WORKING PAPER

Digitisation in the workplace

Case Study: 3D-printing at BAM Infra (Driebergen-Zeist)

[Digitisation in the workplace]

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Related report: Digitisation in the workplace

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency established in 1975. Its role is to provide knowledge in the area of social, employment and work-related policies according to Regulation (EU) 2019/127.

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Case summary

Royal BAM Group is a construction firm with ten operating companies in five European home markets. In the Netherlands, it is the largest construction company (NACE: F.45) based on revenue. For its civil engineering activities, the operating company BAM Infra operates at different sites for the duration of the engineering works. This case study focuses on activities at the construction site of Driebergen-Zeist, where the railway station was rebuilt, the railway crossing removed, roads reconstructed to form an underpass, and an additional railway track added. This project lasted from 2017–2020 at a cost of €120 million.

At the request of management, 3D printing of construction elements was introduced within BAM in 2017 to experiment with this new technique. Joining forces with an innovative 3D printing firm, BAM was able to win a project for the Province of Noord-Brabant to build a 8m-long bridge out of 6 joined printed elements. This assignment was made possible because the province highly appreciated the innovative approach as well as the promise of less material use, and therefore also fewer CO2 emissions (as the production of concrete is CO2-intensive). Soon after, 3D printed elements were integrated in a large scale construction site – Driebergen-Zeist. In parallel, a 3D printing factory was set up in Eindhoven in a joint venture with a cement production firm. New assignments for more 3D printed bridges were won, as BAM is constantly trying to convince its clients to incorporate 3D printed elements in their designs. It is clear that BAM takes a very proactive stance in promoting this new technology – focusing on learning-by-doing rather than rolling out a highly detailed 3D printing strategy. The technology readiness level is at commercial stage (9).

3D printing fits within BAM's larger ambitions of becoming a leader in digital construction. This relatively new development in the rather conservative construction sector encompasses a lot more proactive planning of construction work. Rather than just providing a "blueprint" 2D drawing of a construction, a 3D digitised model is enriched with a fourth dimension (time: which building activities occur when) and a fifth dimension (costs: for each item and personnel time), which together forms a so-called Building Information Model. This allows for a much cleaner and well-planned construction site (fewer building materials are present, only necessary personnel is present, personnel receives detailed instructions), which reduces errors, minimises accidents, and economises on craftspeople. Given the current shortages of skilled personnel in the construction sector, this development leads to more efficient deployment of personnel rather than reduction of personnel.

3D printing within the grand scheme of digital construction has little effect on the current workforce composition. It does, however, affect the discretion of the workers at the construction site. While they operate in teams that are led by foremen, who receive instructions by a scheduler, the traditional work process depended on inventiveness and a problem-solving attitude. With the advent of 3D printed elements, the workers have to adhere to schedules that are determined offsite, to optimise the production process. While this may be beneficial in terms of quality of the product and effects on the environment, it does limit the freedom to operate independently. To find the balance between reaping the benefits of 3D printing while keeping skilled and flexible workers will be a challenge for the construction sector.

Introduction

Background and objectives

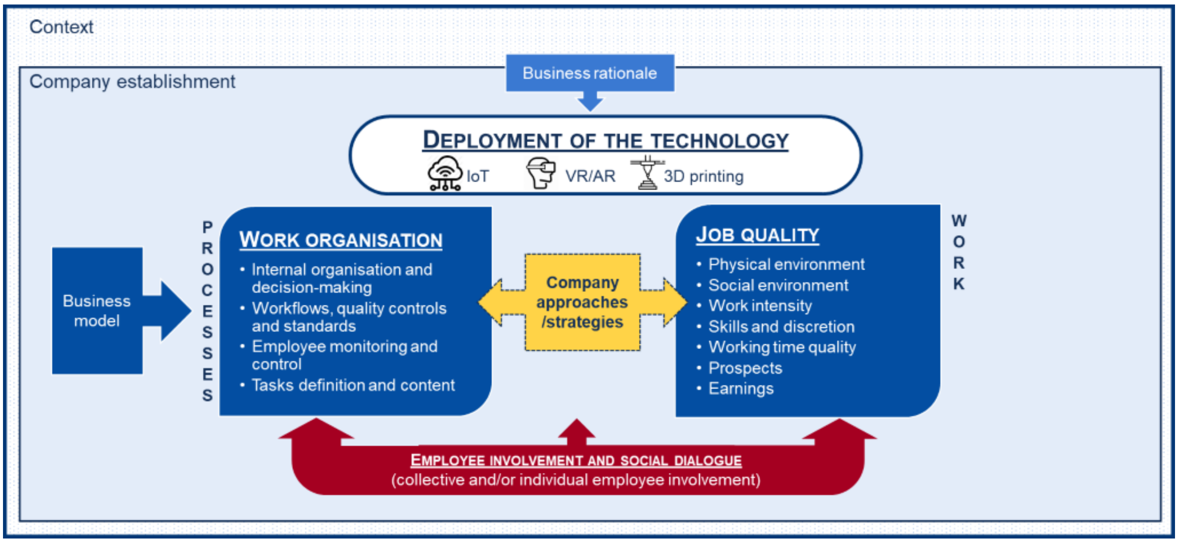
This working paper illustrates the case of BAM Infra in Driebergen-Zeist (the Netherlands) in relation to the introduction and deployment of 3D-printing or additive manufacturing (AM). The working paper explores the impact of this digital technology on the work organisation and job quality, as well as the extent of the employee involvement in relation to the digitisation process.

