (See the next section.)

– *Hire external experts* to conduct independent design reviews and to ensure that the construction process is given appropriate weight in the early design phase. For example, a specialized engineering company provides services that optimize the conceptual design of wind parks; the methods include conducting an economic assessment of a park's layout and the energy efficiency, and reviewing (at an early planning stage) technical parameters like terrain conditions.

– *Conduct value engineering* in consultation with all stakeholders

  EXAMPLE: Contractors for a *large infrastructure project in Florida*, which was initially budgeted at $250 million, identified cost savings of up to $70 million by means of a value-engineering approach. Multidisciplinary teams reviewed the project and recommended alternative designs, materials and methods – such as eliminating unwarranted illumination, reusing current roadways and constructing a multi-use path within an existing pavement rather than acquiring a new one.[57]

Innovative contracting models with balanced risk sharing

To realize the full potential of front-loaded and cost-conscious design and project planning, it is crucial to get all relevant parties engaged and well coordinated early on.[58] All those parties involved in the construction process – owners, contractors, subcontractors and suppliers – obviously have a vested interest in on-time performance and on-time payment, and would benefit by shifting away from the classic sequential design-bid-build approach to a more integrative approach.

– *Construction companies could take on new roles* by applying innovative contracting models. In a design-build (DB) approach, for example, a single company could – through a single contract with the project owner – undertake to provide all design and construction services and therefore contribute to better trade-offs between design and construction decisions. PPPs can accelerate infrastructure programmes by tapping into the private sector's financial resources, as well as its skills in designing, building and operating infrastructure on a whole-life-cycle cost basis. An early contractor involvement (ECI) model integrates design development and construction planning by including a contractor in the early planning stages.[59] In the first phase, the contractor advises on project engineering and planning, and a target price is agreed upon; if that target price is met, the contractor will be retained for the construction phase as well.

  EXAMPLE: The contractor in a *pilot project of six windmills in the United Kingdom* participated in an ECI model when the project's feasibility became doubtful owing to the soaring price of the required steel. The contractor not only helped to find a cost-effective design alternative but also developed, together with the crane supplier, a bold lifting solution with a reduced counterweight.

– *Companies could also begin by developing and applying smart collaboration models*. Unfortunately, any new, collaborative approach increases the risk of conflict between the partners as new routes are embarked on and clear historic "borders" blur. Witness the recent increase in the length and cost of stakeholder disputes: in 2014, each dispute had an average value of $51 million and lasted 13 months.[60] Certain models of cooperative partnerships, however, can reduce the number of such conflicts or at least accelerate their resolution. They do so by establishing a culture of trust and mutual respect among the participants. Figure 11 provides a non-exhaustive list of measures: their applicability varies according to the type and set-up of the project.

Figure 11: Elements of a Cooperative Partnership[61]

Project culture		Project charter with common project goals	Transparent financials ("open books")	Co-location of teams ("big rooms")	Common data platform (e.g. BIM)
Tendering and contract		Choosing most efficient, not cheapest	Multi-party contract with clear accountabilities	Early involvement of key participants	Prudent management and appropriate allocation of risk
Incentive mechanisms		Alternative cost models, such as target cost	Incentives for cost optimization	Premium for early project delivery	Shared risk/reward ("pain share, gain share")
Conflict resolution		Collaborative decision-making and control[1]	Internal dispute resolution via negotiation	Third-party mediation and conciliation	Decision by adjudicator or arbitrator

[1] Potentially including liability waivers among participants
Source: World Economic Forum; The Boston Consulting Group

– Companies should increasingly use models based on these principles. One such model is an "alliance" between a project owner and private-sector parties for delivering one or more construction projects, where the parties generally have to work together as an integrated, collaborative team. Another such model is integrated project delivery (IPD), with core elements such as target cost pricing, shared risks and rewards, common collaboration platforms like BIM, and cross-functional groups.

EXAMPLE: A study by the *Australian Department of Treasury and Finance* found that companies achieved significantly greater value for money when implementing alliance-based delivery methods in infrastructure projects. The reason is that "alliancing has demonstrated its ability to avoid disputes, improve non-cost outcomes and commence projects earlier than by traditional methods."[62]

EXAMPLE: *The California Pacific Medical Center* used an IPD agreement to coordinate the main participants in a project. The project's owner, architect, project designer and qualified construction manager had a shared risk/reward pool and waivers on liability. The cost of IPD pre-construction services was well worth it, as significant savings followed, and the project achieved a 200% return on investment. The savings can be attributed mainly to the target value design process, which made all design-team members accountable for creating maximum value within the target cost. Further success factors were the co-location of teams, and the compulsory use of BIM by all IPD team members, including trades.[63]

In any of those innovative contracting models – whether DB, ECI, PPP, "alliances" or IPD – it is always important to improve accountability and manage risks effectively. These goals can be achieved by making information available to all stakeholders at an early stage, by ensuring prudent risk-allocation among stakeholders and by encouraging a common risk-management strategy.[64] World Economic Forum E&C Governors and Risk Task Force members identify the key levers as follows:

(i) *control the level of risk exposure* by allocating risk to the party that can manage it best, and understand emerging risks better

(ii) *secure fair compensation for the risks*, by understanding their true value, and educate all stakeholders about them

(iii) *control the cost of risk management*, by acquiring the capabilities needed economically and by sharing specialist resources

A common and appropriate framework for project management

The execution of construction projects all too often relies heavily on the expertise or even intuition of the individual project manager. Even though no two construction projects are identical, the "lessons learned" from any one project can prove very helpful when applied to another. Ideally, companies should institutionalize these lessons, so that project management can undergo continuous improvement across projects.

To establish a common framework for project management in this way, construction companies should consider taking the following steps:

– *Collect and consolidate project-management data.* Among the requirements here are an improved project-monitoring system and a strong reporting tool, enabling the continuous collection of project data.

– *Standardize the identification of best practices.* This includes evaluating the performance of individual projects and developing a portfolio of best-practice processes to accommodate a variety of different projects.

– *Make sure that the best-practice standards actually get applied* at the project level. If necessary, educate project managers and other important decision-makers in the appropriate processes, or make the best practices mandatory.

  EXAMPLE: A *mid-sized Swedish construction firm* reduced the choice of building materials for its on-site project managers, so the workers no longer needed to be familiar with so many components, and errors diminished accordingly.

A key facilitator in implementing these steps is a set of company-wide software tools. These tools will help in connecting islands of information, making information easily available and simplifying actual project management (by providing support for scoping, scheduling or costing).

A final note in this regard: formerly, the term "project management" was often used to refer merely to the execution component of a construction project, and the emphasis was mainly on the project manager's ability to deliver in line with budgets, timelines and specifications. Modern project management, however, concerns itself with the planning and strategic components as well; it engages with the "front end", for instance, as the source of particular benefits and value, and assigns great importance to the interdisciplinary, interpersonal and integrative aspects of the project manager's role.[65]

Enhanced management of subcontractors and suppliers

In many developing countries, purchasing materials and components poses a serious problem – namely, the shortage (often temporary) of some critical resources, such as cement or steel. In complicated projects, as in the petrochemical industry, companies – even in developed markets – often have to import components from other countries, and the delivery status and current location of those components may be unclear. As a result, projects are delayed; alternatively, companies will build up large stocks of some materials in an effort to compensate for an unreliable supply chain, and will thereby tie up large amounts of working capital.

It is crucial to integrate suppliers and subcontractors more effectively, and that task falls mainly to the main contractor. Various measures are available, not just in the planning phase but throughout the entire project. The goal should be to establish an agile supply chain able to respond flexibly and promptly to changes in the external environment (weather-related hold-ups, changes in scope and schedule, regulatory changes) and integrate well with other parts of the business in addition to procurement. The supply chain as a whole should be regarded as a business partner.

The first step for a contractor might be to *consolidate some of its internal functions* – such as procurement, quality and logistics – into a central team, to work more closely with the supply chain.[66] The contractor would then abandon the old system – multiple, ever-changing transactional supply contracts, with great complexity and little reliability for both sides – and switch to a new system involving fewer contracts but more *strategic long-term cooperation*. Such a switch not only will reduce the contractor's administrative burden and initial set-up costs, but will enable suppliers to conduct long-term planning, and will often bring innovations to the market. Nevertheless, the long-term commitment should be accompanied by a *transparent, fair and regularly revised evaluation of the suppliers*.

EXAMPLE: The UK-based contractor *Prater* recently won a supply-chain-integration award for its long-term commitment to its suppliers; the company hosts an annual supply-chain conference, for example, where common strategies are developed.[67]

EXAMPLE: The US-based homebuilder *David Weekley Homes* conducts a quarterly evaluation of its suppliers' performance in areas such as reliability, communication and timeliness, and honours "partners of choice" with annual awards.[68]

Finally, the increased adoption of digital technologies like BIM can also help to integrate the supply chain more closely. It could improve service levels and reduce costs, particularly by connecting disparate systems and by providing end-to-end visibility into the supply chain.

EXAMPLE: *SAP* solutions for *Connected Construction* aim to connect all construction equipment onto a single platform and to ensure just-in-time delivery of supplies. The process involves analysing real-time operational data, monitoring exceptions, forecasting changes and adapting to them dynamically as they occur on construction sites.

Lean and safe construction management and operations

Following Toyota's innovative use of "lean" methods to improve productivity in automotive manufacturing, many companies in discrete and process manufacturing industries have applied "lean" to manage complexity and drive step-change improvements in efficiency. For project businesses like construction, it is more difficult to apply "lean", given the great complexity of their operations (one-off projects, varying teams, and so on) and the challenge of external factors such as the weather.

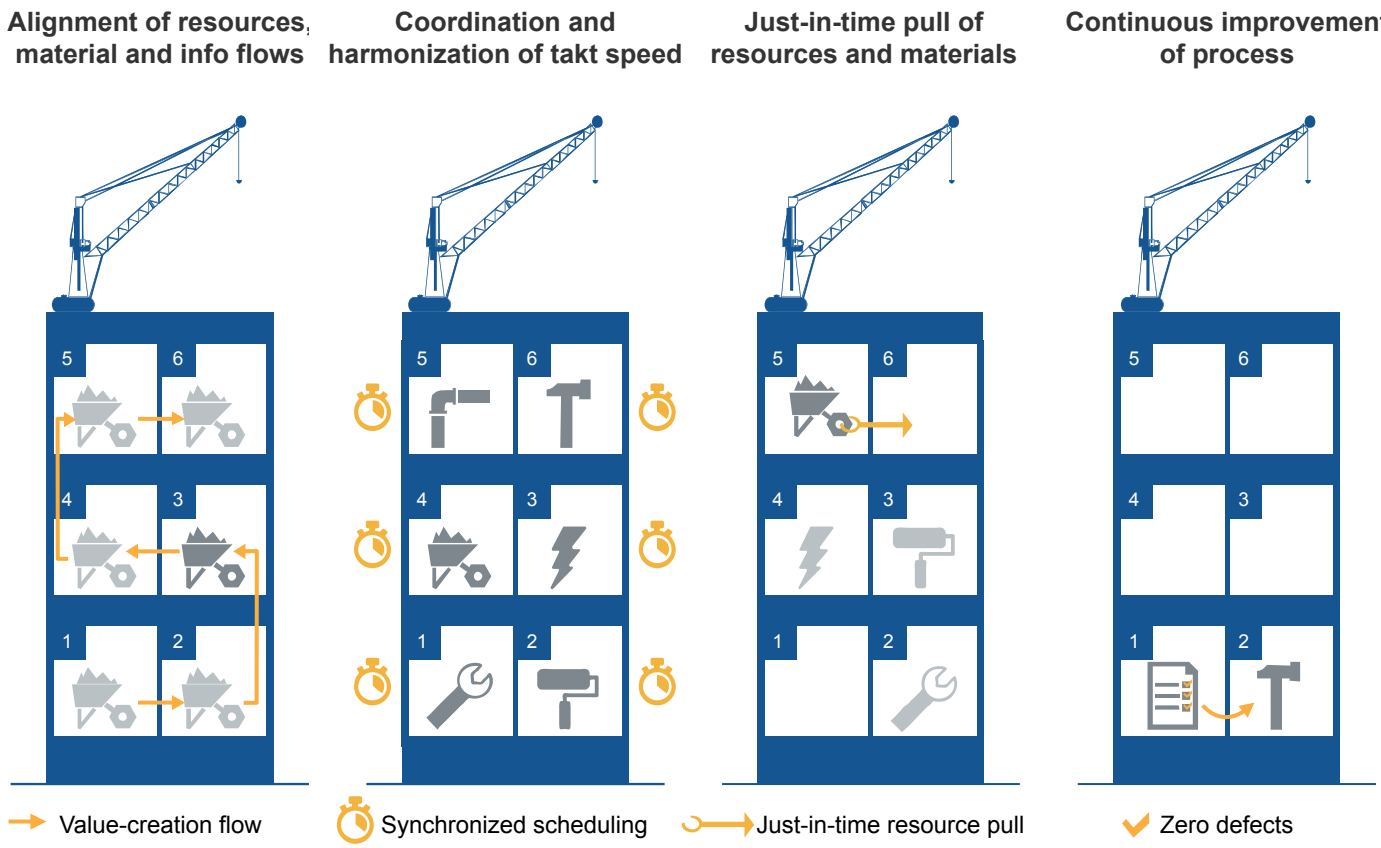
That said, those construction companies that have successfully applied lean methods have reduced construction time by up to 30% and reduced costs by up to 15%. But the adoption of lean methods is still not widely prevalent in the construction industry, despite the relatively low investment needed. To make major and lasting productivity improvements, the industry must embrace lean construction more broadly.

A lean approach reduces complexity and uncertainty by reducing waste and non-value-adding activities throughout the entire value chain: it reduces, for instance, schedule deviations, waiting, stocks of building materials, transportation, rework and unused or underutilized resources. In that way, it makes processes more stable, predictable and efficient.

