Digital Innovation in Architecture, Engineering and Construction Industry

CENTRE FOR CONSTRUCTION, BI NORWEGIAN BUSINESS SCHOOL
SENTER FOR BYGGNÆRINGEN, HANDELSSHØYSKOLEN BI

2019
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Centre for Construction Industry
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The architectural, engineering and construction (AEC) industry has adopted slowly to a use of new technologies and processes (Rajat Agarwal, 2016). Over the past decades, the industry has experienced little fundamental changes, and hence its productivity has barely increased.

Recently, new digital technologies, such as building information modeling (BIM), wireless sensing, 3D printing, and other opportunities to digitize parts of the construction process, have begun transforming the way that built assets can be designed and constructed.

Yet, these new technologies have not been widely adopted across the construction value chain. This is due to technical challenges, project complexity, limited investment in the R&D and shortage of skilled labor, which are factors that require new thinking.

The aim of this report is to provide an overview of digital innovation in the AEC industry (hereafter: construction industry) with a focus on Norway. As such, the report draws on previous case studies, academic studies, industry reports and newspaper articles, as well as insights from companies that have successfully carried out digital innovation. Images provided in this report all have a hyperlink showing their source.

The first chapter of this report provides an industry analysis and addresses digital transformation challenges in the construction industry. The report outlines the present and the future of the construction industry, describes the Boston Consulting Group digital transformation framework for best practices, and key success factors for innovation in the construction ecosystem.

The second chapter highlights key trends that are thought to significantly influence the future construction industry.

Finally, the third chapter of this report provides some examples of digital innovations identified in the construction industry today. The innovations highlighted stems from both technological start-up companies and established AEC-players.
The first chapter of this report starts with the presentation of an industry analysis where we outline some weaknesses, their effects and ideas for development of the industry with a strong focus on digitalization and how to achieve a digital transformation. The chapter also provides ideas for the future strengths of the construction industry.

The chapter is based on interviews with experts as well as industry reports and case studies performed by the World Economic Forum and Boston Consulting Group and is structured as following:

1.1 Analysis of the Norwegian Construction Industry
1.2 Practices in the industry - present weaknesses and areas of development
1.3 Skills and Capabilities of the Industry
1.4 Achieving a framework for digital transformation
1.5 Key success factors for innovation in the construction ecosystem
1.6 Future strengths
1.1 Industry Analysis – The Norwegian Construction Industry

The industry analysis provided below represents only the current and most applicable examples in the Norwegian Construction Industry.

**Threat of New Entrants: MEDIUM**
- Large construction firms (>500 MNOK in revenues) grew by 1.7% (2018), compared to other companies in the value chain.
- Construction industry is able to increase general market share (10.5-12.2% in 2018).
- Higher profits in economy of scale for large firms (e.g. contracts and workers)
- Positive company reputation is highly valued by customers
- Limited resources needed for market entry → project- and technology management capabilities needed

**Bargaining Power of Buyers: STRONG**
- Buyers with networking capabilities have (better) access to information
- Increasing number of powerful buyers (e.g. increasing involvement from the government)
- The industry produces 40% of all CO2 emissions, but buyers increasingly expect a sustainable building process.
- Margins are declining (2017-2018):
  - 4.5% to 4.0% in “Anlegg” and
  - 4.4% to 4.2% for “Bygg”

**Rivalry among the existing competitors - MEDIUM**
- There is an increase in acquisitions and consolidations in the market, making industry more centralized
- Size is one of the most important factors determining the degree of risk diversification, investment in technological development and ability to take on the big projects
- Few companies that are big enough to bid on the largest projects and invest in R&D

**Threat of Substitute: MEDIUM**
- Standardized, prefabricated building(models) (e.g. finished houses)
- Companies from other industry (e.g. ICT) invest in technologies that can occupy activities of construction companies:
  - Activities can be replaced by technical devices (Robotics)
  - Services can be replaced by AI systems (Design)
  - Project Management

**Bargaining Power of Suppliers: WEAK**
- Weak bargaining power due to a vast amount of suppliers (> 50,000)
- Construction materials are available from local and international supplier (increase)
- High level of competition within the machinery rental marked
- Increasing demand for green and sustainable products → but low supply

Source: (Lidsheim, 2019); (Essays, 2018); ("Construction Development ", 2013); (Proff)
1.2 Practices in the Industry – present vulnerabilities and areas of development

**Examples of vulnerabilities**

- Limited use of open standards à makes collaboration, automatization and data analysis difficult.
- Lack of contractual practice à disenables cross disciplinary and cross-organizational cooperation
- Little use of qualitative measures à leads to complex and manual procurement, tendering assessment.
- Focus on coordination instead of cooperation à increases complexity, time and costs
- Attention on single parts of the entire process à extends processes, complexity, overload, miss-understandings and synergies across projects
- Short term contracts and starting each project from scratch à inhibits collaboration, cross-project collaboration, synergies
- Focus on interests of the own company (who gets most profit from the project) rather than the project and industry collaboration à constrains collaboration and long-term relationship building

**Development areas**

- Set up standard for IPD contractors. This requires open standards and full digital delivery from each and every supplier (architects, engineers, constructors)
- Learn to engage in Smart partnerships which enables to think in “chains or projects”
- Take a broader perspective, think of your business as one common process instead of developing multiple small processes
- Treat your contractors as collaborators à build relationships, use synergies and provide long-term perspective
- Integrate contractors and open up communication instead of tacitly hiding information from each contractors à improves collaboration, simplification and triggers smooth process-work
1.3 Skills and Capabilities of the Industry

Examples of vulnerabilities

- Lack of digital competence and culture of iterative learning à makes adoptions of digital tools and systems from other industries difficult and limits ability to collaborate with digital start-ups
- Missing regular diagnosis of prior failures and successes → little learning from prior experience and waste of prior capability building
- Focus on pricing, costs and profit → inhibits to prioritize learning and innovation
- Little future and long-term orientation, focus on short term profit → inhibits building of long-term relationships, including more collaboration, simplification and synergies
- Lack of competency to learn as a team/organization → with every project being started from scratch, successful team-constellations and learnings are lost; individuals rather than collective learns → hence, easy to switch company.

Textbox source: (Dorner, 2016); (Knight, 2018)

Digital mindset - means a shift in the mindset of an organization towards integrating digital technologies (e.g. digital platforms, artificial intelligence, machine learning) into the strategic core intent of the company. For example by developing the core strategic capabilities (e.g. building of long-term relationships with customers, capability to deliver high-quality buildings), on top of aiming to win through optimizing operational capabilities, such as project management or lean operations.

It is the change in the perception of the technology from the “extra” to a central element in creating sustainable business models. Organizations transform their value propositions and each level of an organization, in order to successfully run the company, by becoming data-driven, highly agile and customer orientated.