This case study has been conducted in the context of Eurofound research on the impact of digitisation on the nature of work. This research is set against a conceptual framework elaborated by Eurofound (Eurofound, 2018), which differentiates between three vectors of change, of which one is digitisation, associated with three digital technologies. These are additive manufacturing, the Internet of Things and Virtual and Augmented Reality.

Eurofound's conceptual framework on the digital age (Eurofound, 2018) proposes that the effect of digitisation is most direct on working conditions, as it involves a change in the work environment and nature of work processes. It also involves changes in tasks and occupations and has an indirect effect on employment conditions and industrial relations.

Based on this conceptual framework, Eurofound has developed an analytical model (reproduced in figure 1) that serves to guide the analysis of 9 case studies (including the BAM Infra case) conducted for this research. According to this model, the nature of work consists of two core dimensions, namely work organisation and job quality. Employee participation and social dialogue is a cross-cutting dimension as it can both influence and be influenced by the way the technology is deployed in the workplace. Typically, the technology changes the establishment's (in this case: the construction site's) business model, which in turn impacts the work organisation and elements of job quality (partly depending on how the technology is applied in the workplace). Both contextual factors and site or company specificities may drive the digitisation efforts. These factors should be taken into account for a better understanding of what has either constrained or facilitated the digitisation process within each establishment.

Figure 1: Analytical model for this study



Source: Technopolis & Eurofound 2019

Disclaimer: This working paper has not been subject to the full Eurofound evaluation, editorial and publication process.

This case study draws primarily from qualitative interviews conducted in the context of the construction site in Driebergen-Zeist with:

- one of the company's innovation managers, focused on 3D-printing
- the manager of 3D-printing operations and liaison with the construction sites
- an HR Manager
- a representative from the works council
- an employee working with the 3D-constructed elements.

In addition, interviewees provided internal background material to better outline the procedures in the establishment. Lastly, public information such as annual reports served as a basis for company information.

Reason for selecting this particular case

This particular case study provides insights into the introduction of 3D-printed construction elements at a large construction site. It shows that the use of 3D-printed elements coincides with several innovation streams in the building industry: the use of building information models (BIM) to streamline the building process as well as prefab-construction to reach efficiency gains. The building industry is considered a very conservative working environment in which innovations have to prove themselves before being accepted by the workforce. At the same time, business logic (costs), environmental concerns, as well as shortages of trained personnel, drive the company to implement such time- and material-saving innovations as 3D-printing.

The BAM Infra case was also chosen to gain more information on the use of VR/AR in construction. Whereas VR is being experimented with at the design stage of a construction, to help the designer see their design from all angles or to immerse clients in the final state of their project, it has proven less effective at the construction site. VR/AR glasses are relatively delicate and expensive equipment that does not survive the harsh conditions of the work: handling this equipment would mean that construction workers would fundamentally have to adjust their way of working, which is not deemed practical. BAM has experimented with AR glasses that, once the construction is finished, allow facility management to walk through buildings/sites and receive additional information on requirements and steps for maintenance (especially of complex electronic or mechanical equipment). This use of AR is currently still in the development stage.

Report structure

In the following chapters more context will be provided by describing the establishment in more detail (chapter 1), the analysis will be illustrated by describing the process of the introduction and implementation of the technologies, including the role of social dialogue and employee involvement throughout the digitisation process (chapter 2), the impact of the three technologies on the business model, work organisation and job quality (chapter 3) . The working paper ends with lessons learned drawn from this specific case and some takeaways.

1. Establishment/site profile

Type of entity and ownership structure

Royal BAM Group nv is a construction firm with ten operating companies, one of which is BAM Infra, in five European home markets and in niche markets worldwide. This case study describes the experiences in one construction site of BAM Infra: Driebergen-Zeist.

The company was founded as a joiner's shop in 1869 in the Netherlands. It was renamed Bataafsche Aanneming Maatschappij van Bouw- en Betonwerken (BAM) in 1927 and expanded through acquisition. BAM's European home markets are the Netherlands, Belgium, the United Kingdom, Ireland and Germany. It is a shareholder company with a revenue of €7,208 million (2019) whose shares are traded on the Euronext Amsterdam Stock Exchange.