Four core principles underlie the use of lean methods in construction projects (see Figure 12):

- *Alignment of resources, material and information flows.* Optimize the construction process by, for instance, identifying repeatable elements and sequencing the various work shifts accordingly. For example, the building could be divided into several sections to allow a value-creation flow based on the orchestrated movement of subcontractors and craftspeople through each section.
- *Coordination and harmonization of takt speed.* (Takt speed is, roughly, the work pace or rhythm; typically, work cycles vary from one day to one week.) Synchronize the steps, identify and ease bottlenecks, and smooth the flow of construction work to avoid idle times by, for instance, sizing teams appropriately and moving rework to night shifts or weekends.
- *Just-in-time pull of resources and materials.* Plan work at the "request" of a downstream "customer". Ensure that the availability of materials is in sync with the progress of construction by, for instance, transporting materials "just in time" and to precise locations on the site. This approach also promotes flexibility, by allowing contractors to accommodate their clients' last-minute decisions.

Figure 12: "Lean" Principles in Construction[69]



Source: BCG Lean Construction; World Economic Forum

– *Continuous improvement of processes.* To minimize delays and defects, implement continuous monitoring and make use of regular feedback loops via, for instance, daily and weekly meetings and project steering routines.

EXAMPLE: Despite an initial six-month delay on a plant project in Brazil (due to the need for soil improvements), *BMW* nevertheless completed the construction extremely efficiently: it managed to halve the expected construction costs and build 50% faster than scheduled. This success was largely due to the rigorous adoption of lean construction methods. Prefabrication, for example, enabled takt planning for iterated quadrants; regular stand-up meetings, on-site dashboards and key performance indicators (KPIs) were used to create transparency and to improve the exchange of information; and integration workshops, conducted for suppliers at each project phase, improved collaboration.

Lean processes bring about improvements not only in cost and delivery time but also in quality and safety. Safety is a crucial area of action for the construction industry, during all project phases. The industry has made great progress in the recent past, yet it remains one of the most dangerous industries to work in.[70] It must continue its efforts to reduce the hazards involved and to raise labour standards in construction globally. This imperative applies to the whole supply chain, and it is particularly demanding: the fragmentation of the industry, together with a lowest-price culture, often entails compromises on labour or environmental performance, as evident in informal employment arrangements.[71] New digital tools can help greatly in this crucial endeavour; for example, RFID enables automated collision prevention of workers and machinery. But it takes more than technology, of course: more rigorous approaches are also essential if safety is to improve.

EXAMPLE: *Fluor* addresses the risks to workforce health and safety by launching detailed investigations into even minor incidents, such as a "near miss" when a machine almost has a collision – even if it was "only" with a fence.

Rigorous project monitoring (scope, time, cost)

For the construction industry, accurate and up-to-date budgeting and scheduling are particularly acute challenges. The issue for construction companies is not only the frequent deviations from the estimated costs and schedule; it is also the late detection of these deviations. Typical reasons would include unexpected soil conditions and scope changes agreed on a lower operational level that turn out to have major implications. This late awareness limits the companies' ability to take timely mitigation measures or to revise the contract. In many cases, the financial and reputational consequences are severe.

Currently, project monitoring in the construction industry often consists of little more than post hoc documenting of the cost overruns and construction delays. Project monitoring needs to become more real-time and forward-

looking than that, and to provide data that can immediately be translated into action – action that will bring projects back on course. The following steps are recommended for companies:[72]

– *Establish the right metrics, and monitor continuously.* Define appropriate KPIs that create transparency on the project's progress and enable early identification of any deviation. Monitor regularly, ideally every day, the schedule adherence of each process cycle, and report it as being either "on track" or "requiring action". Leverage state-of-the-art digital tools, big data and new construction equipment in order to generate project-monitoring data more efficiently.

  EXAMPLE: *ImageIn Flight* is using drones equipped with cameras to generate 3D footage of construction sites continuously. Sophisticated software then compares this data against architectural plans and previous images in order to measure progress and identify areas in need of action.

– *Communicate early and inclusively.* Make sure to clarify and visualize all relevant information regarding the construction project in order to foster communication about the schedule and plan. For example, if displayed steering boards show the status of KPIs for scheduling and quality, that should enable teams to track progress regularly and to stay informed about the common goals.

  EXAMPLE: A public shipyard achieved impressive productivity improvements by means of enhanced collaboration and accountability between different teams, using a concept called "project room". The project room, as a central collaboration forum, hosted daily stand-up meetings, lasting just 30 minutes, where all relevant functions were represented – engineering, purchasing, production engineering and production. Each function displayed its own information panel, featuring various colour-coded KPIs, the current state of progress, and a list of ongoing actions.

– *Take the appropriate remedial action.* Introduce processes for translating enhanced monitoring capabilities into improved construction practices, for example by establishing a project-quality-gate cycle involving regular site controls that immediately trigger corrective measures where necessary.

  EXAMPLE: *Fluor* uses a system-dynamics model to simulate the impact of potential changes on a diverse range of construction projects, and thereby to improve decision-making and client information. By seeing the cause-effect paths, planners can more easily establish what remedial actions would be most effective in reducing the impacts.[73]

BIM can play an essential part here: it comprises the graphical model of the asset, information on construction sequences over time and information on costs, and thereby allows for continuous monitoring.[74]

Another important topic is the need to capture "as-built" information from projects, in contrast to "as designed", which is what the original design drawings contain. This is of paramount importance: unless it is possible to know how the asset has been built on the ground, accurate life-cycle performance models cannot be developed and life-cycle costs cannot be optimized via the intelligent planning of future maintenance and rehabilitation actions. Especially with the help of modern equipment and technology, the necessary information can be captured and "as-built" records developed. That will help not only with optimizing the life-cycle costs, but also in confirming that an asset has been constructed as originally intended and thus in protecting clients from fraudulent contractors.

EXAMPLE: *Atkins* has worked with several clients worldwide, including *Heathrow Airport*, to advance the leverage of laser scanning technologies to automate 3D/BIM model creation and support a basis for asset tagging and management to optimize O&M.

2.3 Strategy and business model innovation

Differentiated business model and targeted consolidation and partnerships

Competition in the construction market is traditionally fierce, and margins are accordingly slim. Many construction services are highly commoditized, and tender procedures exacerbate the cost pressure. Many firms are therefore seeking opportunities to differentiate their services in the marketplace and identify their "sweet spot" strategic focus. They need to define their sector coverage – finding the right balance between specializing in a specific industry and developing customized solutions on the one hand, and becoming more general and thereby achieving economies of scale and diversifying risk on the other. And they also need to decide on their value-chain coverage – that is, their scope of services from design and engineering to construction to O&M.

Given the varied and sophisticated customer requirements in today's construction markets, many E&C firms struggle to develop the required know-how internally. One response is to improve collaboration on a project level, as discussed in section 2.2, or on an industry level, as discussed in section 3.1. Another response is to partner with, merge with, or acquire other companies – especially if the target company has mastered the latest technologies or complements the portfolio – as part of a strategy to integrate along the value chain.

EXAMPLE: *Fluor*, in response to the need for great capital efficiency from clients, has focused on being an integrated engineering, procurement, fabrication and construction company. It also plans to integrate further services, such as operations, maintenance and water treatment. It has invested in additional fabrication capacity, allowing for modular execution with pre-assembling, and – in keeping with its aim of strengthening its integrated-solutions capabilities – it recently announced the acquisition of *Stork*, a global provider of maintenance, modification and asset-integrity services.

Liaisons with start-ups or other firms with a digital background can also help large established companies to absorb digital advances quickly and effectively. For instance, a US E&C giant recently partnered with the technology start-up company *Skycatch*, which has unique expertise in the use of drones.

As the boundaries between traditional roles and companies begin to blur (thanks to BIM, for example), new disruptive business models will emerge. Consider the following two examples, which are trying to redefine ways of construction:

EXAMPLE: The British insurer *Legal & General* will invest £50 million in a "flat pack" housing factory to prefabricate complete homes, including white goods and interiors.[75] As part of this disruptive move, the insurance giant has teamed up with the Dutch pension-fund manager *PGGM*. They will construct 3,000 apartments across the United Kingdom, under a £600 million "build-to-rent" plan, to help tackle the housing crisis.

EXAMPLE: *Aditazz* describes its "visionary" approach to construction as being based on innovation, particularly by integrating technology, design and modular manufacturing. From architectural work via engineering to final project delivery, the company handles all aspects of building new healthcare facilities, by means of a single innovative data-driven platform. That suggests a business model heavily inclined towards investments in technology, processes, people and the integration of the supply chain, and a unique selling proposition based on innovation.

Sustainable products with optimal life-cycle value

On a typical vertical construction project, over 30 years of a building's life, the present value of O&M and utility costs is nearly as large as the initial project costs.[76] Even so, it is still not standard in the industry to make a deliberate life-cycle-cost optimization of the final asset. Multiple possible reasons explain this neglect. One reason might be conflicting interests between developer, constructor and asset owner, owing to trade-offs between initial investments and the subsequent life-cycle costs. Another might be the absence of a neutral and unbiased view of the life-cycle value of built assets.

To remedy this unsatisfactory situation, the industry should invest in designs and systems with improved long-term life-cycle performance – considering not only the "first costs" of a building (design and construction expenses) but also long-term costs, such as utilities, O&M and externalities. Several companies are conducting pilot schemes to test such new systems, collect information and generate convincing evidence of value.

EXAMPLE: *LIXIL's U²-Home* and *IoT House* products use sensors to collect data from residents, and then use the data to derive patterns and insights related to human-centred living technologies. In addition, *LIXIL* has developed wireless power-supply tiles based on magnetic field resonance and is thereby improving the life-cycle performance of buildings. The construction phase benefits from the increased flexibility, now that power is available through the building materials; the operations phase benefits, in that lighting and other light home appliances can now be powered without the complication of electrical wiring.

EXAMPLE: *Bre innovation parks, w*ith current hubs in the United Kingdom, Brazil, China and Canada, are showcase neighbourhoods that experimentally incorporate new sustainable construction technologies with increased life-cycle performance. For instance, an insulation material, originally developed by NASA, has been adapted for use in window blinds that control heat in different seasons, and can save up to 40% of energy costs during the operations phase.

In addition to developing products with optimized whole-life-cycle costs, construction companies need to follow another strategic imperative, namely, to incorporate principles of sustainability into their strategies and business models. Given the scarcity of natural resources and the high societal cost of construction externalities (notably, the emission of carbon dioxide, and the pollution of soil, water and air),[77] the industry has a major opportunity here to contribute to a more sustainable world economy. Just consider the amount of construction and demolition waste that is currently not recovered in the United States (see Figure 13) and the manifold opportunities for recycling.

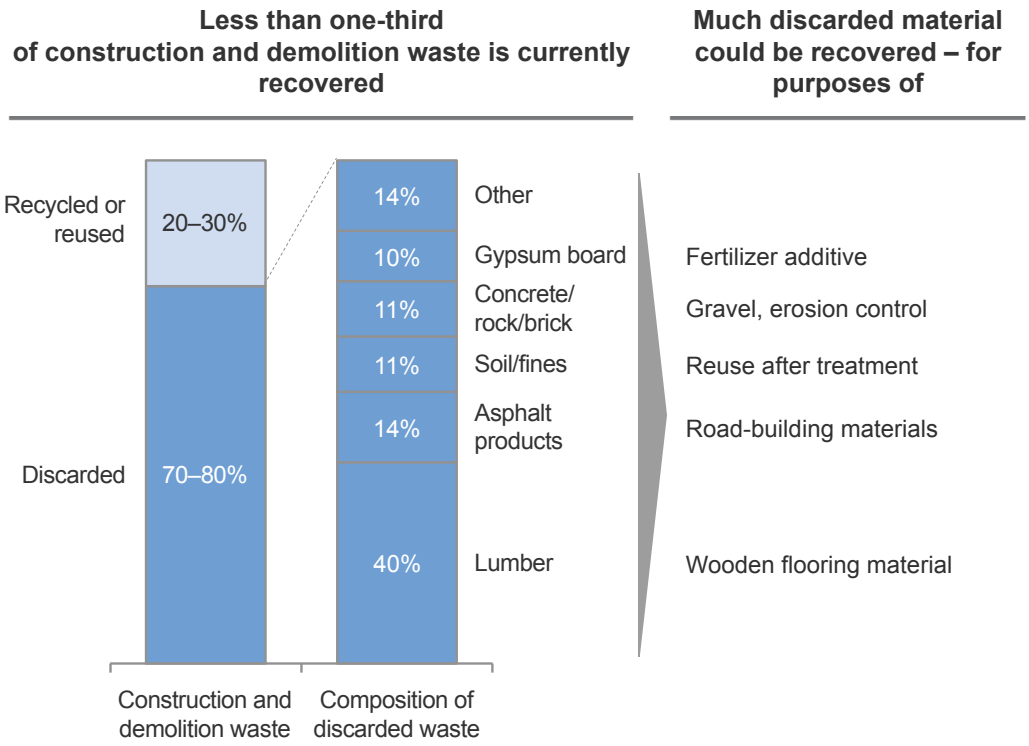
To make their business more sustainable, construction companies should consider closed-loop circular design principles as described in Figure 14, and embed them into their product portfolio and business models.

EXAMPLE: *Tarkett has* committed to making a transition to the circular economy and has developed an approach called *Closed-Loop Circular Design*.[79] The foundations of this approach include choosing "good" materials that can be recycled; minimizing the environmental footprint during production (by such means as a closed water cycle, or the use of biomass to produce energy); creating products containing, for instance, minimum levels of total volatile organic compounds; and changing from an end-of-life to an end-of-use mindset for products.

Another worthwhile endeavour is to develop and institutionalize new forms of planning that incorporate sustainability and whole-life-cycle concepts.