Development areas

- Develop a digital mindset (see textbox).
- Improve strategic digital competence of employees, middle managers and top managers → Digital transformation is a long and exhausting process. It includes the training of employees, iterative cycles of learning, testing and piloting and development of new practices and processes
- Incremental and iterative learning → Start to become familiar with small innovation projects and learn to collaborate (instead of contracting) digital companies
- Set up regular practice to diagnose successes and failures → communicate across functions and organizational units.
- Analyze constellations of internal teams and also constellations of contractors
- Learn from diagnosis → each new project builds on success (team constellations, contractor constellation) elements of previous project
1.4 Achieving a framework for Digital Transformation

The World Economic Forum (WEF) prepared a report in collaboration with Boston Consulting Group (BCG), termed “Shaping the future of construction - A breakthrough in mindset and technology”.

The report presents a digital transformation framework aimed at reaping benefits from utilizing digital tools in construction. The framework is based on best practices and case studies of digital transformation within the construction industry. The framework lists a number of measures grouped into eight topic areas, which could lead to digital transformation of the construction industry.

The measures are further classified into three groups: measures taken by private companies on their own (company level); measures taken in collaboration with their peers - or the industry as a whole (sector level); and measures taken by the government, acting both as a regulator and as a major project owner (government level). Examples of each measurement in the construction industry are listed below:

Company Level:

<table>
<thead>
<tr>
<th>Technology, Materials and Tools:</th>
<th>Processes and Operations:</th>
<th>Strategy and Business Model:</th>
<th>People, Organization and Culture:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced building and finishing materials</td>
<td>Frontloaded and cost-conscious design and planning</td>
<td>Differentiated business model and targeted consolidation/partner ships</td>
<td>Strategic workforce planning, smart hiring and enhanced retention</td>
</tr>
<tr>
<td>Standardized, modularized and prefabricated components</td>
<td>Innovative contracting models with balanced risk-sharing</td>
<td>Sustainable products with optimal life-cycle value</td>
<td>Continuous training and knowledge management</td>
</tr>
<tr>
<td>(Semi-)autonomous construction equipment</td>
<td>A common framework for project management</td>
<td>Internationalization strategy to increase scale</td>
<td>High-performance organization, culture and incentive schemes</td>
</tr>
<tr>
<td>New construction technologies, e.g. 3D printing</td>
<td>Enhanced management of subcontractors and suppliers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart and life-cycle optimizing equipment</td>
<td>Management and operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital technologies and Big Data along the value chain</td>
<td>Lean and safe construction management and operations</td>
<td></td>
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</tbody>
</table>


1.5 Key success factors for innovation in the construction ecosystem

The before mentions report from WEF and BCG presents ten innovation cases from innovation leaders in the construction industry. The ten innovation cases are studied in order to identify what distinguishes these innovation leaders from the rest of the industry and what other companies may learn from these companies. The outcome is a set of key success factors for innovation in the construction ecosystem.

The key success factors are grouped into three main steps:

1. Simulating Innovation
2. Turning ideas into reality
3. Succeeding in the market

Each is listed and explained further in the table below:

<table>
<thead>
<tr>
<th>Industry Collaboration:</th>
<th>Join Industry Marketing:</th>
<th>Regulations and Policies:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Mutual consent on standards across the industry</td>
<td>- Industry-wide collaboration on employer marketing</td>
<td>- Harmonized building codes/standards and efficient permit processes</td>
</tr>
<tr>
<td>- More data exchange and best practice sharing</td>
<td>- Coordinated communication with civil society</td>
<td>- Market openness to international firms and SMEs</td>
</tr>
<tr>
<td>- Cross-industry collaboration across the value chain</td>
<td>- Effective interaction with public sector</td>
<td>- Promotion and funding of R&amp;D technology adoption and education</td>
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<tr>
<td>Public Procurement:</td>
</tr>
<tr>
<td>- Actively managed and staged project pipeline with reliable funding</td>
</tr>
<tr>
<td>- Strict implementation of transparency and anti-corruption standards</td>
</tr>
<tr>
<td>- Innovation-friendly and whole-life-cycle-oriented procurement</td>
</tr>
</tbody>
</table>

Source: (Forum, 2017)
1.6 Future Strengths

The construction industry has great potential to innovate and digitalize through:

**Digital Mindset - Strategic and Operational Digital Competence**

**Increased human safety and resource conservation (as a result of digitalisation of processes and practices).**

**Development and patents of joint communication platforms in construction projects**

**Intra-firm collaboration and "partnering" thinking**

**Open standards for smooth, efficient and sustainable construction and maintaining**

**Increasing available time for creativity and learning**

**Simulating Innovations:**
- Develop a vision and introduce an innovation culture that challenges the construction industry’s status quo
- Create talented, multi-disciplinary teams, and agile organization to accelerate innovation
- Take a customer-centric approach to devising innovations, starting from the pain points of construction clients and facility’s end-users

**Turning ideas into reality:**
- Establish product platforms rather than taking an individual project perspective to create the business case for innovation
- Develop pilot projects and prototypes to demonstrate the potential and provide proof of value
- Nurture the broader ecosystem necessary for implementing the innovation, by developing the (local) supply chain and partnerships

**Succeeding in the market:**
- Embrace business-model innovation alongside technological innovation in engineering and construction
- Advocate new ways of contracting to enable and incentivize effective collaboration with project owners from day one
- Shape the regulatory environment proactively to enable and promote adoption of the innovation

Source: (Forum, 2017)
Several digital technologies can be applied along the AEC industry value chain, and the opportunities enabled by these technologies are many. The second chapter of this report describes digital technologies that has been identified as the most likely to shape the future of the construction industry.

The chapter is structured in the following way:

2.1 Digital technologies along the engineering and construction value chain
2.2 Big Data - gain more insights and make better decisions
2.3 Five trends that will shape the digital future of the construction industry
2.1 Digital technologies along the engineering and construction value chain

Many of the (available) digital technologies in today’s industrial landscape are readily applicable to the three phases of the construction value chain, design and engineering, construction, and operations (see exhibit 1). The following sections will describe how digital technology is thought to impact in the respective areas of the construction value chain (see exhibit 2).

**Design and Engineering**

*Parallel and robust design* - BIM improves design and engineering processes and facilitates parallelization of work activities by helping project partners to merge their models and to identify interdependencies and clashes.

*Virtual migration of physical structure* - Aerial mapping in 3D laser scanning can be used to convert existing buildings and infrastructure into virtual 3D models.

*Data driven design* - Big data helps optimize design decisions (e.g. generative design, parametric design, see page 24). Combining various data collection methods (mobile surveys, security, and camera footage, traffic flow reports) to inform and refine its design decision making in residential and infrastructure projects.