Activities and geographic location

BAM distinguishes two business lines (both falling under NACE code for construction – F.35): Construction & Property as well as Civil Engineering. One of the ten operating companies of BAM operating in Civil Engineering projects in the Netherlands is BAM Infra. Although its headquarters are in Gouda, the Netherlands, this is not where the operations take place – these happen at the sites of the civil engineering projects that BAM Infra undertakes.

At the time of this case study report, BAM Infra was active at 85 sites in the Netherlands, combining several civil engineering activities including asphalt and roads construction, traffic technology, foundations, energy structures, waterworks, and railroads. For each of these sites, project teams are situated for the duration of the project. The site of Driebergen-Zeist was selected for the purposes of this study in consideration of the novel 3D printed elements being deployed at the site.

The reconstruction of the Driebergen-Zeist railway station and surrounding roads was a €120 million project undertaken by BAM Infra for the Dutch railway infrastructure company ProRail (acting on behalf of the Dutch Ministry of Infrastructure, the province of Utrecht and the municipalities of Driebergen and Zeist), that lasted between 2017 and 2020.

Figure 2: New railway station at Driebergen-Zeist

Source: ProRail/BAM Infra

The project included the construction of an underpass for cars, cyclists and pedestrians (eliminating the need for a very congested railway crossing), a reconstruction of the railway station building and its external surroundings, as well as the construction of an extra railway track (see figure 2).

Size and workforce composition

The activities at a project site vary over time, depending on project stage and activities. At the height of activities in Driebergen-Zeist the site hosted 120–150 workers. These are pooled from the 3,500 workers active in BAM Infra. Because of the dynamic nature of the construction process in different phases, precise data on the workers at Driebergen-Zeist are not available, but the workforce is reflected in the general composition of BAM Infra. The female/male ratio is 17/83 and in terms of education, all education levels are represented from unskilled labour, vocational education, to tertiary degree professionals. Roughly 40% of all employees are active on the project sites, while 60% have a supervisory, support or administrative function. Many young employees are on temporary contracts, while the personnel with permanent contracts is ageing (similar to the Dutch average of ~22% at 55+).

At the construction sites, there is hierarchical system in which workers are instructed by foremen, who receive tasks and work schedules from a scheduler (who translates building plans into assignments). The construction work on the whole site is overseen by a construction manager. Given their assignments, and depending on the level of experience and specialisation, the construction workers are to a lesser or greater extent free to solve the problems they are faced with.

Form of employee representation

Employees in the building and construction sector in the Netherlands are represented by several unions, of which FNV Bouw is the largest. However, over the last decade the influence of unions has been declining, especially among younger employees, leaving roughly 1 in 5 workers represented by unions (CBS, 2018a). Still, labour unions have an important role in collective labour agreements in the building and construction sector.

Since the 1950s, Dutch organisations with more than 50 employees have been required to establish a works council (Dutch Works Council Act - WOR). In general, a works council is an internal body representing employees, promoting and protecting their interests. Works councils have consultation rights in respect of certain significant proposed management decisions. Furthermore, they have approval rights in respects of intended company decisions regarding employment policies.

The works council operates at the level of the entire company (Central Works Council or COR) as well as at the level of the individual operating companies (such as BAM Infra). The COR has a committee in which technological developments such as digitisation are discussed, albeit mainly at a general level.

The local works council meets roughly 6 times per year and traditionally has as an important focus on safety issues on the construction floor – this includes safety related to 3D printing. The council regularly receives safety reports from an independent safety advisor and certification company ARBOMA. Works Council members also visit construction sites to talk to employees about issues and incidents.

2. Digital technologies at BAM Infra

To understand the role and importance of 3D printing, one has to see it in a wider context of digitisation in the construction industry. The construction sector is considered very change averse, with a high degree of training on the job. While many other sectors have invested in digitisation, the building sector is lagging behind: many practices are similar to those of 60 years ago, for example, working with paper and pencil. The attitude within the construction sector, and especially on construction sites, has traditionally been focused on getting things done, rather than planning ahead. For a long time, this was considered the general way in which things are done, leading to errors that later had to be fixed on the spot.

In recent decades, the industry has come to the insight that much can be gained with better planning before the start of the project. The pervasiveness of information and communication technologies has allowed the advent of so-called building information models (BIM) that not only allow for 3D-construction models, but also for actual construction site planning including step-by-step simulation of the construction process: when do construction materials enter the construction site, when are they combined and put into position, and when is waste material removed. It is BAM's ambition to become a leader in BIM/digital construction, using the motto: "We make it before we make it".