EXAMPLE: *Atkins* applied Transit Oriented Development – an approach to development that focuses on land uses around a transit station or within a transit corridor – in all development phases of the *Cadre International Center* in Guangzhou. The results included improved living, working and commuting conditions, and enhanced use of public transport. Atkins also applied a new type of urban planning, aimed at boosting sustainability from the earliest stages. In close collaboration with China's Ministry of Housing and Urban-Rural Development and other stakeholders, Atkins developed a clear, practical framework, incorporating a sequential, process-based, step-by-step agenda for sustainable urban planning.

Figure 13: Construction and Demolition Waste: A Notable Opportunity[78]



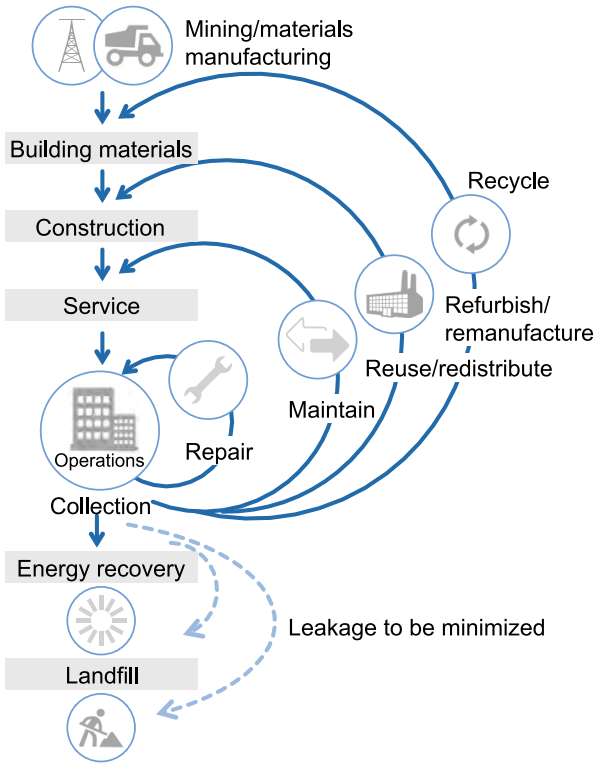
Source: Ellen MacArthur Foundation; World Economic Forum; The Boston Consulting Group

Internationalization strategy to increase scale

Construction firms have traditionally focused on their home countries, as construction is a local business in which local relationships, assets and resources are extremely important. This tendency militates against economies of scale, however, especially for very large, complex construction projects. As emerging countries accelerate their urban and industrial development, new construction markets are opening up for developed-country companies. At the same time, emerging-country companies are interested in getting involved in projects in developed countries. It is crucial for all companies in the industry to develop a clear internationalization strategy.

Many companies are already establishing a foothold in foreign countries and striving to boost their market share there. When entering new countries, companies will usually find that the best strategy is to cooperate with local firms, via strategic equity alliances and joint ventures, or else to pursue mergers and acquisitions. In that way, they can combine their own expertise with the incumbent partner's local knowledge and relationships. In many fast-growing markets, the local authorities actually advise, request or even require such partnerships. The value of local partners is particularly high in respect of understanding national or regional regulatory requirements, dealing with the local labour force, and negotiating a way through cultural or

Figure 14: Circular Economy Principles in the Construction Value Chain[80]



Source: Ellen MacArthur Foundation; World Economic Forum; The Boston Consulting Group

bureaucratic obstacles. Choosing a local partner is seldom easy, however, as knowledge of the candidates is limited.

EXAMPLE: Through acquiring *Foster Wheeler* in 2014, *AMEC* increased its presence in the Latin American market, gained additional expertise in the oil and gas segment, and doubled revenues from developing markets. In 2015, the newly merged company formed a joint venture with the Ghanaian company *BBS Engineering* to combine the incumbent's local skills, knowledge and experience with its own international standards and global capability and quality.

EXAMPLE: *Atkins* recently announced the acquisition of *Howard Humphrey*, based in Kenya and Tanzania, thereby expanding its global infrastructure presence into East Africa. Atkins is leveraging Howard Humphrey's engineering consultancy and project management services in the transportation, water and property markets.

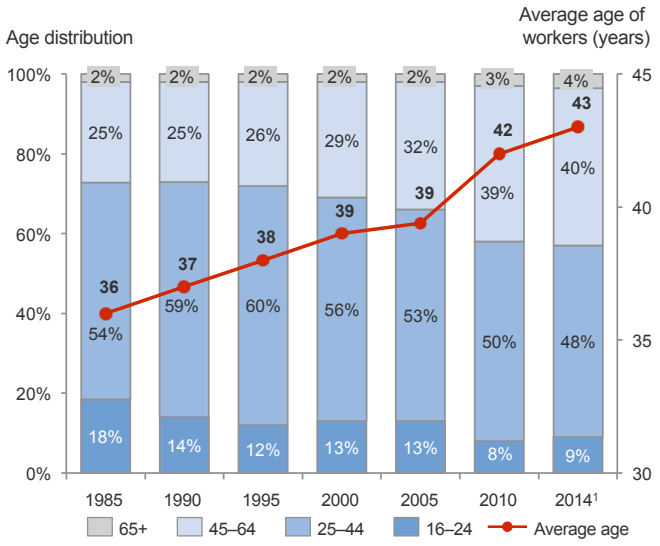
2.4 People, organization and culture

Strategic workforce planning, smart hiring, enhanced retention

The E&C industry will face stiff recruiting and talent challenges in the years ahead. One major challenge is the prospective scarcity of skilled labour, driven by demographic shifts in developed countries. A case in point is the United States: between 1985 and 2014, the average age of construction workers surged from 36 to 43 years, while over the same period the proportion of soon-to-be retirees (aged 45 to 64 years) increased from 25% to 40% (see Figure 15).[81] Another serious challenge relates to the increasing sophistication of technology, which demands new and broader skill sets at all levels of a company. A final challenge is the high volatility of workforce demand and composition: staff demands become evident at short notice following a competitive tendering bid, and the execution of contracts typically requires the short-term integration of a transient workforce from multiple subcontractors.

> **Our business is really all about people. You can have equipment and financial resources, but to truly succeed in a business like ours you need to have the right people in the right places.**
>
> Peter Bjork, Vice-President, Information Systems Strategies, Skanska, Sweden

Figure 15: Worker Age in the US Construction Sector, 1985-2014[82]



¹ Latest figures available
Source: US Bureau of Labor Statistics; World Economic Forum; The Boston Consulting Group

In response to these challenges, construction managers need to engage in *strategic workforce planning*, in order to anticipate their company's workforce needs and priorities well in advance. In addition, they need to develop pre-emptive measures, such as comprehensive talent management, including *smart hiring* and *enhanced retention* strategies.

Strategic workforce planning. This planning involves a scenario-based approach that will keep a business sustainable from a people perspective. The steps are as follows:

1. *Take a long-term view of workforce demand*, by simulating the future project pipeline. This forecast should be made on a granular skill-cluster level: it should consider, for example, future skills requirements in the digital space or the need for local market experts, but also expected productivity gains through technological advances. Note that changes can go both ways: there will be a need to upgrade relevant (digital) skills and provide the appropriate training; on the other hand, some complex tasks will now be performable by lower-skilled workers, thanks to decentralized information and perhaps augmented reality.
2. *Simulate the workforce supply accordingly* based on existing staff rosters; consider, for example, shifts in age profiles and capacity losses through attrition.
3. *Identify gaps and risks*, and devise, on that basis, an executable workforce plan, including interventions to address any over- or under-supply of staff and any skills gaps. Initiate measures, such as recruiting, training, transfers, in-/outsourcing or lay-offs, appropriate to the significance for the business and to the time for qualification. For instance, in more developed markets, the construction sector could provide good entry-level jobs for refugees, whose upskilling potential is great, and who could rejuvenate the current workforce.

EXAMPLE: *Fluor* maintains a database of information on high-performing employees – their experiences, training, mentoring and career goals – and matches it with the expected demand over the next decade in each of the 30 countries where it operates. In this way, the company can align global talent-development efforts with its long-term strategic plans.

Smart hiring. In a 2014 survey of more than 1,000 construction firms in the United Kingdom, 36% of the firms that had tried to recruit skilled staff reported difficulties in filling the positions. This recruiting problem spans all occupational groups – from skilled workers at the construction site to functional specialists at headquarters.[83] In an industry with a traditionally poor employer image on the labour market, smart hiring practices can be a powerful tool to attract the requisite talent. Besides investing into a strong recruiting brand, managers of E&C firms and suppliers should consider taking the following steps:

– Establish customized recruiting channels for key target groups; set up a social-media-focused recruiting team; build up capabilities to address unfamiliar candidate pools (such as IT specialists).

– Increase efforts to achieve gender equality in construction; that involves not only making changes to attract more women, but also recognizing and building on the strengths and characteristics of women.[84]
– Promote the role of technology and the broader societal impacts of construction, especially when pitching jobs to younger people.
– Engage in partnerships that create a pipeline of suitable candidates (for example, university collaborations).

Enhanced retention. Ultimately, the success of any human resources strategy depends critically on the company's ability to create a "preferred employer" position and thereby to retain the requisite diversity of skills and the right number of top project managers. According to the US Bureau of Labor Statistics, the E&C industry records some of the highest employee turnover rates across all industries – in 2014, a remarkable 21.6% of construction workers quit or had to quit their job. This churn is particularly troublesome in long-term large-scale projects.[85] In the United States alone, unwanted employment turnover is creating additional costs for E&C companies estimated at $140 billion annually, in recruiting, training and administration.[86] For E&C companies to mitigate attrition, the following measures are crucial:

– Provide attractive benefits, both intangible (such as training and recognition) and tangible (notably, adequate compensation packages and retention-incentive programmes).
– Tailor messages and career-development offerings to target groups (women, for instance, or millennials).
– Cater for the specific needs of older workers (including workers with reduced physical capacity) – for example, by pairing them with junior workers in blended crews.
– Consider all psychological aspects (corporate social responsibility, executives as role models, and so on).

EXAMPLE: For several years in a row, *DPR Construction* has been ranked among Fortune's "100 Best Companies to Work For". Notable elements of the company's human resources strategy are a strong mission statement ("we exist to build great things") and progressive values (integrity, enjoyment, uniqueness and ever forward); title-less business cards to allow individuals to take on multiple roles and levels of responsibility; an open-office environment, including wine bars; and free use of company-owned vacation property.

Continuous training and knowledge management

Continuous training of staff can help to address the various challenges confronting the E&C industry – the demographic changes, the technological and process advances, and the legislative and regulatory requirements. For instance, project managers will eventually manage multi-billion dollar projects – and the required skills need to be developed accordingly, starting in the early stages of a career. In addition, the provision of training can make employees feel more appreciated and can contribute to a more vibrant company culture. Relative to other industries, construction companies conduct few people-development initiatives. In the United Kingdom, for example, only 57% of construction firms funded or arranged training for their staff in 2015; just one sector fell below that figure – the agriculture sector, with 50%.[87]

Effectively designed training systems should improve both the performance and the engagement of workers, and also their health and safety. The best practices include the following:

– *Align training efforts to business strategy.* Design or adapt training programmes and curricula to prepare employees for the organization's current and future needs. Occupational safety and health (OSH) training should be a key element.[88] Break down functional silos by, for instance, complementing technological know-how with commercial capabilities, or broadening the skill set through job rotation along the value chain. Pay adequate attention to soft skills (notably, leadership or cultural interests) and hard content (such as lean construction or project management). One of the top priorities of many E&C companies over the next few years will be the upgrading of digital skills.[89]
– *Offer rich development opportunities.* Effective training combines multiple approaches: in-house and external (for example, through partnerships with education providers, corporate universities or key suppliers, such as chemicals or equipment firms), as well as formal (classroom courses) and informal (coaching and mentoring, on-the-job) to ensure that knowledge is efficiently transferred to the younger generation. Exploit technology, by adopting e-learning, simulation-based training and automated tracking of learning progress.
– *Include all staff.* Customize offerings to different target groups (for instance, construction workers, functional experts, senior management), taking into account the different needs of diverse generations within the workforce (traditionalists, baby boomers, generation X, millennials).

EXAMPLE: *Fluor* recently gave $1 million to the University of Houston to establish a partnership in construction-management education, focusing on research and professional development.

EXAMPLE: *Skanska* has implemented an organization-wide, cloud-based training system to continuously track capability development along the employee life cycle. For example, as employees take classes, the supervisors can consult the system to monitor progress and align the content to each individual's development plan.

So, people development ensures that staff continuously grow and acquire the right skill set. It does so by leveraging the company's knowledge base. But what happens to the extra knowledge or intellectual capital that is being created every day on projects or in internal R&D? That too needs to be actively managed and exploited. *Knowledge management* should be given a key role on any corporate agenda, yet many construction firms make poor use of such a rich resource. Accordingly, they fail to benefit from experience as they move from one project to another,

working with different partners along the value chain. E&C companies need to take action in three main areas, as follows:

- *Take a structured, coherent approach to knowledge management.* Implement appropriate processes and functions, so that the capture, consolidation, dissemination and reuse of (project) knowledge become everyday activities. By institutionalizing things in this way, companies enable their employees to access and apply the right knowledge, at the right time and in the right place.

  EXAMPLE: *Fluor*'s Vice-President of Innovation brings innovations into the organization by acting as a cauldron of ideas, evaluating new methods qualitatively and quantitatively; Fluor's Vice-President of Continuous Performance Improvement makes sure that tools and techniques are continuously updated and improved.
- *Foster a culture of proactive knowledge sharing.* In the E&C sector, many experienced professionals view knowledge as power and are reluctant to share it. What's more, the workforce often seems unwilling to learn from others' experiences. To overcome these cultural barriers, companies need to clearly articulate objectives and guiding principles for knowledge sharing – and provide appropriate incentives.
- *Create transparency on the internal skills available.* Given the enormous variety of construction projects and the difficulty of instantly finding individuals with the relevant expertise or project experience, E&C companies should maintain centrally an accurate employee database. Only in this way will they be able to optimize their workforce allocation. The database should include at least the work record and project experience of each employee, and thereby facilitate the informal exchange of knowledge.
- *Leverage technology.* Information technology has long been recognized as a critical facilitator of successful knowledge management. Among the most common and useful tools are groupware systems, intranets and extranets, and content management systems. For E&C companies in particular, BIM has the potential to greatly facilitate the management of project knowledge – for instance, by integrating comprehensive object libraries and by enabling real-time, on-site access to supplementary information. Companies can also derive great value from augmented reality, as a means of providing visual instructions to workers on-site, particularly those engaged in O&M work.