*Simulation and rapid prototyping* - Holographic technology (rapid prototyping with 3D printing) speeds up design iterations and improves visualization.

*Interactive design and engineering* - Automatically generated design alternatives supporting value engineering and enhancing design-to-cost, design-to-fabrication, and an analysis of how sustainable the design is.

**Construction**

*Real time data sharing, integration and coordination across stakeholders* - BIM in the cloud enables all parties involved in construction to share real time data.

*Data-driven construction planning and lean execution* - Big data obtained from past projects and RFID (radio-frequency identification) enables optimization of resource allocation, scheduling at the construction site etc.

*New fabrication methods* - Building information models contain detailed information that can facilitate new approaches to fabrication, including modularization, prefabrication, and 3D printing.

*Automated and autonomous construction* - Robots and intelligent machines enhance productivity, precision, and safety. Remote controlled systems and 3D model guidance enable advanced levels of automation.
Rigorous construction monitoring and surveillance - Digital measuring and monitoring enable companies to track construction processes and activities more rigorously.

Operations

BIM enhanced operations and maintenance - BIM facilitates operations and maintenance of a building by providing a virtual model of it. Information is generated during the earlier phases of the project, as well as supplemented during the operations.

Virtual handover and commissioning - Streamlined commissioning process by data collected through mobile devices and techniques (mobile equipped with barcode scanners) transfer data directly to the counterpart object in the 3D model.

Smart operations and maintenance - By merging and analyzing data from multiple sources, companies can increase the efficiency of operations and maintenance activities.

Condition monitoring and predictive maintenance - With real-time access to accurate data, companies can monitor buildings continuously.

Fast renovation decision and efficient termination - A well-maintained BIM model can assist designers and engineers evaluating the likely impact of major repairs, or the implications of closing down a facility.

By applying the right technologies in the right way, companies can not only reduce the facility's construction time and life cycle but also enhance the quality of processes and improve safety, working conditions, and sustainability. The role of BIM is vital in this context, both for providing new use cases and for facilitating existing ones (see exhibit 2).

Source: (Philipp Gerbert, 2016)
2.2 Big Data – gain more insights and make better decisions

Traditional information systems are excellent tools for recording basic information about project schedules, CAD designs, costs invoices, and employee details. Yet, they are limited in their ability to work with unstructured data like free text, printed information or analog sensor readings. Often, they can only handle orderly digital rows and columns of numbers.

The aim of collecting big data is to **gain more insights and make better decisions** in construction management. By properly analyzing the data, collected one can draw practical construction project conclusions. In fact, big data, like truckloads of bricks or bags of cement, is not useful on its own. It is what you do with it big data analytics programs that counts. Following examples show how big data can be applied in different phases of a construction project.

**Design** - Big data including building design and modelling itself, environmental data, stakeholder input, and social media discussions, can be used to determine not only what to build, but also where to locate the building. Historical big data can be analyzed to identify patterns and probabilities of construction risks, to avoid them.

**Operations** - Big data from sensors built into buildings, bridges and any other construction makes it possible to monitor the progression and performance of a project. This data can be fed back into BIM systems to schedule maintenance activities when they are required.

**Construction** - Big data from weather, traffic, and community and business activity can be analyzed to determine optimal phasing of construction activities. Sensor input from machines used on sites to show active and idle time can be processed to draw conclusions about the best mix of buying and leasing such equipment, and how to use fuel most efficiently to lower costs and ecological impact. Geolocation of equipment also allows logistics to be improved, shared parts to be made available when needed, and downtime to be avoided.
2.3 Five trends that will shape the digital future of the construction industry

The global consulting company, McKinsey has identified five ways the AEC-industry can transform itself over the next few years.

1. Higher - definition surveying and geolocation - Rapid digital mapping and estimating
2. Next generation 5D building information modelling - Design platform for the future
3. Digital collaboration and mobility - Moving to paperless projects, from the office to the workforce
4. The Internet of Things (IoT) and advanced analytics - Intelligent asset management and decision making
5. Future proof design and construction - Designing with materials and methods of the future.

These five ideas are grounded in innovations that are applicable to the construction sector. They are either being deployed or prototyped and they are designed to work together to deliver greater impact. The following will explain each trend in more detail.

1. Higher - definition surveying and geolocation

Geological surprises are a major reason that projects are delayed and run over budget. Conflicts between ground conditions and early survey estimates can require costly last-minute changes to project scope and design. New techniques that integrate high-definition photography, 3D laser scanning, and geographic information systems, enabled by recent improvements in drone and unmanned-aerial-vehicle (UAV) technology, can dramatically improve accuracy and speed.

Example of higher definition surveying and geolocation in construction:

LIDAR - Light Detection and Ranging is a remote sensing method used to examine the surface of the earth. LIDAR is already widely used in the construction industry. LIDAR’s applicability has been further developed and can now be used on drones (UAVs), handheld 3D laser scanners, and other handheld platforms. LIDAR can generate above-ground and underground 3D images of project sites. This feature is particularly important in dense, environmentally sensitive, or historical project sites, where disturbance should be kept at a minimum. These
advanced survey techniques are complemented by geographic information systems that allow maps, images, distance measurements, and GPS positions to be overlaid. Thereafter information can be uploaded to other analytical and visualization systems for use in project planning and construction.

2 Next-generation BIM

The construction industry has still not adopted an integrated platform that spans project planning, design, construction, operations, and maintenance. The industry still relies on tailored software tools. In addition, project owners and contractors often use different platforms that are not compatible with one another. There is no single source that provides an integrated, real-time view of project design, cost, and schedule.

**Next-generation 5D BIM** is a five-dimensional representation of the physical and functional characteristics of any project. It considers a project’s cost and schedule in addition to the standard design parameters in 3D BIM. It also includes details such as geometry, specifications, aesthetics, thermal, and acoustic properties. A 5D BIM platform allows owners and contractors to identify, analyze, and record the impact of changes on project costs and scheduling. Moreover, the visual and intuitive nature of 5D BIM allows contractors to identify risks earlier and thus to make better decisions. For example, project planners can visualize and estimate the impact of a proposed change in design on project costs and schedule.

3 Digital collaboration and mobility

Process digitization means moving away from paper and toward online real-time sharing of information to ensure transparency and collaboration, timely progress and risk assessment, quality control, and eventually, more accurate and reliable outcomes.

**Digital solutions for construction need to deliver a seamless, real-time experience.**

There are several potential use-cases: Design management, scheduling, materials management, crew tracking, quality control, contract, performance and document management.