BAM's digital construction strategy (BAM, 2017), focuses on six main areas. It should be noted that not all elements of this strategy are already fully functional, but the use of 3D and 4D (time) BIM is becoming standard practice in tenders and projects.:

1. **Scanning**

   • 3D scans of the actual site, used as a basis for 3D model designs.

2. **Design**

   • Integrated 3D modelling, with BIM software, combining the different disciplines such as steel, concrete, installations, reinforcement, in one 3D model

   • Parametric design based on algorithms, which offers engineers new design possibilities – this is also how some 3D printing models are made

   • Generative design to quickly have the computer calculate design alternatives with a focus on specific constraints

   • Certification to the international ISO 19650 (BIM) standard

3. **Simulations**

   • Virtual reality: 3D visuals of the design for all stakeholders, and also used for safety training and safety walks

   • Simulating actual excavation plant movements and verifying construction methodology;

   • 4D (project scheduling) and 5D simulation (costs)

   • Sustainability modules to calculate the energy use of a building, waste management, etc.

4. **Production**

   • Off-site (modular) development and construction, DfMAD (design for manufacturing assembly and disassembly)

• 3D concrete printing: modular building services skids for office buildings

• Mechanical robots to apply bricks to modular façade elements for housing

5. **Assembly**

• Tablets/smartphone devices for quality and health & safety monitoring

• Machine guidance & control technology to improve efficiency, safety and reduce CO2 emissions

6. **Operations**

• Augmented reality, virtual reality, and BIM data to support service engineers in operating and maintaining projects (schools, hospitals, roads), so after the construction phase

• Artificial intelligence: BAM proactively scans roads with satellites and scanning vehicles. The collected data enable easy and efficient identification of road problems

In 2017, the Driebergen-Zeist railway station in the Netherlands was considered one of BAM's prime examples of professional use of digital construction. (Royal BAM, 2017)

Figure 3 Printing 3D concrete elements (which are not made of solid concrete, but save on material)

Source: BAM Infra

Motivation for the introduction of the technology

Given its ambition to become a leading player in digital construction, BAM invests heavily in innovation projects that contribute to this ambition. In the latest annual reports of Royal BAM (2017–2019) there was ample attention for digital construction and the innovation pipeline of the company. 3D printing was seen as contributing to the overall ambition and something that needed to be tested throughout the company – first by starting a pilot and (if proven beneficial) rolling out the technology in other assignments/projects.

While learning-by-doing and experimenting was the main motivator for trying out 3D printing, the other advantages that are associated with additive manufacturing were known: freedom to design more complex shapes (and thus contributing to the uniqueness of the project/wishes of the client), the promise of less waste/material use, and the possibilities of efficiency gains:

- No more storage of materials on the construction site (as 3D printed elements are remotely produced and delivered as needed)
- Building materials and/or elements arrive on the site as they are needed
- Transport (of 3D printed elements) to the construction site can take place outside building times (outside traffic), minimising disturbance to the surrounding area
- Low amount of waste leads to clean working site, with fewer safety risks
- Reduction in labour-intensive work

Place in the workplace for the technology and its embeddedness

The building of a construction work consists of breaking down the project into many different assignments and tasks that are picked up by teams under the guidance of a foreman.

At Driebergen-Zeist, the 3D printed elements that were used were of an ornamental nature. The handling of printed elements could be seen as a shift in the type of tasks that construction workers need to carry out on the construction site – no specific changes to the team were made or deemed necessary. At the construction site, work encompasses hauling and hoisting construction materials to the right place and then having craftspeople (carpenters, bricklayers, etc.) assemble these materials in the construction according to predetermined building plans. 3D printed elements would need to be hauled into their spot, just like traditional building elements – it would only require more delicate handling during the hauling procedure.

3D printing is an example of precast concrete technology. This is an alternative to using cast-in-place (reinforced) concrete elements, for which the tasks include: constructing the formwork (temporary or permanent molds into which concrete or similar materials are poured) by a carpenter, positioning and securing steel reinforcing bars by a steel fixer, and pouring the concrete. The curing of the concrete then takes quite some time (up to several weeks for large constructions) before the next step in the building process can be taken. In the meantime the craftspeople work elsewhere (within the construction site or perhaps on different projects). With 3D printing, the work of the carpenter and steel fixer, as well as the curing, is done off-site by a 3D printer.

While in Driebergen-Zeist the number of 3D printed elements did not dominate the construction process (as these encompassed ornamental elements), future visions of construction work with precast concrete (produced by 3D printing) include assembling buildings and other constructions like lego blocks. In such a future prospect, the requirements as regards craftspeople on site might change as fewer carpenters may be needed and workers would need to be able to correctly assemble prefabricated elements. BAM indicates that it cannot envisage what the work division of such a future situation would look like.