EXAMPLE: *Arup's* approach to knowledge management is regarded as one of the most advanced in the E&C industry. The company's resources include:

(i) a system for capturing lessons learned on projects and for accessing key project data

(ii) a comprehensive BIM library with more than 25,000 objects

(iii) virtual communities that globally link employees who work on different projects but face similar problems

(iv) various facilitation techniques to encourage knowledge sharing (for example, Arup university lectures, workshops and story-telling events)

High-performance organization, culture and incentive schemes

Many construction firms are still characterized by a rather conservative company culture and mindset, and are often hampered by organizational inertia. To support their overall business goals, companies need to drive organizational change – an iterative process, which requires careful alignment of company culture and goals, organizational design and incentive schemes. In particular, it involves the following steps:

- *Conduct an organizational "health-check" and refine the company's purpose and culture.* Evaluate the degree to which company culture and the working environment are conducive to individual and team performance, innovation and improvement, collaboration and knowledge sharing, ethical principles (for instance, related to safety, the environment or transparency), diversity and inclusion, and openness and trust. Create a (revised) mission statement and statement of values, as well as a detailed plan for achieving new goals.

  EXAMPLE: *Skanska* crystallizes its company purpose in the motto "We build for a better society" and its core values in the injunction "Care for life, act ethically and transparently, be better – together, and commit to customers". These credos underline the company's focus on ethics, responsibility and sustainability.
- *Establish a supportive organizational design.* Construction is a local-project business that requires decentralized operative decision-making, close to the client. In such a context, it is perhaps more difficult,

though no less important, to create an effective organizational design that reinforces a common company culture and supports strategic objectives. In optimizing the organizational design, E&C managers should consider taking the following measures:

(i) Align the organizational design with individual capabilities and roles, accountabilities and collaboration

(ii) Define appropriate structures and operating models for corporate, support and project functions; choose the appropriate structure (notably sector, regional or matrix perspectives), carefully aligned with strategic goals; define clearly the role of the centre, and pursue the solution that is best for the company rather than for the project (for instance, apply frame contacts more rigorously)

(iii) Streamline the organization (by de-layering, for instance) and optimize work dynamics (for example, by applying lean principles); develop hybrid organizational solutions offering the best of both worlds (centralized vs decentralized) and finding a compromise between scale and efficiency, while maintaining a business focus (for instance, a centralized organization for megaprojects, such as nuclear power stations, requiring global expertise vs a decentralized organization for municipally-driven local projects, such as water supplies)

(iv) Break down silos: reduce cultural differences between different parts of the organization, and ensure that staff of newly acquired companies are properly integrated

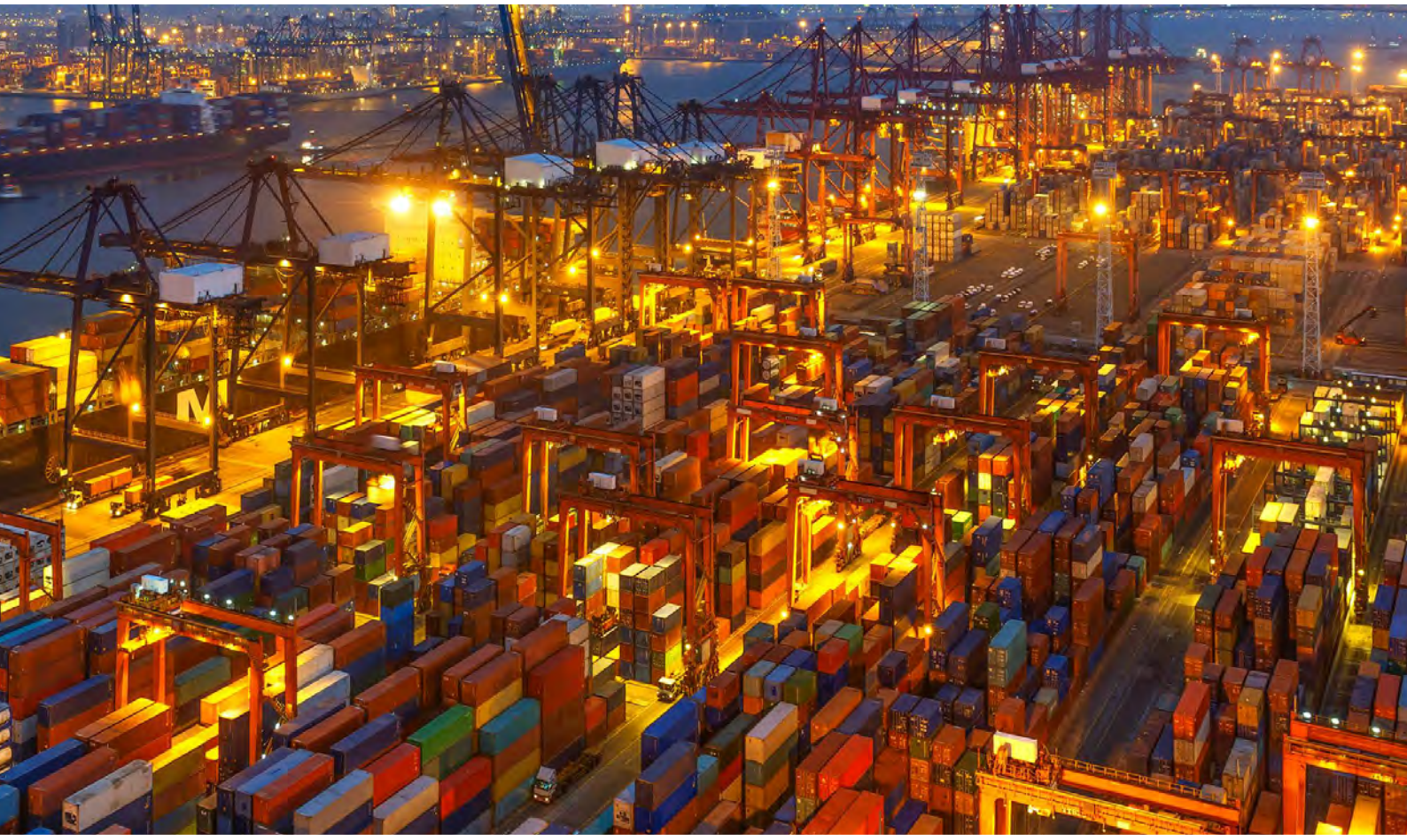
– *Incentivize desired behaviours.* Establish incentive schemes and related measures to reinforce engagement and affiliation and to drive behavioural change:

(i) Motivate value-maximizing behaviour, aligned with business objectives (for example, reward over-fulfilment – instead of bare fulfilment – of time/budget targets); make sure that individual, project-based performance goals are in line with overall company aims; establish an effective accountability system; build self-esteem, morale and a sense of belonging

(ii) Implement recognition programmes that publicly acknowledge and reward employees for innovation, desired behaviours (such as knowledge sharing), or outstanding achievements (for instance, a "Work Crew of the Year" award, decided by peers)

(iii) Offer management-development programmes that focus on culture, as well as targeted mentorship programmes to transmit desirable values

EXAMPLE: To engage employees in improvement and innovation, *Skanska* has implemented several initiatives, including a consultation forum for front-line workers, a dialogue week on safety issues and a mobile app for submitting ideas for improvement.



3. The Industry As a Whole Needs to Drive Transformation

3.1 Industry collaboration

Mutual consent on standards across the industry

Standards are desirable for different reasons. Adherence to standards helps to ensure that products are safe, interoperable and good for the environment. Harmonizing technical specifications of products and services can make industries more efficient, and can break down barriers to trade. For instance, the Transatlantic Trade and Investment Partnership, a proposed trade agreement between the European Union (EU) and the United States, aims at promoting trade and multilateral economic growth by harmonizing differing standards and regulations.

The construction industry lacks robust global arrangements on standards. As a result, it has forfeited the productivity gains that a proper modernization of the industry would have brought. And it could in future forfeit the potential inherent in digital technologies: if it remains such a fragmented industry, unable to agree on internal standards, it is hardly likely to have much influence in determining cross-industry standards. The E&C sector as a whole should take concerted action, along the following lines:

- *Affiliate and organize.* For E&C companies it already means a great deal to establish standards within their companies when working on different projects with a single client, and even more when working on different projects across different clients or even industries. E&C companies should strive to form organizations, representing all stakeholders along the value chain, at a national, international or even global level. They should also make sure that relevant experts (from academia, for instance) are represented, and that the organizations are large enough and varied enough to truly represent the interests of the sector as a whole.
- *Identify key standardization topics and develop a common stance.* Given the huge potential for improving collaboration among the different stakeholders in construction projects, it is vital that companies act in concert, and that all the stakeholders are on board and speak with one voice. The industry as a whole should define key areas to work on and should agree on a common perspective:
  (i) Standards in software systems, interfaces and communication protocols will facilitate the digitalization of the industry as a whole: in particular, companies should establish standards in machine code for robots and automated construction equipment, and in interfaces between different systems such as BIM and Geographic Information Systems.
  (ii) Standard interfaces between prefabricated modules and components will enhance system compatibility, provide economies of scale for suppliers, act as a powerful productivity driver and thus accelerate the industrialization of the sector.
  (iii) The standardized definition of costs, classifications and measurements along the whole life cycle will lead to greater comparability and compatibility among projects.
  (iv) Standards in legal arrangements, such as alliances and IPD contracts, will reduce initial costs and pre-empt legal complications for individual companies.

  EXAMPLE: The *DGNB*[90] (*German Sustainable Building Council*), an organization concentrating on sustainable construction, with members along the value chain, has developed certification schemes that provide a uniform basis for evaluating the planning, construction and operations of sustainable buildings.

  EXAMPLE: *Australia* is pioneering the standardization of project alliance agreements to reduce the initial costs involved in establishing these agreements.[91]
- *Shape the agenda.* To define and set standards across different industries is a complex, multidimensional endeavour, involving multiple and sometimes competing interests. Standard-setting organizations are established for industries or specific topics, nationally, regionally or globally. The E&C sector has to make sure that it is represented in the relevant industry bodies and consortia, and can make its voice heard and drive the agenda.

  EXAMPLE: *Atkins* is providing a convenor for an ISO Steering Group (with members from private construction companies, government and academia) advising on industry standards for information management, specifically on the use of BIM during the construction phase of projects.

In many cases, industry standards are referred to in regulatory frameworks, either directly or indirectly, and they are sometimes incorporated into national building codes. For this reason, the industry must strive to set optimal standards ahead of regulation, so that it can shape the public agenda.

More data exchange, benchmarking and best-practice sharing

In the past, proprietary knowledge was the key differentiator of companies in many industries. Now, the pressure is increasingly on companies to join forces with other companies to create new products and services in an increasingly complex world. That applies especially to fragmented industries such as E&C, with so many facets and challenges. But it is not so easy to put this imperative into practice.

To promote partnerships or even informal sharing among individual companies, a large-scale, even global, effort is needed. Increased knowledge sharing among peers can help to close the gap between technological development and application. For this purpose, the industry should establish a platform – perhaps a formal association – comprising top E&C firms across all regions. That platform, from its neutral and respected position, could encourage the regular sharing of best practices, benchmarking across peers, and could optimize data by ensuring its availability, comparability and protection. If offered the right incentives, companies will readily share knowledge and advice.

EXAMPLE: The *Construction Industry Institute* in the United States collects best-practice insights and makes them available to its members; topics range from partnering models to project planning and constructability.

The benefits of many technological advances, such as BIM, will materialize only if the whole ecosystem is ready, but investments have to be made on an individual company level, of course. As a consequence, first movers are at risk, yet if nobody dares to move, the industry as a whole will be the loser. To break this vicious circle and avoid stagnation, the industry needs to agree on common targets. A joint effort based on shared commitments – on deploying new technologies, for instance – could help to reduce the risk for individual companies and provide an opportunity for an industry-wide boost.

Bear in mind that all forms of collaboration between companies have to take appropriate precautions against violating antitrust or competition legislation. It is the companies' responsibility to ensure that the government authorities or the courts do not interpret "cooperation" as "conspiracy".

Cross-industry collaboration along the value chain

Better collaboration is needed not just between peer companies but also between companies of different types along the value chain. The current tendency is to push risk down the value chain instead of pulling innovations out of it. A good way to encourage cross-industry collaboration among companies along the value chain is through industry-wide initiatives, such as joint R&D efforts and data-generation projects. Platforms could be established to facilitate knowledge exchange across the value chain, and to align perspectives on design, construction and operations. And measures should be introduced to enable independent certification and quality assurance, and thereby accelerate the adoption of new technologies.

EXAMPLE: In late 2014, the *German Association for the Construction Industry* established the initiative "Planen und Bauen 4.0", involving various industry associations, such as those of architects, machinery suppliers and real estate. The aim was to create a national centre of competence and a communication partner for research, advice on regulation and market implementation. The initiative, with its multistakeholder cross-industry approach, should take a trailblazing role in the implementation of BIM and other digital innovations in the German construction industry.

More specifically, great benefit can be had from creating permanent industry-wide bodies or institutions involving all participants along the value chain. Such entities would stimulate collaboration and foster horizontal and vertical linkages, and would establish common rules and frameworks in an unbiased way. They could also incorporate trade associations (which currently tend to focus on transactional issues within their own technical specialist silos), interest groups, academics, and local associations and trades.

EXAMPLE: *Desso* (a *Tarkett* company) works closely with one of its yarn suppliers, which turns recovered post-consumer carpet fibres into new yarn. The two companies have shared their experiences within the *Circular Economy 100 network* – an innovation programme bringing together companies, governments, cities and academic institutions – in an effort to inspire circular-economy thinking among other companies.