4 The internet of things (IoT) and advanced analytics

The IoT is a reality in many other sectors; sensors and wireless technologies enable equipment and assets to become intelligent by connecting the two.
There are several potential use-cases:

**Equipment monitoring and repair** - Advanced sensors can enable machinery to detect and communicate maintenance requirements, send automated alerts for preventive maintenance, and compile usage and maintenance data.

**Inventory management and ordering** - Connected systems can forecast and alert site managers when stocks are running short and when orders need to be made. Tagging and tracking of materials can also pinpoint their location and movement and help reconcile physical and electronic inventory.

**Quality assessment** - “Smart structures” that use vibration sensors to trust the strength and reliability of a structure during the construction stage can detect deficiencies and then correct them at an early stage.

**Energy efficiency** - Sensors that monitor surrounding conditions and fuel consumption for assets and equipment can foster on-site energy efficiency.

**Safety** - Wearable devices can send alerts if drivers and operators are falling asleep or if vehicles or other assets are stationary or non-operational for a given window of time during operating hours.

New building material, such as self-healing concrete, aerogels, and nanomaterials, and innovative construction approaches, such as 3D printing and preassembled modules.

**Example of future-proof design in construction**

**Preassembly** - Modules of a larger building are put together before final assembly at the construction site. Techniques such as prefabricated, prefinished volumetric construction (PPVC) integrate off-site capabilities to transform the construction site into a manufacturing system. The result is greater efficiency, less waste, and improved safety.

**3D printing** - Printing submodules or complete concrete structures before assembly could transform the industry with respect to the objectives of design, cost, and time. However, 3D printing is still in the early stages of its development and cannot yet be deployed at the scale and speed required for large projects.

**Robot assembled construction** - Construction projects are inherently unstructured and often unpredictable; they can also be located in difficult terrains and environments. For these reasons, the use of robots has been limited so far. However, robots are now being selectively used for repetitive and predictable activities, such as tiling, bricklaying, welding and spool fabrication, demolition, and concrete recycling.

**Source:** (Rajat Agarwal, 2016)
The aim of this third chapter is to outline examples of digital innovation cases in construction, and by doing so, demonstrate the potential of digital innovation in the industry. The highlighted innovations stems from the US, China, and Western Europe. Furthermore, the cases described include digital innovations made by technology startups, as well as established actors in the AEC industry and the examples are collected from industry reports, news articles, company websites and case studies performed by researchers and consultancy firms. The sources of the information are provided in the endnote for further reading.

The examples are categorized in groups, corresponding to the five trends highlighted in the preceding chapter, namely:

3.1 Higher - definition surveying and geolocation
3.2 Next generation 5D building information modelling
3.3 The Internet of Things (IoT) and advanced analytics
3.4 Future proof design and construction
3.5 Digital Innovation Processes
3.6 Digital Innovation Implementation

Each example first briefly describes the company, thereafter, the digital innovation, and finally the impact of the innovation on construction projects. The concluding chapter provides further examples of an implementation of digital innovation.
3.1 Higher – definition surveying and geolocation

**UPTAKE**

UPTAKE is a predictive analytics software company, founded in 2014 by Groupon founders Brad Keywell and Eric Lefkofsky in Chicago. The firm offers predictive analytics solutions for fixed and mobile assets, for industries such as rail, mining, aviation, agriculture, energy and construction. The firm has developed a predictive analytics platform for construction equipment owners. The platform uses real-time and historical data about weather and the environment, which allows construction equipment owners to optimize operations. The functioning of Uptake’s platform can be divided into three elements.

**Data ingestion and integration** - Data inputs from various data systems (SAP, CAD, weather, geography, etc.) are screened, harmonized into a common language and fed into the platform.

**Data analysis** - The common language enables real-time analysis and rapid iterations to generate insight.

**Workflow integration** - The actionable insights are translated back into the original system language and integrated into workflows - for example alerting equipment operators.

**IMPACT**

Uptake’s predictive platform allows construction clients to increase productivity of their equipment and generate new revenue streams, by turning data into value. This is done in two ways. First, it allows construction firms to organize their fleets with increased efficiency. Second, because the platform enables equipment manufacturers to develop new service offerings, such as refined diagnosis and repair solutions, AEC companies can derive greater value and longer working lives for their machinery. For a pilot customer of the platform, the overall outcome is an estimated 30% reduction in workshop time, 10% reduction in unnecessary repairs and 40% reduction in recurrent visits to the repair facilities.

**Source:** (UPTAKE); (Forum, 2017)
DOXEL AI

DOXEL AI is a technology start-up company, founded by 26-year-old Saurabh Ladha. The company has produced an artificial intelligence and computer vision based system, Doxel AI uses autonomous devices to monitor visually every inch of a project, and then feeds this data to its proprietary deep learning algorithms. The algorithm processes visual data, examines installation quality, and identifies how much material has been installed accurately. Doxel’s cloud based platform then provides project managers with real time feedback on productivity, as well as how actual costs and time spent are comparing to the original budget and schedule.

Artificial intelligence (AI) is a machines ability to perform cognitive functions associates with human minds as for example reasoning, learning and problem solving.

Three types of AI from the business perspective meet needs of organizations: automation of business processes, insight from data analytics and support in the form of engagement with customers and employees.

As a result, project managers can better control outcomes and keep their projects on time and on budget. It enables them to react to inefficiencies almost immediately and boost productivity. A recent pilot test of the technology on an office building project increased labor productivity by 38% and the project as a whole came in 11% under budget.

Source: (Deloitte, 2018)  Textbox source: (Michael Chui); (Ronanki, 2018)

SMARTTAG BY SMARTVID.IO

SMARTVID.IO is an industrial photo and analytics platform, which includes a “SmartTag” engine that can tag photos and videos of the jobsite automatically by using machine learning, speech and image recognition. The platform then organize the data and make them easily searchable.

Smartvid.io named its proprietary machine learning technology for the Very Intelligent Neural Network for Insight and Evaluation (VINNIE). VINNIE uses a deep learning model to analyze vision and speech to automatically tag construction data and proactively suggest safety measures for the client.
A case study shows that VINNIE was able to analyze 1,080 submissions of construction site photos for the ENR Photo Competition in under 10 minutes and correctly detect 446 images with people. In comparison, human construction safety specialists needed 4.5 hours for the same task and managed around 414 correct detections. In addition, the company claims that VINNIE was able to spot 32 images containing personnel with missing safety hard hats, and 106 images with workers missing high visibility clothing.

Source: (Smartvid.IO); (Bharadwaj, 2019)

SPACEMAKER is a Norwegian startup founded by Håvard Haukeland, Anders Kvåle and Carl Christensen. The company has developed AI software, which assist property developers and architects in making design decisions.