Technically, the 3D printing factory is not part of the workplace, but it is an essential step in the production of the 3D elements. For its location Eindhoven was chosen, close to the Technical University of Eindhoven, from where the operators were hired fresh out of university. The factory is basically a large hall in which a printer robot is placed. The hall provides a good indoor climate (temperature/humidity) for the cement to cure (dry) and allows for storage of printed elements. From the factory, the elements are picked up and transported to the construction site. The factory provides work for five highly trained operators.

Timing of the introduction and progress thus far

The decision to start working with 3D printing was made around 2017; it was a company board level decision that had to be implemented in an actual BAM assignment. An alliance was made with a company that had pioneered in 3D metal printing, and a client willing to invest in innovative construction methods had to be found. The Province of Noord-Brabant, which had expressed an interest in being a launching customer for environmentally friendly construction methods, was willing to invest. By October 2017 the world's first 3D printed concrete bridge, consisting of six elements, totalling a length of 8 metres and a width of 3.5 metres, was delivered.

To be able to provide the 3D printing technology, a project was started together with the Technical University of Eindhoven, Weber Beamix (as the supplier of the concrete mix), and several consulting engineering firms to provide expertise in novel building techniques. The first bridge was printed within the university's labs. In 2019, however, BAM and Saint Gobain (Weber Beamix), opened a dedicated printing factory facility in Eindhoven. BAM uses this facility to accelerate the embracing of this technology and to bring viable projects and products to the market.

While still working on the pilot bridge, BAM bid for new assignments where 3D printing would become an integral part of the construction process. The Driebergen-Zeist railway hub (a €120 million project lasting from 2017–2020) became one of the first sites to incorporate 3D ornamental elements in a large assignment. This shows the typical learning-by-doing process that BAM engages in: starting from the premise that 3D printed elements should be used, the construction team had to learn to handle these new elements. In Driebergen-Zeist, one of the lessons learned was that the 3D printed elements needed to be hoisted more carefully than traditional building materials, as the elements were designed for stress in certain predetermined dimensions. The stress from grappling these elements was not calculated in the design, and one element broke due to rough handling.

BAM is continuously trying to incorporate 3D printing into new assignments, to further develop the technology and make optimal use of its dedicated 3D printing factory. While Driebergen-Zeist was being constructed a new assignment for building an even longer bridge was acquired in the city of Nijmegen. The printing of this bridge started in May 2019 and four further bridges are currently in the design phase.

Initial expectations of the introduction of the technology

As indicated above, there are several promises of 3D printing that were expected:

- rather than producing solid blocks of concrete (as is the case with casting concrete), 3D printing allows for only printing material that is needed to provide the required strength of the construction, which saves on large amounts of concrete (which emits large amounts of CO_2 in its production process)
- it does not require formwork, leading to less waste
- it allows for curing (drying) the 3D printed concrete elements under ideal (factory) circumstances, leading to stronger concrete elements
- it allows off-site construction, so that the elements can be produced while other work is being done on-site (saving on-site space and disturbance)

- it can produce the elements just-in-time[1]
- the 3D printing instructions can be exported directly from the original 3D BIM, meaning the printing can be done fully in accordance with the original design

In short, there were high expectations of the introduction of 3D printed elements. While especially the handling of the 3D printed elements proved more difficult than anticipated and there was a noted loss in flexibility due to the 3D printed elements having to be produced and shipped from Eindhoven, the overall promise of less construction waste, less use of material and faster construction speed (fewer workers hours) was upheld and led BAM to continue down the 3D printing path.

Initial strategy for the introduction of the technology and adjustments during its deployment

The introduction of 3D printing was seen as a special (pilot/demonstrator) project for the Province of Noord-Brabant. In terms of project size the bridge could be considered relatively small and thus an ideal experiment for the new 3D printing techniques. BAM secured the support from an innovative 3D printing firm (that had become known for printing a metal footbridge), knowledge partners, consulting engineers, and a concrete producer to ensure the pilot was securely thought through from different angles.

As mentioned in several interviews, BAM’s strategy for the further introduction and dissemination of 3D printing was through its (ad hoc) learning-on-the-job mentality: construction workers were given assignments to use the 3D printed elements and thus gain experience in handling the material. By introducing these elements in different construction processes more and more workers would learn to work with these elements.

Role and involvement of employees before, during and after the technological change

For the construction workers, dealing with 3D printed elements could be considered just one of the assignments they have to deal with. As such, they had little involvement before the change and were confronted with novel elements they had to learn to handle. Also the works council was not directly involved: it was informed of the possibilities of the new 3D printing method. Innovations like 3D printing or VR/AR come to the table of the technical developments committee of the works council as interesting developments and are discussed at a general level unless specific incidents call for further investigation.