EXAMPLE: The *Canadian Construction Association*, the national voice for the construction industry in Canada, represents more than 20,000 member firms in an integrated structure of about 70 local and provincial associations. Its Lean Construction Institute, founded in 2015, provides a platform for all supply-chain participants – owners, designers, contractors, traders and allied services – to collaborate on the development and application of lean tools and techniques along the building life cycle.

3.2 Joint industry marketing

Industry-wide collaboration on employer marketing

In an industry where women constitute just 9% of the workforce and where employee turnover will be an estimated 33% in the next 10 years – both values at the extreme, relative to other industries – a joint marketing effort by employers is seriously needed.[92] The objectives are to persuade young people to pursue a career in construction, to challenge preconceptions about working in construction and to demonstrate the variety of career options and entry routes.

Ideally, formal centralized organizations would be set up, to pool the respective competencies of construction companies and align marketing efforts across the industry. The organizations would get all member companies to adopt a uniform stance and become involved in creating a consistent image of the construction industry. An active and wide-ranging communication effort would convey that consistent image to target groups, via marketing campaigns using multiple channels.

EXAMPLE: The *Construction Industry Training Board*, a centralized organization representing the interests of the construction industry in the United Kingdom, initiated a comprehensive marketing campaign called *goconstruct.org*. The website provides details on qualification requirements, job opportunities and salaries; a video provides several job profiles and information; and a full advertising campaign disseminates information on the sides of buses, on billboards and in phone booths.

Coordinated communication with civil society[93]

The E&C sector will also need to engage constructively with the public at large. Thus individual companies should adopt best practices regarding construction sites, should protect communities and the environment and should secure everyone's safety.

EXAMPLE: The *Considerate Constructors Scheme* – a non-profit organization founded by the United Kingdom construction industry to improve its image – addresses concerns relating to the general public, the workforce and the environment. It has established a *Code of Considerate Practice* to guide the behaviour of its members.

The main influence on people's perception of the industry, however, is their personal experience of construction projects or assets. By involving the affected communities throughout the asset's life cycle – from planning and construction through to operating the asset – companies can sustainably enhance the image and reduce the likelihood of political intervention, particularly in infrastructure projects. In most cases, infrastructure projects are extremely beneficial for the wider society, and all stakeholders have a common interest in seeing this message communicated effectively.

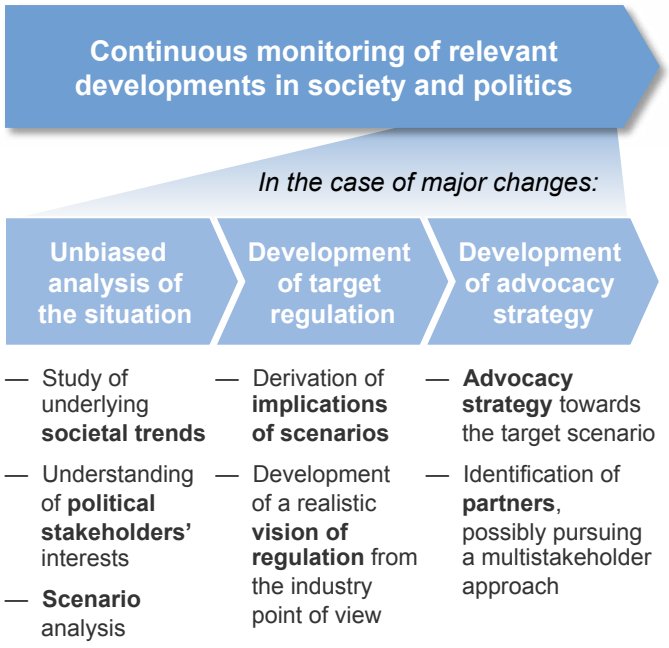
Infrastructure projects can provoke public disapproval in various ways. Many projects have a very disruptive impact on the local community despite their acknowledged advantages for wider society. And the public tend to object when projects exceed their budgets or schedules, especially when national debt rates and austerity measures are on the increase.

So companies would be well advised to engage the community early on, and continue that engagement throughout. During the planning process, for example, they should arrange formal consultations with the community as part of their environmental-impact and social-impact assessments. Such consultations will help to ease local anxieties, and also to fine-tune the design of the project and reduce inconvenience during the construction period: well-planned route management, for instance, will make diverted traffic more bearable for local residents. In general, companies need to maintain a strong communications strategy. During the planning period, and throughout the construction phase, project developers should keep the local community fully informed on progress and potential impacts – to satisfy curiosity, allay fears and even rally public support for the project.

EXAMPLE: The redevelopment of *Vienna's main station* was supported by the "Infobox", Europe's highest wooden tower. It became a magnet for visitors, and hence a fertile venue for circulating details of the project's goals, progress and long-term advantages.

Engagement with the community should not end when the construction phase ends. Ongoing public support for the infrastructure asset is crucial, and cannot be taken for granted. During the operations phase, various public relations and educational measures are possible, such as guided tours in ports and viewing decks in airports.

Figure 16: An Approach to Regulatory Engagement[94]



Source: World Economic Forum; The Boston Consulting Group

Effective interaction with the public sector

Companies should also take steps to engage constructively with the public sector to avoid misunderstandings, discuss the impact of regulations and ensure good relations. Figure 16 outlines one approach to regulatory engagement.

The advocacy strategy is especially important as a counterweight to the regulatory regime, which is always subject to change at a national or even international level. Ideally, the industry would engage in joint initiatives with government, working closely together towards the common goal of taking the industry forward.

EXAMPLE: *Construction 2025* is a partnership in the United Kingdom between E&C and government to transform the industry by optimizing the relationship between private companies and public authorities. E&C is acknowledged as an "enabling sector having a massive impact on the performance of the wider economy".[95] It has set out a vision and a plan for long-term strategic action by government and industry: they are to continue working together, especially on smart technologies, green construction and overseas trade.

Once again, effective communication between the two sides is crucial.[96] The industry needs a well-designed communication initiative for each phase in the life cycle of an infrastructure project. During bidding and contract negotiations, for example, companies should refuse to give any misleading information, even if such information is requested by the public-sector representatives. During the construction phase, the contracted company should be open and proactive in reporting progress or problems to the public-sector agency. And ideally, the company will employ a high-level individual as the dedicated point of contact, to build trusting relationships and resolve issues promptly.

4. Government Needs to Encourage and Support this Transformation

4.1 Regulation and policies

As a regulator and policy-maker, a national government can influence the E&C industry in various ways. Primarily, it acts as a warden of health, safety and environmental conditions in and around construction, and it should perform this task as efficiently as possible to mitigate adverse effects on productivity. It also impacts on firms' strategies and operational practices by preventing or supporting competition nationally and internationally. And it can influence the speed and direction of technology development and diffusion.

Harmonized building codes/standards and efficient permit processes

Smart regulation is the key: it ensures that standards are met in an efficient and effective way. In addition, the regulatory framework should leave room for technological progress and should anticipate emerging needs. To achieve these objectives, it is crucial to have well-designed building codes and standards, as well as transparent and streamlined permit processes.

Regarding building codes and standards, the following best practices stand out:

- *Strive for more uniform regulations.* Multiple overlapping or highly fragmented standards can cause builders and local authorities to become confused. This results in delays, uncertainty and disputes. To reduce complexity, it is therefore crucial to harmonize building codes and standards at a national (or international) level, while at the same time taking into account location-specific requirements concerning geography, climate and traditional building practices. For efficient application, building codes and standards should also be easily accessible; ideally, they should be freely available online and through electronic devices.

  EXAMPLE: The *Eurocode initiative* harmonized methodologies for design and calculation for construction projects in the EU, though specific rules and detailed standards still remain at the national level.
- *Update provisions regularly.* Building codes and standards need to be adaptable and up-to-date to appropriately reflect economic, societal and technological change. This regular updating is particularly important in the light of growing environmental concerns and the emergence of new digital tools such as BIM.
- *Implement outcome-oriented standards where appropriate.* Performance-based building codes are an effective means to encourage innovation in construction techniques and materials. The codes specify the performance standards that a building must abide by, rather than specifying the ways of achieving those standards. The codes do involve a cost: to maintain control, it is imperative to ensure the adequacy of every single design and construction path selected. This can be an intricate task, especially if there are a great many alternatives and if their performance is difficult to measure.

  EXAMPLE: *New Zealand's building code* is exclusively performance-based. For example, it prescribes that in the event of fire, the evacuation time must allow occupants of a building to move to a place of safety without being exposed to a fractional effective dose of carbon monoxide greater than 0.3.[97]

Construction-permit processes are a major source of project uncertainty and delay in many countries. A government can apply measures such as these to improve efficiency:

– *Make approvals more convenient and faster for builders.* Building plans often need to be approved by multiple different agencies. To coordinate their efforts better, and to increase the speed and convenience for permit seekers, regulators should strive to ease any bottlenecks and reduce bureaucracy associated with processes. For example, they could establish "single-window" systems and one-stop centres that combine the required competencies under a single roof and commit to specific timelines for approval.
– *Differentiate approvals by risk.* Different assets vary in their social, economic and environmental impact. Simple or low-risk projects require fewer checks and can be approved faster than more complex structures. Effective regulations therefore involve rigorous yet differentiated approval processes, which treat buildings according to their risk level.

  EXAMPLE: The *European standard* defines three "Consequence Classes" based on parameters such as size, construction method and final use. Each building category lists recommended interactions with the authorities, including fast-track approval procedures for low-risk buildings.

– *Digitize construction permits.* A proficient deployment of IT not only reduces the costs of approval processes, but also enables regulators and practitioners to cope with increasingly complex building standards and additional policy objectives (such as those related to energy efficiency). Particularly promising in this context is the development of BIM-based software tools that are capable of automating the verification of building-code compliance.

  EXAMPLE: In the *United States*, advanced e-permit systems and mobile inspection technology have reduced approval times by 30% and the number of required on-site inspections by 25%.

Finally, governments should establish appropriate control mechanisms and sanctions to help enforce their statutory provisions, and thereby better protect public health, improve safety and safeguard the environment. In many developing countries, 60-80% of buildings (generally referred to as "informal housing") continue to evade any form of building-related controls, which imposes significant risks and costs on the community.[98] The problem arises in developed countries, too: in the United States, the team assessing the aftermath of Hurricane Katrina concluded that a major cause of the amount and magnitude of damage to buildings along the coast was, in fact, non-compliance with the building code. Strict implementation can pay off financially: a task force led by the Institute for Market Transformation found that every dollar spent on strengthening building-energy-code compliance and enforcement efforts will return six dollars in energy savings.[99]

Market openness to international firms and small and medium-sized enterprises

Market openness to foreign firms stimulates trade as well as the movement of capital, technology and skills across the global E&C sector. It also increases the opportunity for economies of scale and scope, and for specialization of firms – two important sources of competitiveness.

Most countries have now removed legal bans on the operations of non-domestic companies, but there are still some other, equally effective barriers to foreign market entry that restrict international competition. Among the most prevalent impediments are tariffs and duties (such as fees for imported construction services); an insufficient recognition of foreign professionals' qualifications; and strict capital requirements for foreign firms (for instance, financial reserves that cannot be used during the duration of the project). All of these barriers need to gradually be eliminated by national governments; only then can the fully open, global E&C market become a reality.

EXAMPLE: Within its Construction 2020 initiative, the *European Commission* plans to take action in three main areas to enhance international competition: a more open trade in building materials; a more straightforward recognition of the qualifications of foreign architects; and support services for EU-wide operations of small and medium-sized construction companies.

In addition, public procurement has traditionally inhibited foreign companies' market entry – particularly because governments have often tended to favour their domestic industry when awarding contracts. Local implementation of multinational agreements, such as the Agreement on Government Procurement within the framework of the World Trade Organization, can help to liberalize government procurement markets. Such agreements establish rules that require less discriminatory and more competitive forms of tendering among participating countries.

EXAMPLE: *Brazil* – a non-signatory to the Agreement on Government Procurement and historically a relatively closed construction market – has recently launched an infrastructure investment programme that explicitly encourages international participation. All infrastructure concessions of this programme are open to foreign firms, while airport concessions actually require the participation of foreign airport operators.

In addition to international market openness, regulators should promote diversity and competition in the local construction sector by encouraging participation from a broad variety of small and medium-sized enterprises (SMEs). In this regard, local authorities could take the following measures:

- Put in place a simplified licensing system for SMEs (such as the one recently introduced in Indonesia)[100]
- Promote the formation of alliances between international, national and local construction firms
- Provide financial support for SMEs in E&C (such as partial risk cover for SME loan portfolios)
- Ensure equal treatment of SMEs in public-sector tenders, particularly by reducing the bureaucratic burden of procurement

Promotion and funding of R&D, technological adoption and education

Given the economic significance of the construction sector, R&D investments among E&C companies are surprisingly small. In fact, the 2014 EU Industrial R&D Investment Scoreboard ranks construction among the least R&D-intensive sectors, with a mere 1% of net revenues allocated to R&D.[101]

National governments can create a more fertile environment for developing technological innovations by providing appropriate support to companies and academia. In particular, they could take the following steps:

- Establish centrally funded research institutions and joint industry-academia funds and technology centres
- Provide venture capital for E&C-related start-ups
- Offer tax incentives and establish schemes for contested R&D funding (by open competitive tendering, for instance)

EXAMPLE: In 2015, the *US Federal Highway Administration* provided – through multiple schemes – funding of almost $500 million for hundreds of research projects related to improving the design, construction and operation of roads, tunnels and bridges.