The software is described as an AI-assisted design and construction simulation software for the property development sector. It allows for a speedy generation and evaluation of optimal environmental design for multi-building residential development. In order to do this, the software crunches various data, including physical data, regulations, environmental factors and other preferences. The software then tests billions of possible solutions, and the output is a few designs, which the machine has deemed to be optimal for the plot. Spacemaker collaborates with property developers. It has received funding from Aspelin Ramm, AF Eiendom, Sintef, Forskningsrådet, Innovasjon Norge and Simula.

The software calculates how to build in the smartest way and what measures you may take to optimize the value of a plot (based on parameters set by its user).

Source: (Offergaard, 2017);(O'Hear, 2019);(Tobiassen, 2017)
A Research project has developed a new BIM-enabled method for activity-level construction site planning, which can proactively improve construction safety. The method establishes automated workspace visualization in BIM, using remote sensing and workspace modeling technologies as a central part of construction safety planning. Global Positioning System (GPS) data loggers were attached to the hardhats of a work crew constructing cast-in-place concrete columns. Novel algorithms were developed for extracting activity-specific workspace parameters from the recorded workforce location tracking data. Workspaces were finally visualized on a BIM platform for detecting potential workspace conflicts among the other competing work crews or between material lifting equipment.

The developed method can support project stakeholders, such as engineers, planners, construction managers, supervisors and site supervisors and workers with the identification and visualization of the required or potentially congested workspaces. Therefore, it improves the foundation on how decisions are made related to construction site safety as well as its potential impact on a productive and unobstructed work environment.

In a more recent study, Golovina et al. (2016) developed a method for recording, identifying, and analyzing interactive hazardous near-miss situations between workers-on-foot and heavy construction equipment. Using spatiotemporal GPS real-time location tracking system data to measure automatically a hazard index on a heat map, a project team is able to automatically generate personalized safety performance reports.

The data will help define and validate safety parameters, such as entry of workers in equipment blind spots, to determine the root causes that lead to equipment and visibility related issues on construction sites. Thus, transforming safety training and preventing accidents in the first place.

Source: (Golovina, Teizer, & Pradhananga, 2016)

**nLink** is a technology company that develops robotic solutions for the construction industry. Robots provide precise drilling in construction ceilings, controlled and guided by an easy-to-use app and laser. Halvor Gregusson and Konrad Fagertun found the company in 2012 with the goal of revolutionizing the industry. The company has 14 employees and a turnover of NOK 24 mil with an annual profit of 978,000 in 2018.
OPENSPACE

OPENSPACE is a startup founded in 2017 that uses artificial intelligence to create automatically navigable 360-degree photos of the construction area. The software is used on the Garming VIRB 360 camera. Openspace captures the imaginary and uploads it to the cloud followed by machine learning sorting the photographs and stitching them together and thus mapping them to project plans. In this way, you can keep a digital record of projects as they progress. The software has been deployed on projects like MIRA building in San Francisco and Spiral- 65-floor skyscraper, New York.

Source: (Sawers, 2019)

3.2 Next – generation BIM

ADITAZZ

ADITAZZ INC. was founded in 2011 in Silicon Valley, with the aim of revolutionizing building design. The company has introduced the construction industry to automated design of buildings, a concept taken from the semiconductor industry. The Aditazz platform assists owners, architects and engineers in the development of building design with the help of software algorithms.

The input to the platform is a set of design rules based on client requirements, constraints, building codes and workflows. For example, a nurse needs to reach a patient's bedside in 60 seconds or less. Further input is added from a library of predefined objects, e.g. a standard-size office. The technology then automatically generates a variety of different designs that integrate all of these inputs. The final output is a BIM model that can be further processed and modified with standard software, and, in addition,
a set of metrics for the building, including likely capital expenditure (capex) and operational expenditure (opex), required quantities of building materials and operational performance.

Many project owners are relatively inexperienced and sophisticated in collecting, storing and using data. Although many project owners have plenty of data, it tends to be unstructured, decentralized, and thus, inaccessible to facility departments. Hence, Aditazz has developed an additional service for hospital project owners. The service offers data-integration whereby time stamps are extracted from health records and the information obtained used to improve hospital efficiency. This service enables clients to gain even more benefit from the Aditazz solution.

**IMPACT**

Aditazz’s service allows for space optimization and improved overall lifecycle performance. This translates into cost savings, such as smarter and denser layout, lower construction costs, fewer building materials and greater energy efficiency. By automating complicated, often mundane tasks and eliminating errors and omissions in projects, Aditazz has shown that it can improve design and construction productivity by approximately 30 %, cut up-front costs by approximately 10 % and save a further 10 % on the whole-life cost of ownership.

*Source: (ADITAZZ);(Forum, 2017)*

**ALICE TECHNOLOGIES**

**ALICE TECHNOLOGIES** is a construction-engineering and software company, which was developed from research at Stanford, as a collaborative effort between experienced construction managers, software engineers and computational specialists. They develop construction engineering scheduling software, ALICE, that uses artificial intelligence to automatically create a project schedule. The software scans through information in BIM to collect data related to geographic location and quantity and types of construction materials. Beyond the information available in BIM, the software understands the delicate complexities of scheduling. For instance, it estimates the time it requires to shift tools and infrastructure from one site to another. Instead of telling ALICE how to build every individual column, window or girder, parametric scheduling uses a "recipe" system. Engineers only need to tell ALICE how to build a single column and the program will then extrapolate that process to all other columns.
Because it is parametric, contractors can easily adjust recipes. It takes only a few seconds to adjust a planning parameter such as the number of available crews or crane locations and see how the change would influence the overall schedules. Thus, contractors and engineers can weigh priorities such as cost savings or expediting work to deliver the best possible project at the most cost-effective price. Once the project has started, ALICE communicates directly with construction teams and subcontractors, and can reschedule objectives in response to delays. The web-based properties of the software allows it to be accessed at any time from any device and at any location.

Since ALICE went into beta testing in the summer of 2017, Alice Technologies has continued to improve the software based on user feedback and requested features, such as the ability to track the schedule’s history. The software will get more robust as time passes, and the company are continuing to add more layers to the artificial intelligence. One of the next features to be introduced is the ability to link construction crews directly with ALICE so that they are actually getting their instructions from the software each morning.

**Impact**

ALICE saves an average of 14.7% on project labor costs and brings projects to completion 16.2% faster. It also significantly reduces construction waste.

*Source: (O'Connor); (Morkos, 2014) Textbox source: (Poli, 2001)*

**GenieBelt**

GenieBelt is a technology start-up company founded in 2012 in Copenhagen, Denmark. The company has created a project management software for the construction industry. The interface bundles a few valuable features such as all necessary information about a project, communications, live monitoring, web and mobile access as well as easy-to-perceive reporting material. It connects the program to project teams in real time, enabling everyone to communicate, collaborate, and gather around the plan. Moreover, GenieBelt is an AI and construction management software that measures and manage all building materials in warehouses, predict procurements for upcoming iterations, to receive automatic invoices, providing detailed analytics and reports through customizable dashboards.