In handling the 3D printed elements, the solution-oriented nature of construction workers was called upon, as practical handling issues (how to temporarily store and lift the elements) had not been thought through. In the end, handling the elements was considered as something that was imposed upon them from the top, but they had “mastered” through learning-by-doing. The initial criticism of

[1] Just-in-time (JIT) manufacturing, also known as just-in-time production or the Toyota Production System (TPS), is a methodology aimed primarily at reducing times within the production system as well as response times from suppliers and to customers.

the innovation was replaced by an appreciation of the possibilities that this new approach to building and concrete casting could offer.

At the front end of the design phase, there was much more involvement from engineers who designed the different elements to be 3D printed. This had to be done in close cooperation with knowledge partners (Eindhoven Technical University, consulting engineers Witteveen + Bos, Bekaert), as whole new ways of calculating the constructive strength and safety had to be thought through.[2] Also, while there was more freedom to the designs of printed elements, these designs were not unlimited: they were constrained by the layer-by-layer approach to printing (which included inserting a steel cable for reinforcing the concrete), as well as the required strength of the construction.

[2] For concrete, construction strength was traditionally calculated for solid blocks of concrete. However, as with other materials, the strength of concrete does not diminish if precisely calculated holes are present in the construction. This calculation method had to be developed for 3D printed concrete.

3. Impact of the technologies in the workplace

Changes to the business model

At its current level of deployment, 3D printing allows for parametric design of construction elements – special shapes – that could not have been realised previously with traditional concrete casting methods. This freedom to shape construction elements adds to the degree of design freedom of construction works, and unique design is something that clients are interested in. Thus, 3D printing opens up new options to satisfy customers.

As compared with the total volume of work in the Driebergen-Zeist project, the impact of the 3D technology was not large: most of the construction work was still done conventionally, while some formwork and ornamental elements were produced with 3D printing. The deployment on site (and on several other sites using 3D printed components) proved that integration of 3D elements in a construction site does not pose any problems on site (save some handling issues). Furthermore, the technology promises major cost reductions due to 1) less waste 2) more precise construction elements and 3) savings on construction time and thus personnel costs. It is therefore logical from a business perspective that construction companies will develop more project works using 3D printed elements. BAM continues to promote 3D printing, but is dependent on clients who are willing to incorporate this novel technique in their constructions.

3D printed elements fit into the larger shift of the business model of construction companies: rather than establishing a large construction site and organising most of the building activities on this site, the construction work becomes more of a just-in-time logistical process, in which only those materials are present at the construction site that are needed at that moment. 3D elements will be ordered to arrive at a specific moment, where they will be hoisted and fixed to their designated positions. Overall working with digitised working processes has allowed construction companies to save up to 22% in construction costs (ISO, 2019). One of the interviewees stated that for Driebergen-Zeist the reduction in personnel time/cost has reached 60–80%.

Impact on the work organisation

Internal organisation and decision-making

At the construction site of Driebergen-Zeist, the organisation of the work had not changed much: the work was still taking place in teams of construction workers headed by foremen who received their instructions from schedulers. In large part the site hierarchy remained intact.

What was noted was a greater dependence on the 3D designers. Construction sites were always considered places of (relative) autonomy, where issues could be solved on the spot. It became clear that due to the intricacies of the construction design, not all problems could be solved on site anymore, but had to be relayed to the designers, often operating at a distance. In other words, construction workers become more dependent on designers and planners. Once that errors occur, they cannot be solved on site anymore and have to be solved at higher hierarchical levels.

Workflows, quality controls and standards

The dependence on (off-site) designers and planners goes hand in hand with a more planned workflow and shifting to a more just-in-time based construction process. The workflow becomes more predictable at the overall level for the client and the contractor (BAM), but therefore also offers less room for autonomy at the local (on-site) level. Since construction workers are already used to receiving instructions, the change may be considered gradual. At the same time, the instructions do leave room for improvisation as many elements of the construction work and workflow remain unpredictable and require room for adjustment and ad hoc problem solving.

Using and depending on 3D printed elements adds a layer of quality controls off the construction site: the elements are checked at the production factory for adherence to specifications. When the elements are placed, still regular quality checks of the whole construction are required.

Construction standards have not altered through 3D printing, although new shapes and forms have become possible. These still adhere to all the regular construction standards, which put the burden of proof on consulting engineers and academics who supported the calculation of construction strengths.[3]

On a global scale, beyond BAM, what is relevant is that there is a standard for "Organisation and digitisation of information about buildings and civil engineering works, including building information modelling (BIM)", ISO 19650. This is a guideline to help the (global) construction industry deal with relevant definitions and approaches to BIM.