Promoting R&D is just the first step: technological advances realize their full potential only when they are widely adopted across the industry.[102] In a highly fragmented, multistakeholder industry such as E&C, it is therefore equally important to foster the diffusion of innovations, by such steps as these:

- Providing financial support for demonstration projects involving new technologies and processes
- Setting up incentive schemes for innovation deployment and capability development

EXAMPLE: *Singapore,* through its Construction Productivity and Capability Fund, partly reimburses the cost for:

(i) BIM software/hardware, consultancy and training
(ii) equipment and machines that improve productivity by at least 30%
(iii) development projects featuring process innovations

Finally, project managers and the entire construction workforce need to be upskilled appropriately with regard to new technologies and processes. A government can support workforce education through the following policy measures:

- Offer training programmes at job centres and in cooperation with companies
- Implement effective and leading-edge curricula in universities, technical colleges and apprenticeship schemes
- Enhance the attractiveness of E&C professions through image campaigns

EXAMPLE: The EU-wide construction-sector initiative *BUILD UP Skills* provides a joint platform for national programmes and projects aimed at training and educating the current and future construction workforce on energy efficiency and renewable energy.

4.2 Public procurement

In addition to its role as regulator, the public sector also has an immense impact on E&C through its role as project owner. Government procurement accounts for a major share of total construction expenditures worldwide: for example, 31% in the United Kingdom, 44% in Germany and a staggering 57% in the United States.[103]

As the E&C industry's most important client, governments need to actively manage and coordinate public-sector demand, and thereby drive industry change. It is also their duty to prevent corruption in the system, in order to promote efficiency in procurement and provide equal opportunities for bidders. The more progressive governments have started to reform procurement and are adjusting bidding requirements and processes to stimulate innovation and whole-life-cycle optimization.

Actively managed and staged project pipelines with reliable funding

Given the sheer size and complexity of the public-sector project pipeline, its active management is a challenging task, and one that is often badly neglected. Ideally, a government defines and implements a holistic strategy to optimize procurement along several dimensions – notably, the composition of the project portfolio, the governance of procurement activities and the attractiveness of the project pipeline to potential bidders.

When it comes to compiling the public-sector project portfolio, multiple objectives (conflicting to some extent) need to be aligned. For an optimal prioritization of projects, it is crucial to first develop a strategic procurement plan. Such a plan provides guidance for the required cost-benefit analyses at the project level, and helps to reconcile economic considerations and industrial, social and environmental targets. Once a project has been chosen, the procuring authorities should focus on maximizing efficiency in the acquisition of goods and services – for example, by choosing smart delivery mechanisms and by implementing rigorous evaluation and benchmarking processes both within and across departments.

A more effective governance of public procurement can be achieved through the following measures:

- Put in place clear organizational structures and operating models for planning and execution
- Assign task forces to drive high-priority projects
- Apply lean principles to public procurement – for example, by appointing process owners and specifying cycle and lead times
- Equip government teams with the appropriate skills and tools to function as an "intelligent client"

Finally, the public-sector project pipeline should be attractive to potential bidders. This attractiveness can be enhanced through such measures as these:

- Ensure visibility of the forward pipeline to help providers respond to market opportunities and ensure a stable project pipeline over time
- Provide a clearly defined bidding model and information-rich tenders
- Offer SMEs training on public procurement procedures
- Provide dedicated, continuous funding, ideally through a public fund

EXAMPLE: The *United Kingdom* recently launched several initiatives relating to the management of the public-sector project pipeline. To mention just a few:

(i) Project pipelines for 19 sectors are being published online and updated every six months to create a level playing field for providers of any size.

(ii) Cost benchmarking of construction projects across departments now provides a solid baseline for cost-led procurement.

(iii) The Major Projects Leadership Academy, in cooperation with the Saïd Business School, has been established to enhance project-management skills and capabilities across government.

Strict implementation of transparency and anti-corruption standards

Bribery and corruption exist in all industries but, in E&C-related procurement, collusions between government staff and bidders are particularly common, even in developed countries. A study prepared for the European Commission, examining 192 public procurement projects in eight EU countries, found a probability of corruption of 9-21% in the road and rail sector, 28-43% in water and waste, and 37-53% in urban or utility construction.[104] Corruption drives up procurement cost substantially, by an estimated €1.3-1.9 billion per year, in the eight countries studied.

To ensure integrity in public contracting and thereby promote efficiency and fairness towards bidders, governments need to rigorously implement comprehensive anti-corruption and transparency frameworks. These efforts should address all stakeholders along the value chain, and should include the following measures:

Create a corruption-resilient procurement environment

- Generally, implement laws, institutions and practices for preventing corruption in line with international standards (for instance, the United Nations Convention against Corruption and the OECD Anti-Bribery Convention); join integrity pacts, such as the Partnering Against Corruption Initiative led by the World Economic Forum
- Ensure that procuring authorities and tenderers commit beforehand to anti-corruption
- Offer anti-corruption training courses and foster knowledge sharing across procurement departments to create a transparent culture aware of corruption risks

– Implement operational best practices, such as job rotation and screening of pre-employment history, to ensure the integrity of procurement departments and staff

Implement fair and transparent procurement procedures

– Establish clear procedures so that all parties are equally aware of project dimensions, criteria for evaluation, and the timeline and stages of the procurement process
– Ensure that evaluators act independently from tenderers (by engaging probity auditors, for example)
– Enhance transparency by making all details of the procurement process and the results available to the public (via social networks and video streaming, for instance)

EXAMPLE: The *Construction Sector Transparency (CoST)* initiative is a partnership between participating countries and international stakeholders, designed to enhance the accountability of procuring bodies and construction companies for the cost and quality of public-sector construction projects through a standardized public-disclosure process. The disclosure includes comprehensive information about the project at different points in its life cycle, as well as justifications for any significant deviations from budget and schedule. A CoST pilot in Ethiopia, for example, showed that public-sector projects exceeded their cost targets by more than 50% and their time targets by more than 100%. As a result, departments have now committed to ensuring greater compliance with procurement regulations and to performing feasibility studies for any major project.

Establish clear practices regarding the prosecution of corruption

– Introduce national and international laws aimed at punishing corruption
– Perform proper screening of contractors and suppliers, including the possibility of blacklisting
– Conduct regular and independent audits based on the data provided during the procurement process
– Collaborate with independent investigation agencies

Innovation-friendly and whole-life-cycle-oriented procurement

Traditionally, public procurement has largely relied on design-bid-build schemes with a strong tendency towards the lowest bid. This focus on initial construction costs not only neglected the total cost of ownership, but also seriously inhibited innovation and productivity improvements. The traditional approach is gradually being replaced, however, as governments start to see the merits of DB and PPP, and introduce more flexible and outcome-oriented bidding requirements. The new procurement models are being used in numerous major public-sector projects worldwide – including *Crossrail*, one of the world's largest infrastructure projects.

To improve bidding schemes in respect of innovation and construction performance, a government should first review the asset and process specifications in light of newly available technology and materials, as well as other procurement objectives such as total-life-cycle cost and sustainability.

On the basis of that assessment, several steps can be taken to create the right incentives for bidders:

– Introduce more flexible bidding and contracting models with improved risk sharing, such as DB and PPPs

  EXAMPLE: *Seattle*'s largest water-treatment facility, which provides 70% of the city's drinking water, was procured on the basis of a design-build-operate contract. That produced cost savings of 30% relative to the city's initial estimate and enabled state-of-the-art water-treatment technology that had previously been inaccessible to the public sector.
– Engage in performance-based procurement (including such factors as sustainability criteria)
– Integrate TCO and life-cycle costing into bidding requirements, and link operator payments to KPIs

  EXAMPLE: An *EU Directive*, in force since February 2014, allows the procurement of projects on the basis of cost-effectiveness throughout their whole life cycle. This reflects a shift towards longer-term, holistic thinking, and a shift away from a focus on initial cost.
– Require that answers to requests for proposals make reference to new technologies and building materials

  EXAMPLE: The *United Kingdom* requires the use of fully collaborative 3D BIM (with all project and asset information, documentation and data being electronic) on government projects by 2016.
– Ensure compliance with labour standards; for example, ensure that the work is carried out in a safe physical environment, in conditions that respect workers' rights as defined in national laws and international conventions

  EXAMPLE: In the *International Labour Organization Declaration of Fundamental Principles and Rights at Work,* core labour standards are defined, covering four areas:

  (i) elimination of forced or compulsory labour
  (ii) elimination of child labour
  (iii) elimination of discrimination in respect of employment and occupation
  (iv) freedom of association and the effective recognition of the right to organize and the right to collective bargaining

5. The Way Forward

The E&C sector will remain a cornerstone of the world's economy and of almost all other industries, since they rely so heavily on buildings or infrastructure assets. It will continue to define our daily lives in so many ways, because our homes, our workplaces and the means of travelling between them are all components of the built environment.

E&C has been far slower than many other industries to adopt new technology and is only now beginning to undergo a modern transformation. Its labour productivity, static for decades, is on the increase at last, and should surge once the new digital technologies are more widely adopted.[105] The industry has also been slow to adapt its business strategies, but companies are now starting to pay more attention to a building's total life-cycle cost, for instance, and to be more amenable to partnering with other companies. Project owners and investors will have an important part to play here.

The new era in construction will bring great benefits: for the wider society, by reducing construction costs and adverse social effects; for the environment, by improving the efficient use of scarce materials or by reducing the adverse environmental impact of buildings over time; and for the economy, by narrowing the global infrastructure gap and boosting economic development in general. This potential will blossom very soon, and very dramatically. In fact, profound changes are already taking place, though not yet on a sufficiently wide scale. More remains to be done.

Imperative for action

All stakeholders along the value chain – individual companies, the industry as a whole (and associated experts in civil society and academia) and governments – should take action to move the industry forward.

Private companies should actively shape the transformation. For their own purposes, they should assess the opportunities inherent in the new technologies and materials, and then adjust their processes, operations and even business models accordingly. If companies structure their organization optimally, they stand the best chance of success when implementing the opportunities on a large scale. The transformation areas of the E&C industry, ranked according to their importance, are listed in Figure 17, based on a survey conducted as part of the Future of Construction project.

Figure 17: Importance of Different Transformation Areas for the E&C Industry

Source: Future of Construction Survey; World Economic Forum; The Boston Consulting Group

The industry as a whole should enhance coordination and cooperation across the value chain, and agree on common goals and standards. And to gain the support of society at large, the industry again needs to work collectively with all stakeholders, along multiple dimensions.

The government, finally – both as regulator and often as key project owner – should create a fertile environment for the transformation of the E&C sector. High-profile projects, such as *Crossrail* in the United Kingdom, show how public projects can spread and speed up the adoption of new technologies throughout the industry.

Many of the issues and challenges are common across the construction industry, but overall the industry remains very diverse and fragmented. Companies have very varied circumstances and starting points, according to their region, the sector they are active in and their size. So the numerous developments and measures discussed in this report, even though described holistically as parts of a single transformation framework, will not all be equally relevant to any particular company. Companies have to choose the innovations and action areas that best suit their own ambitions and their clients' needs. Provided they do choose wisely – and pursue the choices actively and astutely – they should secure their own future, and ensure a flourishing and exciting future for the entire industry that they represent.

Abbreviations

ABM	Advanced Building Material
B20	Business 20
BIM	Building Information Modelling
CAGR	Compound Average Growth Rate
CoST	Construction Sector Transparency
DB	Design-Build
DfMA	Design for Manufacture and Assembly
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (German Sustainable Building Council)
E&C	Engineering and Construction
ECI	Early Contractor Involvement
EU	European Union
GDP	Gross Domestic Product
HSE	Health, Safety and Environment
IoT	Internet of Things
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Performance Indicator
NASA	National Aeronautics and Space Administration (USA)
O&M	Operations and Maintenance
OECD	Organisation for Economic Co-operation and Development
OSH	Occupational Safety and Health
PPP	Public-Private Partnership
R&D	Research and Development
RFID	Radio Frequency Identification
SME	Small and Medium-Sized Enterprise
TCO	Total Cost of Ownership
UN	United Nations
UN DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNEP DTIE	UNEP Division of Technology, Industry and Economics
UNEP SBCI	UNEP Sustainable Buildings and Climate Initiative
USACE	US Army Corps of Engineers

Appendix: Future of Construction Survey Results

For the World Economic Forum survey on the Future of Construction, approximately 50 Steering & Advisory Committee Members, as well as selected industry experts, were approach to answer questions about the current state of the industry and its key challenges. A total of 30 participants completed the survey, mainly from organizations with a global footprint.