**Parametric design** is a design process that utilizes the latest parametric modeling techniques in order to set up the structural geometry of the project. It is used to iterate the structural design with architects and clients, and to make final decision about the design. In other words, through parametric design we can supply all the dimensions, detailed information that is critical to the design and that is consistent with both engineering specification and marketing concept.
Several case studies of GenieBelt can be found on their website. The presentations of the different case studies involve descriptions of the benefits GenieBelt provide to the project. Implementing GenieBelt enables companies to; manage teams on construction sites, delegate tasks in an iterative system, tracking changes to the schedule, reduce paperwork, improve collaboration across sub-contractors, and timely sharing of critical information.

Source: (Geniebelt, 2015); (Geniebelt)

RECONSTRUCT is a software-as-a-service construction technology company that integrates three things simultaneously: integrating reality modeling, 4D BIM, and predictive data analytics. This integration enables construction companies to visually track progress, analyze productivity, and proactively identify potential delays using predictive analytics.

Reality capturing - Using daily and weekly progress photos taken with smartphones, consumer-grade cameras as well as camera drones, the platform continuously reconstructs reality in 3D and over the timeline of a project.

Location driven 4D BIM - The platform takes in 3D BIM from 60 different file formats, including Autodesk Revit and Navisworks, or Industry Foundation Classes (IFC) data models. It also includes project schedules from Primavera P6 and Microsoft Project. By easily and quickly integrating BIM and project schedule via work locations, project teams can create and manage 4D BIM throughout their projects. By visualizing reality models directly within 4D BIM, planned work, trade locations, safety and quality issues can be documented and communicated to the project team in real-time.

Analytics - By visualizing reality directly within 4D BIM, construction progress and productivity rates are measured and communicated within the project team. Using predictive data analytics, risk for potential delays, as it relates to the project look-ahead schedule, is also analyzed.

Source: (RECONSTRUCT)

CATENDA delivers bimsync, next generation cloud based collaboration platform. They provide the construction industry with a platform and tools to collect and connect all relevant information. The company is a spin-off from SINTEF Building and Infrastructure. Has a strong national and international market position and holds a central position in the developing bodies for IFC, BCF, bSDD standards under building SMART.
3.3 The Internet of things (IoT) and advanced analytics

5G to 6G

The next years of R&D will address the fiber-terahertz connection in 6G. As internet traffic is growing exponentially, more capacity will be needed. 6G is supposed to transport data in Terabits per second speed, as opposed to 5G transports 100 Gbps.

Although 5G mobile networks are not reality yet, companies (e.g. Huawei) have started R&D for 6G technologies already. With many tasks and systems infusing the AEC industry (e.g. AI systems to design buildings, BIM systems as input and output), higher speed and capacities are needed, leading to the assumption that 5G and later 6G will become a highly necessary infrastructures to the AEC industry. Companies offering platform services (such as Piscada) or AI design systems (such as Spacemakers) will benefit greatly from 5G and 6G infrastructure.

5G and 6G networks support the creation of data from AI, machine learning and related systems. It also comprises the evolution of computing to include coordination between edge and core platforms and a paramount need for datacenter evolution. Such next generation 6G capabilities in the areas of sensing, imaging and location determination will generate vast amounts of data that must be managed on behalf of the network owners, service providers and data owners.

In Norway, for example, 5G is supposed to be installed by 2020 (according to Telenor). Public transport is already working on using 5G for connecting vehicles and making traffic more safe and more efficient. In construction, 5G will be useful for onsite processes (use of sensors) as well as coordination (communication) and more efficient planning and use of resources.

However, eyes are already in the direction 6G and creative disruption for the AEC industry.
**EquipmentShare**

*EquipmentShare* is a peer-to-peer equipment rental company established in the US. The company has developed a platform for contractors, which allows them to rent and lend contracting equipment such as skid loaders, excavators, lifts and more at rates well below those of commercial rental companies. In addition to providing a platform on which to rent, buy, or borrow machinery, *EquipmentShare* also provides logistics to assist lenders and renters.

In addition, *EquipmentShare* has developed a telematics platform called ES Track, which gives the company real-time data about the location, usage and health of the equipment. Comparing an excavator or a crane’s performance data against a large database of historic records, *EquipmentShare* can predict when equipment is about to break down.

**IMPACT**

The platform allows construction assets to be more efficient. Benefits accrue to both lenders and renters of equipment. Lenders can increase their asset utilization, and thus generate extra revenue. Renters can rent equipment at lower rates than those offered by traditional rental companies. Furthermore, the telematics platform allows construction firms to improve smart management of their maintenance schedules, hours of service and more.

*Source: (EquipmentShare)*

**CONVERGE**

*CONVERGE* is a London-based startup company that specializes in monitoring concrete maturity, including temperature, humidity, pressure, and pH levels. It develops wireless and cloud-based technologies to monitor sensors in real-time. The technology of Converge involves data collection and online inspection of infrastructure. Exploring assets online makes it easier to quickly make decisions, and avoid potential hazards and adapt future solutions. The technology automates manual monitoring and analysis of sensor data on site, helping civil engineers optimize their program time and build safer structures more efficiently. Some of their customers have experienced a 27% reduction in cycle time.
The benefits of Converge are described by six elements of a construction project:

1) It is cost effective - providing real-time alerts straight to phones. The time saved waiting for results keeps concrete cycles consistent and at low costs.

2) It promotes safety - by measuring the temperature of the concrete, they provide highly accurate data, which means reduced cracking, failure, and deflections.

3) It advance predictiveness. The platform access historical data and export relevant information. Reports make it easy to plan and make the right decisions.

4) It is “hassle free” - with Converge, there is no need for early strike test cubes, and no need to wait on labs for progress reports. Converge provides wireless accessibility from anywhere, and real-time data is always available.

5) It facilitates sustainability - the solutions assist in reducing the carbon impact of concrete.

6) It is versatile - Converge works with all pours, frames, and buildings sites. That includes slab, core, wall; regular RC frames and PT frames; residential buildings and tunnels.

Source: (Construction); (Construction, 2015)

HEXAGON

HEXAGON is a global leader in sensor, software and autonomous solutions. The company uses data to increase efficiency, productivity and quality across among other industrial, manufacturing and infrastructure applications. The company consists of six divisions, that of Agriculture, Manufacturing Intelligence, Mining, Positioning Intelligence, PPM, Geospatial and Geosystems. The division of Geosystems has the most value to the constructions Industry as offers a unique geospatial and industrial solution centric portfolio. Their reality-capture technologies create digital worlds that provide information vital for understanding, planning and executing, such technology is HxGN SMART Build.