Employee monitoring and control

The implementation of 3D printed elements in no way altered the normal activities at the construction site. A scheduler would be responsible for assigning the tasks to foremen who guided the construction workers. Monitoring and control of employees would still take place by direct supervision.

Task definition and content

In the grand scheme of digitalisation and digital planning, there is a shift towards front-end planning in the construction process by 3D modellers and calculators who operate off-site. These are generally tertiary level engineers who have the skills to break down large plans into operable assignments using 3D models and computers. It is at the front-end of the process that VR has a future role to play: modellers can step into their 3D designs and inspect whether the 3D rendered construction looks the way it should (and adjust, as needed). Clients can also be given a virtual tour.

Once the 3D models are finalised, they are turned into working instructions by schedulers, who are also tertiary level engineers, but with a more practical inclination. They generally already have learned the skills to handle 3D models in their education. As 3D planning is becoming more important, one way for construction workers and foremen to progress in their career is to learn to read 3D plans, so that they can move towards the position of schedulers (or take their role in smaller sites).

The work at the construction site has to fit into a larger logistical process in which the specific construction elements (e.g. parts of columns or walls) that have been printed in the printing factory arrive at a predetermined time. This requires just-in-time management at the construction site.

[3] The engineers had to prove that 3D printed elements (with strange shapes and holes) had the same strength as solid concrete blocks.

At Driebergen-Zeist, there was a subtle shift in requirements for formwork: less of it was required (as elements are 3D printed without the need for formwork but also formwork was printed) and carpenters were freed to work on other, regular carpenting tasks. All in all, the need for carpenters on site has declined somewhat, which meant they could be deployed on other sites.

As 3D elements are somewhat more fragile if they are subjected to forces they were not designed for (such as hoisting), this required more precision in handling the 3D components once on site. In all, the diversity of the tasks was not compromised, but carpenters did less formwork and steel fixers did not need to fix the steel for the printed elements. In the future, a construction site may have a much larger fraction of elements being 3D printed, which would lead to fewer carpenters and steel fixers at the site.

Impact on job quality

Physical environment

A main concern in construction sites is the physical safety of workers, as handling large and heavy materials is risky. The handling of 3D printed elements requires some additional attention as these elements are relatively fragile if unintended forces are applied to them. This proved to be no problem after some initial mistakes and could be considered in line with standard working practices (rather than hoisting non 3D printed elements, they also hoisted 3D printed elements).

In addition, 3D printing allows for creating a “cleaner” construction site, and the logistical planning allows for handling only elements as they are required. This is considered as contributing to site safety as more materials on the construction site means more hauling, more movements, but also more waste, thus more risks for accidents.

The 3D printing factory is formally outside the scope of the construction site, but its physical environment may also be considered part of the calculation as without the factory no 3D elements would arrive at the site. The current 3D printing factory in BAM is a highly controlled site, in which only a few highly trained engineers (university graduates) handle a 3D printer in a large hall. While the 3D printing robot is a large machine, its movements are very predictable and thus constitute a small risk.

Social environment

The majority of the construction work is still organised in the traditional way of setting up construction sites: workers being instructed by foremen, who receive their instructions by (on-site) schedulers. The social environment on the site is not fundamentally changed as workers are still assigned to teams that fulfil certain tasks. The printing of 3D elements takes place off-site and there is no interaction between the workplace and the 3D printing factory.

Work intensity and working time

Work at a construction site is always time critical, depending on the exact agreements with the client. In Driebergen-Zeist activities generally took place from 7h to 16h, which is within the limits of what can be considered normal working schedule for such construction works. If under pressure, construction companies scale up their activities to shifts working around the clock, with the more unusual working times receiving higher compensation.

This intensity is not lowered by introducing 3D printed elements. More importantly, the just-in-time logistics (no storage on site) does put some pressure on workers to handle the elements as they arrive (since they have a fixed time slot to install the element until the next one arrives). Due to tight planning, all components of construction work become more time critical: delays lead to unwanted storage of materials on site which causes ripple effects in the supply chain. As we will describe below, this limits the discretion of teams.

Skills and discretion

The mix of skills required at the construction site calls for (slightly) fewer carpenters and steelfixers due to the introduction of 3D printed elements. In future construction projects, it would mean that some craftspeople will be needed for a shorter period of time at one site before they move on to the next. Also, as BIM become more prominent, it requires a different working attitude of construction workers: working more precisely according to agreed working orders, with more defined steps: more factory-type work.

Developing digital skills to understand 3D construction plans and translate them into actionable tasks would prove beneficial for construction workers who want to. However, at the same time, digital tools such as VR/AR glasses or tablets will need to become much more robust and easier to use before they can be deployed in the rough environments of construction sites. Although BAM has tried out several AR prototypes, with which it would be possible for construction workers to see the whole construction while still building and thus to understand the larger picture of the work they are performing, one of the reasons why VR/AR glasses are not used is that they are too expensive and break too easily.