First, the industry's performance in fostering a transformation in the E&C industry was assessed at various levels:

- At a company level, specifically on *2.1. Technology, materials and tools*; *2.2. Processes and operations*; *2.3. Strategy and business model innovation;* and *2.4. People, organization and culture*
- At a sector level, particularly on *3.1. Industry collaboration;* and *3.2. Joint industry marketing*
- At a national level, regarding governments' role in *4.1. Regulation and policies;* and *4.2. Public procurement*

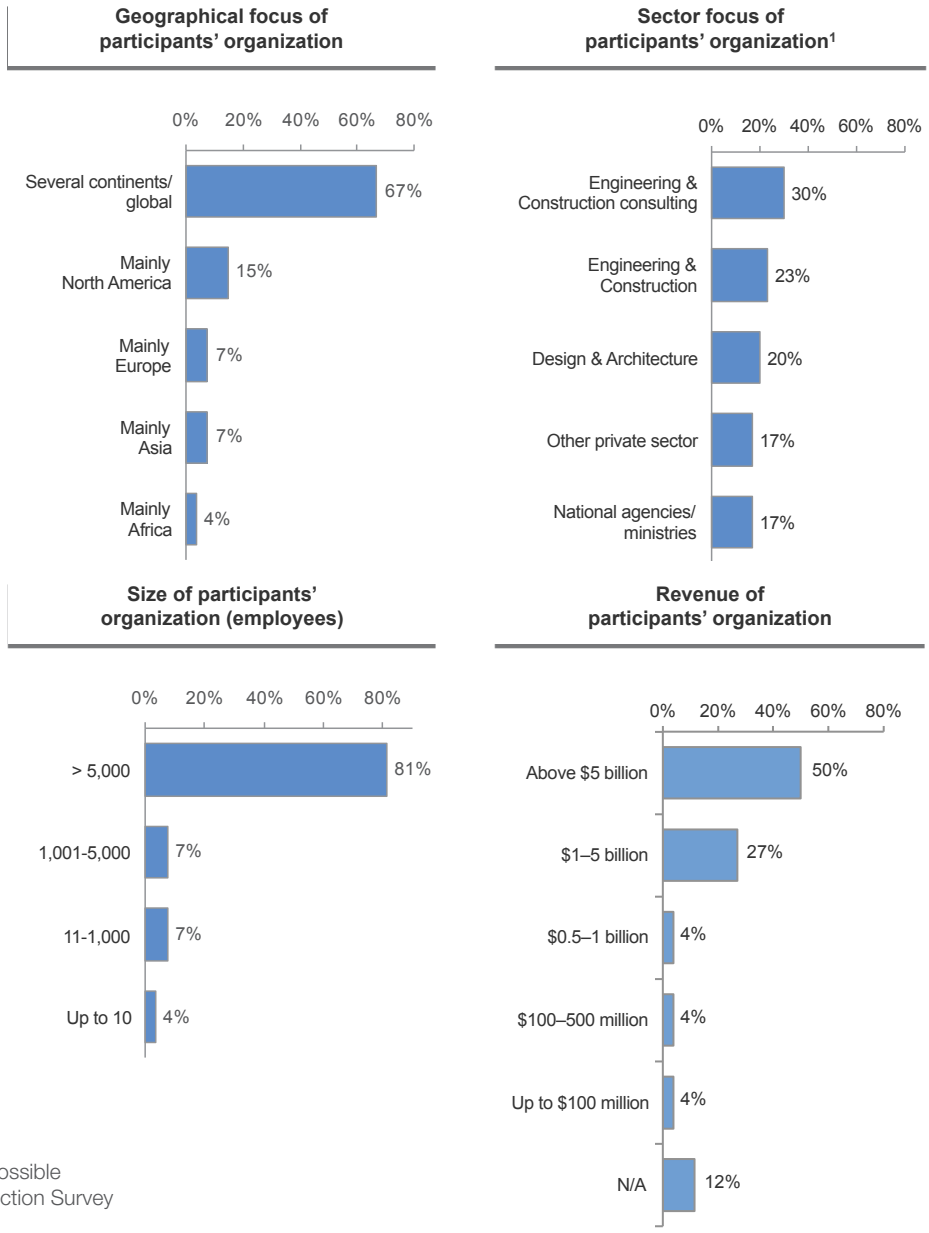
Second, the likelihood and impact of promising *technologies, materials and tools* on the E&C industry was assessed.

Third, the importance and the impact of *several megatrends* on the E&C industry was examined.

Fourth, the most important transformation areas of the E&C industry were identified.

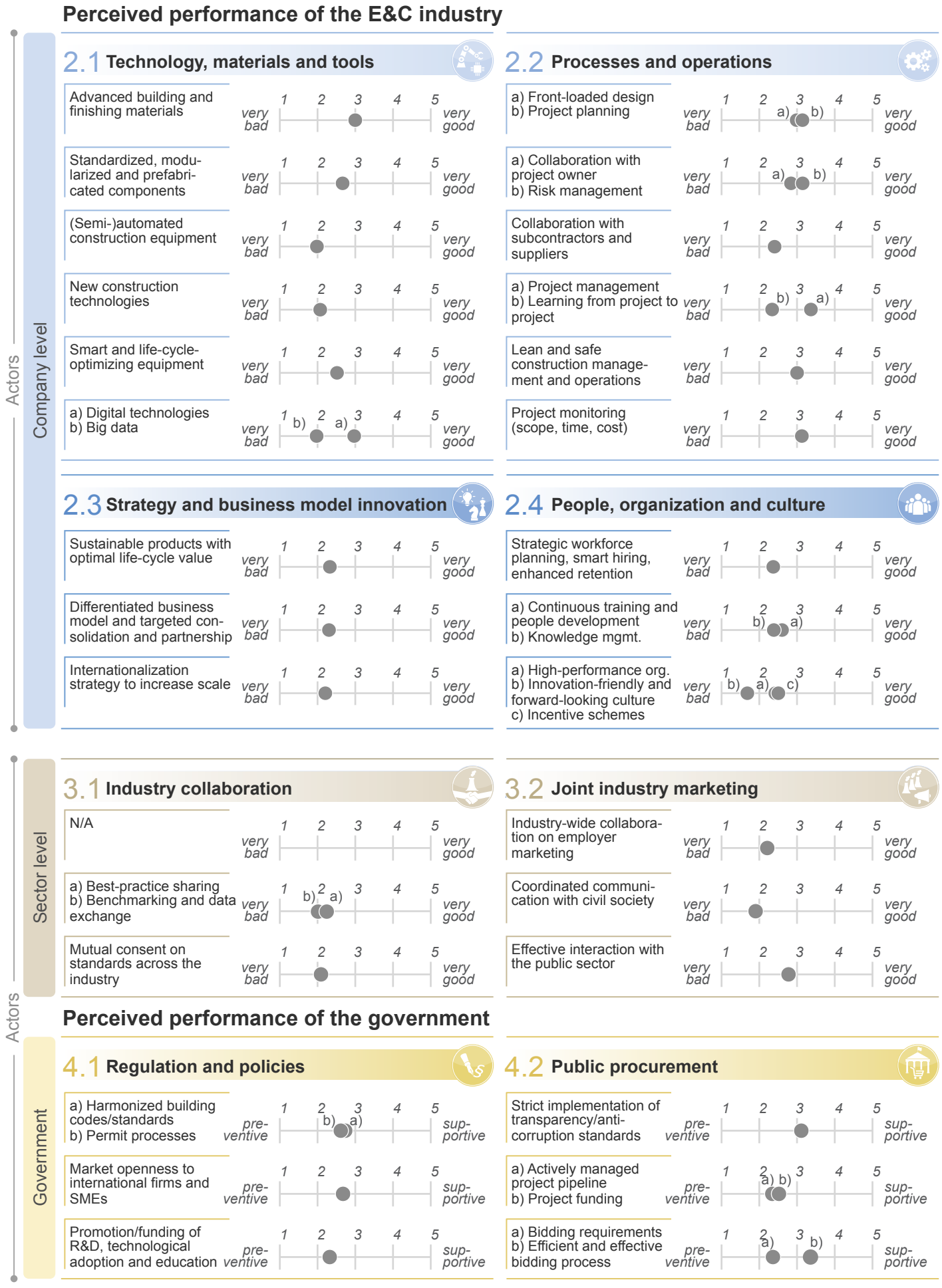
Selected results of the survey are presented below.

Figure 18: Composition of the Survey Participants



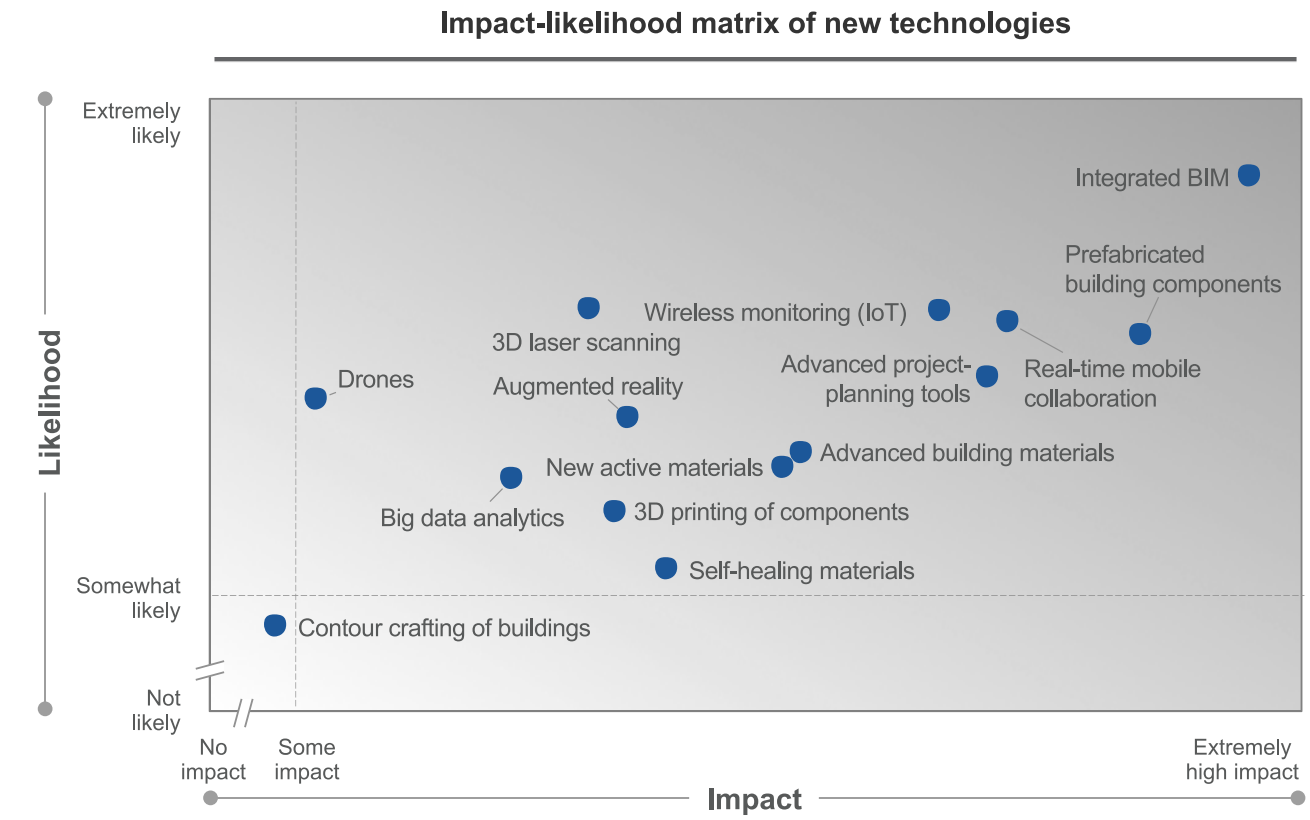
[1] Multiple answers were possible
Source: Future of Construction Survey