This technology is a Cloud-based solution build from ground up, with zero install that is easy to get up and running. The platform synthesizes all the information together in a digital form. The system then can be connected to ERP such that when the actuals come in, they automatically come into the project control solution allowing for a running audit trail that shows you graphically the original plan versus the today picture. This allows construction companies to not only see how much it will cost to complete the project but also run what-if scenarios thus finding solutions to solve problems in a more cost-effective way.

Improvement in productivity by 70 to 80 %, thus allowing the time of people to be used on the analysis of the project and what-ifs scenarios thus protecting their margins, meeting expectations of their clients and increasing profitability. Source: (Hexagon, 2018)
3.4 Future – proof design and construction

**MX3D – autonomous robotic**

**MX3D** is a technology start-up that is developing a “plug & print” robotic additive manufacturing software platform. The platform transforms standard industrial robots into large-scale, mobile, 3D printer for construction.

MX3D’s particular interest is metals, and the company specializes in wire-arc additive manufacturing (WAAM) technology, which use standard welding wire and is faster, cheaper and easier to scale than rival additive manufacturing technologies. The MX3D software can be applied to other materials as well, such as concrete, plastics and resins.

MX3D’s flagship project is a steel pedestrian bridge in Amsterdam. The project has brought MX3D into creative collaboration with some major industry players. These partners include the industrial-robot specialist ABB, the design- and engineering-software provider Autodesk, the Dutch E&C company Heijmans, the specialist gas supplier Air Liquide, and the steel producer ArcelorMittal. Other stakeholders in the project include the Amsterdam City Government and Delft University of Technology.

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

**IMPACT**

The main advantage of 3D printing technology is that it allows freedom of design to be a practical option. AEC companies can utilize algorithm-based software to optimize the design of buildings and to design special lightweight beams and other components. MX3D’s printing technology also offers environmental benefits.

By being fully integrated into digital construction models and tools, it provides a very accurate method of producing structures, with zero waste and minimal, costly rework.

**Source:** (Forum, 2017); (MX3D)
WINSPUN, in 2013, owing to its expertise in materials and experience succeeded in 3D printing a residential house for the first time and more specifically, a batch of ten houses, making global headlines.

The technique uses a special ink made of cement, sand, and fibre, together with a proprietary additive. In a kind of prefabrication approach, the company prints the walls in the factory and assembles the building on site. The basic process begins with the client’s design (in the form of a Computer-Aided-Design (CAD) 3D model). The spray nozzle adds the material layer by layer, each layer being between 0.6 and 3 centimeters thick, until a wall of the desired shape and size is completed. The technology is able to produce hollow structures, accommodate piping, wiring and insulation as specified. The finished wall parts are transported to the construction site, installed on traditional foundations and reinforced with traditional steel structures or cement in keeping with regional building regulations. The unpolished walls can then be supplemented with various fittings or finishes according to customer preferences. In principle, the applicability of the technology seems unlimited. Winsun is already developing prototypes for use in infrastructure assets, such as columns for bridges or pipes for water systems. It will no longer be necessary to create temporary formwork on the construction site. Instead, 3D printed molds (“printed formwork”) are installed and filled with reinforced concrete. Winsun also have plans to apply its technology to the construction of high-rise building (buildings of 100 meters or more), by using a mobile printer that could print directly on the construction site.

In the future, Winsun plans to set up a cloud-based platform to connect the company and its clients to designers. Designs will be uploaded to the platform for clients to review, make an initial choice and request a virtual model or printed prototype to be viewed in an exhibition center. Once approved, the final design is sent to the 3D printing factory.

By using the 3D printing technology, Winsun has increased productivity and made it possible to realize significant cost savings. A standard house can now be built for about $30,000. In particular, by printing the walls in a factory prior to assembling the building on site, Winsun can greatly increase the speed of construction. New buildings can now rise one floor per day, which is much faster than standard construction processes. For example, construction of a two-floor
1,100m² mansion took one day of printing, two days of assembly, with internal bar structures created in advance, requiring three workmen only.

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

Source: (WINSUN); (Forum, 2017)

3.5 Digital Innovation Processes

Thanks to the ability to gather vital information more quickly and easily, project teams can put more of their time and effort into proactively anticipating problems. By automating the reporting of performance and tasks, those in the construction industry will be able to focus on critical thinking, where the input of experienced construction professionals adds the most value. Exhaustive processes will be performed by smart tools, with speed, efficiency, sustainability and profitability all improved.

Design thinking is a mindset that is inspired by challenge and difficulty, a passion for imagining what might be possible. Design thinkers embrace all ideas, and do not judge but test them. They do not fall in love with any of them, but keep what works and discard those that do not until an optimum outcome is reached. This cycle is endless. That means using all possible tools to innovate and succeed.

This thinking process of analyzing, seeing patterns and making new connections in processes, tools, systems and data, and then using that information to innovate, actually embraces adapting to disruption without being paralyzed by it. It is in this way that opportunity is turned into real business advantage and sustainability.
lean offers new functionalities and some disruptive improvements. This includes keeping physically distant team members always connected, with access to real-time, up-to-date plans, analyzing huge amount of information to improve business decisions, and tailoring information sharing to people’s roles and responsibilities. Several digital applications already exist that include some lean planning functionalities, but it is not enough to fully support a lean planning process. By applying digital lean methods at the construction site, estimates show that companies can improve their plan completion rate to more than 70 % (compared to the 50 % completion rate of today’s projects).

Digital applications need to include four key design principles:

| Tailored interfaces | All key personnel need interface tailored to their specific roles. For example, planners at headquarters need a detailed interface accessible from a desktop computer that allows them to perform advanced tasks, such as managing activity dependencies, computing delays etc. |
| Visually effective | A good digital lean planning tool should have a simple interface that delivers easy-to-read reports and clear graphs to engage people at all levels of the organization. |
| Enchanced meetings | Digital lean applications can make it easier to plan meetings, conduct meetings remotely, and even mimic certain critical meeting dynamics, such as a commitment button or similar function that team members can click on to commit to a plan. |
| Modular and expandable | Any lean planning application should be modular, allowing people to implement lean planning step-by-step over time. Specifically, the company should look to digitize activities that can complement and strengthen planning by capitalizing on a shared data set. |

AGILE INNOVATION

Efficiency will be measured in how well teams have a common understanding of their customers, as it allows them to target their work more precise towards the desired outcome. Designer teams can create better user concepts, development teams can prioritize better on features based on the customer value and manager will gain more confidence in taking the right.