Not directly related to this case study, but at a larger scale, the importance of electronics is increasing in construction work in general: the electronics components of buildings (such as electricity and communication cables and switch boxes, heating and ventilation equipment, lighting, and sensors) take on an increasing share of the project value and highly trained technicians are required.

When moving up the chain of command, schedulers are the employees who are confronted with the 3D and BIM plans that they have to translate into working orders. They are often tertiary level engineers who have learned to interpret digital drawings on computer screens; the younger ones have already learned these new tools during their education. It is clear that understanding and handling 3D drawings is (becoming) essential for this group of workers.

In terms of discretion there is a large shift due to the introduction of 3D elements. Construction workers are used to relative autonomy at the construction site. With the advent of BIM and 3D elements, this changes as workers have to adhere to a predetermined plan. While a high degree of inventiveness is needed to solve construction issues at the site, this innovativeness is somewhat tempered if some of the solutions have already been predetermined. Errors in the prefabricated construction elements cannot be solved on site anymore but have to travel up the chain of design to 3D modellers who are often not present – if due to 3D printing more prefab elements are introduced, fewer problems can be solved on site.

Prospects and earnings

None of the interviewees believe that in the coming years specific positions will become redundant – there is always a mix of skills required at any site. Moreover, the construction industry faces shortages of personnel which will not suddenly decrease. Many experienced workers (~22%) are above 55 years of age and thus will retire within the next 10 years (CBS, 2018b). At the same time, the energy transition ambitions of Europe call for increased speed in renovating buildings towards low energy use, which will increase the demand for construction personnel that can handle the connections between different prefabricated elements (mechanical, but also electronic) and the demand for prefabricated construction.

As for the current situation, 3D-printing has had no direct impact on prospects and earnings of the construction workers. Construction workers are still in high demand, and although 3D-printing may speed up some of the construction activities (thus creating efficiency gains), none of the interviewees expect this development to lower the need for qualified personnel such as carpenters and steelfixers, as their skills are in high demand. Carpenters would be less active on constructing the formwork (as this is either 3D printed or replaced by 3D printed elements), but would still be in high demand for other carpenting assignments, such as the building of temporary wooden ballustrades.

For all construction workers the ability to handle 3D models and derive actionable information from them would be beneficial for their career in a world where BIM, 3D models and just-in-time management become more important.

At the level of BAM, the further roll-out of 3D-printing led to the construction of a 3D-printing factory. This created new jobs for five specialist college-degree engineers. Again, providing more prefabricated and 3D printed elements fits into a larger move towards more digitised building and BIM planning activities before the actual construction starts. The setup of the factory is scalable, so that if 3D printing is in higher demand, the setup of the factory can be copy-pasted in another site.

Lessons learned and conclusions

- The construction industry is involved in a transition towards increased importance of Building Information Models (BIM) and pre-construction planning, which shifts some of the work to the front end of the construction process (prefabricated construction elements and more detailed planning of the building process). This requires more tertiary educated (college and university level) personnel to engage in the planning activities.
- At the same time, the building industry is confronted with the enormous challenge of refurbishing existing buildings towards low or no-energy standards. This requires a change in the working mode from on-site building to off-site production of prefabricated elements and on-site assembly.
- 3D-printing technology fits into the two aforementioned developments: it allows for better planning of construction site activities and allows for more production with the same number of professionals, so that high quality building elements can be assembled faster.
- In terms of workforce, there is a high need for trained personnel which will not decline in the foreseeable future. A relatively large part of the construction workforce at BAM (but also in the sector as a whole) is 55+, which means shortages will become larger in the next decade.
- At the current use of 3D-printed elements as seen in the Driebergen-Zeist site, mainly for decorative elements and formwork, the work activities are not altered significantly. Some concrete formwork is not created on site anymore – instead, prefabricated elements are transported to the site and have to be lifted into place.
- The current experiences with 3D printing have not led to major changes in BAM Infra, as a range of craftspeople is still needed to solve the many different issues that occur at a construction site. Further deployment of 3D printed elements and the introduction of other innovations, such as mechanical bricklaying robots, might shift the need for specific skills in the future.
- Craftspeople do look at the digitisation process critically, as stories of being replaced by robots are easily told. The truth of the matter is that with the current technology, the innovativeness, versatility and flexibility of construction workers is still in high demand.
- Obvious advantages of 3D printing and building information models and planning are quality control, decreased waste and CO_2-emissions, as well as efficiency. However, any construction site will still require innovativeness, versatility and flexibility of its all-round construction workers. A balance will have to be found to keep workers with these specific skills interested in their jobs, while reaping the benefits of the described innovations.

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