Figure 19: Perceived Performance of the E&C Industry and Government



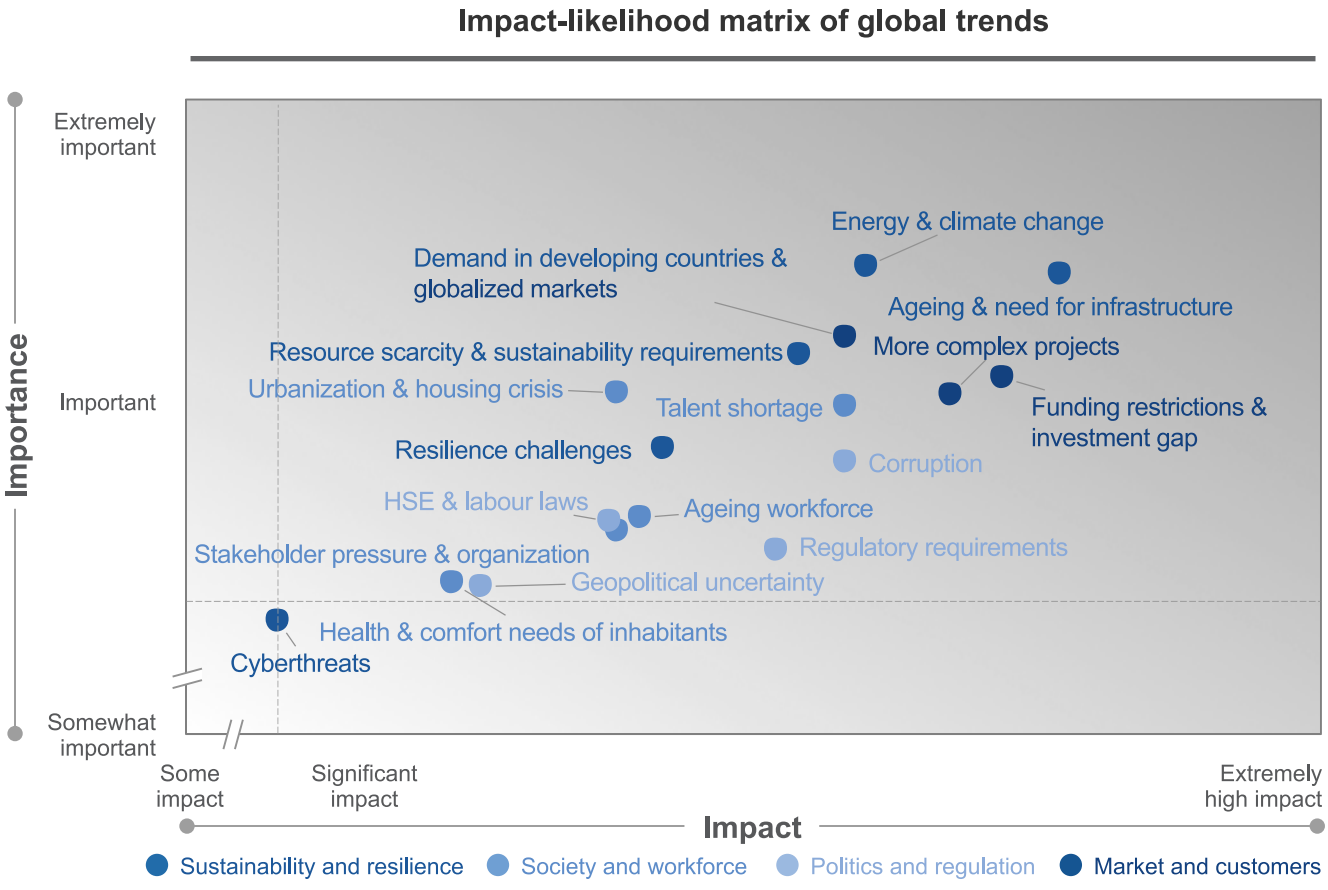
Source: Future of Construction Survey

Figure 20: Future Impact and Likelihood of New Technologies



Source: Future of Construction Survey

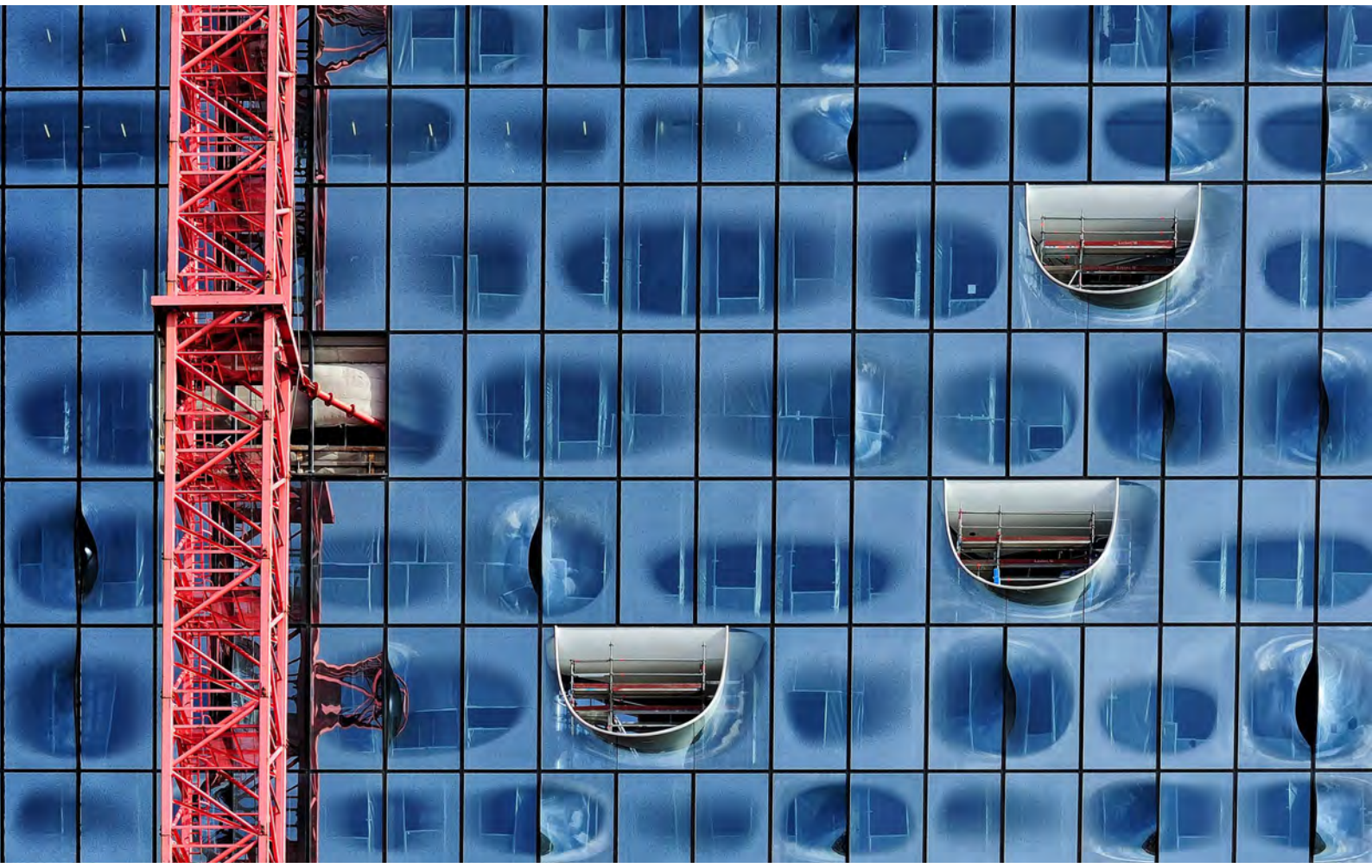
Figure 21: Global Trends – Their Importance for and Impact on the E&C Industry



Source: Future of Construction Survey

Figure 22: Importance of Different Transformation Areas for the E&C Industry

Source: Future of Construction Survey



Endnotes

1 See World Economic Forum, 2012; World Economic Forum, 2013; World Economic Forum, 2014; and World Economic Forum, 2015a.

2 The Boston Consulting Group, 2016a outlines the key technological developments and the potential impact on and implications for key stakeholders.

3 Very broadly, parametric design is a process for designing objects by using a set of rules or parameters.

4 See The Boston Consulting Group, 2015a. In section 2.2, "lean" is described in detail.

5 Kats, 2003 explains how an initial upfront investment of $100,000 to incorporate green building features into a $5 million project could lead to savings of $1 million over the lifetime of the building.

6 This issue is underlined by many items of disturbing evidence. According to the Center for Construction Research and Training (CPWR), 2013 for example, the E&C sector in the United States has the lowest share of working women among all industries, and the lowest share of workers with health insurance, employment-based pension plans and high school diplomas among all non-agriculture industries. It also has the highest rate of projected employment change and the highest number of fatalities among all industries. The issue and its solutions are discussed more fully in sections 2.4 and 3.2.

7 See https://www.ccscheme.org.uk/.

8 The German national initiative on energy transition, *Energiewende*, included a module focused on buildings, *Plattform Gebäude*. The key recommendations were developed jointly by the construction industry and the government and were incorporated into a national action plan, *Nationaler Aktionsplan Energieeffizienz (NAPE)*.

9 See HM Government, 2013b.

10 See Klepeis, Nelson, Ott, Robinson, Tsang and Switzer, 2001. Several studies assess the interrelation between "constructed assets" and health. For instance, Wang et al., 2009 shows that the annual cost per user for bike and pedestrian trails was substantially lower than the per capita annual medical cost of inactivity. Johnson et al., 2009 describes the positive effect of improved indoor air quality on children's health.

11 The aspects here include aesthetics (design and colours, for instance, for Alzheimer patients), indoor air quality (notably, asthma and allergy related to volatile organic compound levels), comfort (for instance, acoustic) and safety (such as slip prevention or infection control). The need for healthy buildings is critical, given that such a large proportion of a human life is spent indoors.

12 This calculation is based on 2014 data from IHS, 2015; Oxford Economics Aggregates, 2015; and World Bank, 2015a.

13 See Global Construction Perspectives and Oxford Economics, 2013.

14 This estimate applies specifically to public-sector investment into infrastructure. The effect is lower in emerging markets, because of the generally lower efficiency there of public-sector investment. See International Monetary Fund, 2014.

15 See World Steel Association, 2015.

16 See Environmental and Energy Study Institute, 2014.

17 The issues and opportunities of a circular economy are discussed extensively in, for instance, Ellen MacArthur Foundation and Fung Global Institute, 2014a; Ellen MacArthur Foundation, 2013; and Ellen MacArthur Foundation, 2014.

18 See United Nations Environment Program, 2007.

19 See Flyvbjerg, Bruzelius and Rothengatter, 2003.

20 See World Economic Forum, 2015a.

21 See UN Department of Economic and Social Affairs Population Division, 2014 and United Nations Human Settlements Programme, 2014.

22 Particularly in fast-ageing countries such as Japan, a heavy push towards these technologies is under way.

23 For a view on the potentially negative impact that a general workforce gap would have on national growth, see The Boston Consulting Group, 2014. The impact would be particularly severe where the cause is undereducation.

24 See KPMG International, 2011.

25 See Setar, 2013.

26 For new buildings in Germany, the Energieeinsparverordnung (Energy Conservation Ordinance) sets requirements relating to basic energy demand, taking into account the building's external insulation as well as the energy efficiency of its appliances (for heating, domestic hot water, ventilation, cooling and – for non-residential buildings – lighting).

27 For a detailed assessment of such risks in infrastructure projects, see World Economic Forum, 2015a.

28 Based on The Boston Consulting Group, 2015a; The Boston Consulting Group, 2015b; and The Boston Consulting Group, 2015c.

29 For instance, in a survey of almost 15,000 companies from enterprises in the United Kingdom, innovation activeness was consistently ranked as one of the lowest priorities. See HM Government, 2014.

30 See imshealth, 2015.

31 See HM Government, 2013a and United Nations Environment Programme, 2009.

32 See B20 Australia, 2014.

33 See United Nations Environment Programme, 2009.

34 See HM Government, 2010.

35 Witness the shake-up that digital photography brought about in its associated sectors.

36 See European Commission, 2014a, European Commission, 2015 and United States Census Bureau, 2007.

37 It is less risky to recommend materials that have been used for many years than to recommend new materials that might turn out to be faulty or less effective.

38 See also The Modular Building Institute, 2010.

39 It is also used to some extent by subcontractors providing electrical services, for example.

40 See wired.com.

41 See Schwab, 2016.

42 Refer also to The Boston Consulting Group, 2015c.

43 See Wall Street Journal, 2015a

44 See Financial Times, 2014 and The Guardian, 2015.

45 See IEEE Spectrum, 2015.

46 Demand response is a change in power consumption by a consumer to create a better match between the demand and the supply.

47 See The Boston Consulting Group, 2016a.

48 See The Boston Consulting Group, 2016a for a more detailed description of the relevant technologies and enabled use cases along the value chain.

49 See also Wall Street Journal, 2015b.

50 Based on The Boston Consulting Group, 2016a.

51 Work on such projects is often carried out in contaminated and radioactive areas and poses challenges throughout the project's life cycle.

52 See also Forschungsinitiative ZukunftBAU, 2013.

53 See Conject, 2015.

54 See Arup, 2015.

55 See Autodesk, 2008.

56 The numbers do not add up because the design and engineering costs are not included. Figures are indicative not definitive: the actual proportions vary greatly from project to project, depending on the costs included (such as the cost of the building equipment or the labour costs). See The Builders' Association, 2013.

57 See American Association of State Highway and Transportation Officials, 2011.

58 One caveat: solutions offering benefits from early involvement must maintain full legal compliance, ensuring equal treatment of all bidders, for instance, and operating a robust system of checks and balances.

59 In a construction management at risk contract, an ECI approach is often combined with a guaranteed maximum price.

60 See Arcadis, 2015.

61 Based on American Arbitration Association, 2009; RICS Professional Guidance, UK, 2012; The American Institute of Architects, 2010; The American Institute of Architects, 2007; International Association of Dredging Companies, 2008; and Bundesministerium für Verkehr und digitale Infrastruktur, 2015.

62 See Department of Treasury and Finance, Victoria, 2009 for more details.

63 See American Institute of Architects, AIA Minnesota, School of Architecture - University of Minnesota, 2012 for a more detailed description and further examples of IPD models.

64 See Flyvbjerg, Bruzelius and Rothengatter, 2003.

65 See Morris, 2013 for a detailed account of the modern view.

66 See Bain & Company, 2015 and The Boston Consulting Group, 2016b.

67 See Prater, 2015.

68 See David Weekley Homes, 2015.

69 Based on The Boston Consulting Group, 2015d.

70 Although the construction industry accounts for only around 4% of employees in the United States, 20% of fatalities in the US private sector take place on construction projects. United States Department of Labor, 2013.

71 See OECD Development Centre, 2009.

72 See The Boston Consulting Group, 2015d for a detailed description of the monitoring of construction projects as part of the lean approach.

73 See Cooper and Lee, 2009 for more details.

74 Further "dimensions" of BIM include sustainability information on energy usage, emissions and recyclability and facility management information on operability and maintenance.

75 See The Guardian, 2016 and This Is Money.co.uk, 2016.

76 As stated in Stanford University Land and Buildings, 2005, the actual ratio varies according to project type and region. Rising energy costs are likely to increase the relevance of the operations phase.

77 World Economic Forum, 2016 describes the environmental impact of the built environment.

78 US figures from 2008 are based on Ellen MacArthur Foundation, 2013.

79 Tarkett works closely with the Environmental Protection Encouragement Agency for a "cradle-to-cradle" assessment of products.

80 Based on Ellen MacArthur Foundation, 2013 and Ellen MacArthur Foundation and Fung Global Institute, 2014a.

81 See The Center for Construction Research and Training (CPWR), 2013.

82 See United States Department of Labor, 2015.

83 See Construction Industry Training Board (CITB), 2014.

84 See Gurjao, 2006.

85 See United States Department of Labor, 2014.

86 See Construction Industry Institute, 2005.

87 See UK Commission for Employment and Skills, 2016.

88 New techniques, such as BIM, may be used to promote OSH, as explained by the International Council of Research and Innovation in Building and Construction, for example.

89 See The Boston Consulting Group, 2016a.

90 Deutsche Gesellschaft für Nachhaltiges Bauen e.V.

91 See Capelli and Slocombe, 2013.

92 Figures are relevant for the US Construction market. See The Center for Construction Research and Training (CPWR), 2013.

93 In the context of PPPs, this topic is elaborated in detail in World Economic Forum, 2015a.

94 Based on World Economic Forum, 2015a.

95 See HM Government, 2013b.

96 Again, in the context of PPPs, this topic is elaborated in detail in World Economic Forum, 2015a.

97 "Fractional dose" means the fraction of the dose that would render a person of average susceptibility incapable of escape.

98 See World Bank, 2015b.

99 See Vaughan and Turner, 2013 and Majersik and Stellberg, 2010.

100 See OECD, 2012.

101 See European Commission, 2014b.

102 See Fairclough, 2002.

103 The Boston Consulting Group estimates for 2012 are based on data provided by Euroconstruct (www.euroconstruct.org) and Infrastructure United Kingdom (www.gov.uk/government/organisations/infrastructure-uk).

104 See PwC and Ecorys, 2013. Countries included in the study: the Netherlands and France (lower-than-average corruption levels); Poland, Spain, Hungary and Lithuania (average corruption levels); Italy and Romania (higher-than-average corruption levels). See also World Economic Forum, 2015c.

105 See The Boston Consulting Group, 2016a for an analysis of the digitalization trend in E&C.

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