How agile operates:

The fundamentals of agile are simple. To tackle an opportunity, the organization forms and empowers a small, focused, cross-functional, self-managing team. The team’s initiative owner, who typically comes from a business function and divides his or her time between the agile team and key stakeholders, uses techniques such as design thinking to build a catalog of
promising ideas or features. The initiative owner continuously ranks that list based on the latest estimates of value to customers, financial results and other innovation initiatives. A process facilitator protects the team from distractions and puts its collective intelligence to work (see Exhibit 3).

Source & Textbox source (Brown, 2017); (Link, 2017); (Darrell K. Rigby, 2016)

**3.6 Examples of digital innovation implementation**

**THE EDGE** was a project focused on building a flexible and sustainable office for Deloitte Netherlands. It combines smart building design and innovative technologies. An innovative element of The Edge is the way that the many different elements of the building are interconnected. Every technical system in the building is controlled within a single network, enabling a live view of the building and modulated for maximum efficiency: the lift, the lighting and cooling systems, the robot that cruises around the building at night as a security guard, even the coffee machines and towel dispensers.

By working closely with suppliers, the developer introduced 21 innovations that had never been applied before, such as Phillips’ Ethernet-connected lightning and safe plastic for cable insulation that is non-toxic in the event of fire. The 6,000 low-energy luminaries, on which the lightning system is based contain multiple sensors for measuring temperature and light, and even for detecting movement. These sensors- and a further 28,000 positioned throughout the building - are linked to the building network and integrated into a data analytics platform enabling smart facility management. This helps, for example, guide cleaning staff to heavily used areas, or refilling the towel dispenser before it runs out, and allow predictive maintenance of the LED lights by monitoring their usage.

One novelty is the building app; which employees can operate on their smartphones or tablets. The app allows employees to instantaneously adjust the lightning and heating at each workspace to their personal preference, reserve meeting rooms or parking places, track their progress in the on-site gym (treadmills are connected to the building’s electricity grid too), or locate their colleagues within the building.
The Edge is widely considered the most sustainable office building in the world. Thanks to its solar panels (including some on rented roof space nearby), its aquifer thermal energy storage systems (ATES), and demand reduction through such factors as efficient lightning and smart building design, the building’s energy consumption is net negative - an estimate - 0.3 kWh/m²/year versus +40.7 for traditional office buildings. The Edge offers many advantages. The flexible set-up, together with the smart data system and the building app, allows for accurate hot-desking, so much so that the building’s 1,100 workspaces now serve more than 2,500 employees, even though originally intended for 1,700.

Source: (Forum, 2017)

Rambøll is a leading engineering, design and consultancy company founded in Denmark in 1945. Rambøll has 15,000 experts with 300 offices in 35 countries. Rambøll combines local experience with a global knowledgebase to achieve inspiring and exacting solution that make a difference to clients, the end user and the society. Rambøll uses a multidisciplinary approach to create a sustainable society with improved quality of life and economic growth. Rambøll works across markets such as Buildings, Transport, Planning & Urban design, Environment & Health, Water, Energy and Management Consulting.

One of the most highlighted projects that Rambøll works with is the Nordhavnen in Copenhagen, Denmark. Nordhavnen is Scandinavia’s largest and most ambitious city development project with the vision of becoming the most sustainable city of the future. Furthermore, it is the only new urban district to receive DGNB’s (German Sustainable Building Council) gold certification for sustainability.

Source: (Ramboll, n.d.-c); (Ramboll, n.d.-b); (Ramboll, n.d.-a)

Another example of an innovative project that Rambøll works with is the Sustainable one-family homes. One of these examples are the 165 residences in Upton, Britain. They feature renewable energy sources such as solar panels, solar hot water, green roofs and other facilities that reduce utilization of energy and ensure low energy consumption.
The traffic station at Gol has been a pilot for the Statsbygg owned project named Digibygg. Digibygg has a special focus on project delivery and operations. As such, the project workers used the most advanced digital tool available and the building itself is now operated with the help of big data, sensor technology and remote control. Some of the innovative measures taken throughout the project were as follows:

**Digital construction site** - BIM kiosks at the construction site replaced paper drawings. This allows construction workers to access updated versions of the drawings at any time.

**Drones** - Right from the start of the project, drones were used to collect geo data.

**Progress planning** - Products for the construction site were traced using radio frequency identification (4D). In addition economic planning (5D), environmental information (6D) and facility management information (7D) was included in the BIM model.

**Workspace safety** - Safety and security at the construction site was maintained with a digital simulator, safety training and reporting of unwanted situations in BIM.

**Automation** - Drilling robot was used to hang technical systems. This result in reduced strenuous work for workers, as well as reduced dust.

**Virtual reality** - Virtual reality glasses was employed so as to see the completed building virtually.

**Augmented reality** - Augmented reality glasses allowed the users to visualize the BIM model, or parts of the model, on top of the users’ sight.

**Facility management** - FM is optimized through automation, remote control, and automated steering, based on available real-time data (e.g. temperature, air, light, sound, weather).

The project is considered as Norway’s first fully digitalized construction site. In addition, the project received the golden helmet, an award for projects that focus on security, health and work environment on the construction site. According to project manager, Bjarni Einarsson, the digital processes has led to active participation from the different actors, zero incidents and a high level of reporting from all actors.

**Source:** (Byggeindustrien, 2018);(Statsbygg, 2016)
The Centre for Construction Industry
BI Norwegian Business School

The Centre for the Construction Industry at BI Norwegian Business School was established in 2005. The main purpose of the Centre is to provide research-based knowledge related to organizing, managing and strategizing in the context of the architecture, engineering and construction (AEC) industry.

The goal of the Centre for the Construction Industry is to strengthen and support the industry's efforts in increasing value and be sustainable, and in its pursue of utilizing new technologies in these efforts.

Through close cooperation between researchers and organizations, it

- Addresses the socio-economic importance,
- Conducts research on the processes and practices,
- Develops relevant capabilities and skills, and
- Disseminates knowledge and builds networks within the AEC industry.

The Centre for the Construction Industry has more than 15 researchers affiliated and it combines a rich variety of different backgrounds in engineering, management, strategy, pedagogics and sociology. The researchers share a common interest in advancing knowledge in and about the construction industry.

This report was created by researchers at the Centre for Construction Industry, Department of Strategy & Entrepreneurship, BI Norwegian Business School.

The report draws on results from prior publications and knowledge from experts in the focal field. Respective references are found in the back of the report.

Please contact Ragnhild Kvålshaugen, Professor at the Department of Strategy and Entrepreneurship, for further information (ragnhild.kvalshaugen@bi.no).

November 2019, Oslo

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Picture Front Page: (c) Mariya Khanamiryan
Appendix

Exhibit 1:

Exhibit 2:
Exhibit 3:
Reference List:

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