
3D-Printing Technology in Construction: Results from a Survey

3D-Printing
Technology
in
Construction

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Nils O.E. Olsson and Ali Shafqat

*Department of Mechanical and Industrial Engineering,
NTNU Norwegian University of Science and Technology,
Trondheim, Norway*

Emrah Arica

SINTEF Digital, Trondheim, Norway

Andreas Økland

SINTEF Building and Infrastructure, Trondheim, Norway

Abstract

Purpose – The purpose of this paper is to study the introduction of 3D-printing of concrete in the construction sector.

Design/Methodology/Approach – A survey was conducted to collect professional view on ongoing innovations in the construction sector, including 3D-printing. Participants were selected among the members of Norwegian networks for project and construction management research.

Findings – The survey highlighted effective leadership, collaboration with partners and industry-academia collaboration as primary enablers of innovation. Few of the respondents to the survey have used 3D-printing technologies.

Research Limitations/Implications – It is difficult to obtain representative samples in this type of research, including this study. The study can be seen as a snapshot of attitudes in the sector.

Practical Implications – 3D-printing appear as a potentially interesting technology, especially for unstandardized construction components. Further work is needed to materialise the expectation for technological development in the construction sector.

Originality/Value – Most research on 3D-printing has focused on demonstrating technical potential. This study adds a practitioners' perspective, with a large dose of pragmatism.

Keywords 3D-printing, Concrete, Implementation, Additive, Hybrid additive/Subtractive manufacturing, HINDCON

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1. Introduction

This paper studies 3D-printing of concrete in the construction sector. As an innovative technology, 3D-printing offers interesting opportunities for the construction industry, such as increased flexibility and reduced operational costs. However, it is important to analyse and use the previous innovation experiences to increase the success potential of implementing the 3D-printing technology in the construction industry. The study is a part of the EU-funded research project HINDCON (2018).

The aim of this study is to investigate the implementation of 3D-printing in the construction sector. The following research questions are set up:

- What is the status of implementation of 3D-printing technology in construction industry?
- What are the expectations for 3D-printing in construction industry?

2. On 3D-printing as an innovation in construction

The construction industry has evolved from a craftsmanship to an industrialised and service-oriented business, owing to the significant efforts in development and implementation of technological and organisational innovations over the past 70 years. Nevertheless, it is questionable if the introduced innovations have yielded their full potential and promises in the construction industry. Many studies show that construction industry has failed to adopt innovations to improve its performance as in other industries (World Economic Forum, 2016). The lack of stakeholder's involvement, high initial innovation costs, lack of risk funding, inherent conservative behaviour of organisations and initial non-profitability of innovations are some examples of barriers leading to fails in innovation (Ozorhon *et al.*, 2013). As an innovative technology, 3D-printing and hybrid additive/subtractive manufacturing offers significant opportunities for the construction industry, such as increased flexibility and reduced operational costs. However, it is important to analyse and use the previous innovation experiences to increase the success potential of implementing the 3D-printing technology in the construction industry.

2.1. About 3D-printing and additive manufacturing

3D-printing is an automated, additive manufacturing process for producing 3D solid objects from a digital (i.e. CAD) model, where the 3D CAD model is sliced into a series of 2D layers that are later deposited by the printer to construct the model (Boothroyd, 1994). A more recent definition for 3D-printing is "the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology" (American Society for Material and Testing 2009). The term "additive manufacturing" (AM) is more generally defined as: "the process of joining materials to make objects from 3D model data, usually layer upon layer" (American Society for Material and Testing, 2009). Additive manufacturing can deliver parts of intricate and complex geometries, built from tailored materials with near-zero material waste, while being applicable to a variety of materials (Bikas *et al.*, 2016).

Three important aspects of additive manufacturing are: material, process, and design. The main categories of 3D-printing have been detailed by (Labonnote *et al.* 2016) solid-like, viscous-like, powder-like and liquid-like. More complete overviews on previous and current additive construction experiences can be found in (Perkins and Skitmore, 2015; Labonnote and Rütger, 2016 and Wu, Wang *et al.*, 2016).

PWC (2014) did a general about use of 3D-printing in manufacturing. It showed that about 25% of the companies were involved in prototyping using 3D-printing and 29% were experimenting how they can use it.

2.3. Drivers and barriers to use of 3D-printing in construction

A driver that supports the use of 3D-printing in construction is the significant customisation opportunities (Labonnote *et al.* 2016). Minimisation of waste (Berman, 2012) and improved carbon footprint (Achillas *et al.*, 2015) are also interesting possibilities. There is a potential for cost-efficiency through high automation and reduced manpower requirement (www.3ders.org, 2014). Automation such as 3D-printing can reduce danger for human workers in harsh environments (Millsaps, 2015). 3D-printers also have quick deployability (Peter, 2015).

Issues that may serve as barriers include uncertainty regarding the size of demand for mass customisation and availability of high-strength printing materials. The literature also find it unclear whether 3D-printing could lead to reduced or increased construction cost (Wu, Wang *et al.*, 2016). Owing to size limitation of existing 3D printers, it is difficult to print a multi-story building at a time (Gibson *et al.*, 2002). However, users can print structural components piece-by-piece and then assemble them together as a real-scale building (Feng and Yuhong, 2014). Intellectual property issues have been raised in particular in connection with concerns that digital objects (including a digital file describing the construction of a given structure) can easily be copied and re-sold (Berman, 2012). There are also cyber security risks (Campbell *et al.*, 2014).

3. Research approach

The paper presents findings from a questionnaire on use and expectations for 3D-printing in construction industry. Based on initial literature studies, the first version of the questionnaire was developed, which involved several workshops with the authors and the HINDCON team members. The result presented here is related to the 3D-printing experiences and expectations in the construction sector. In the second phase of the survey, the questionnaire was piloted in three companies with follow-up interviews. The questionnaire was adjusted after the feedback. The third phase of the survey was to collect an e-mail list of potential respondents. Survey participants were mainly selected among the members of Norwegian networks for project and construction management research. The types of companies involved in the survey are engineering and construction management consultants, clients, building owners, architects and suppliers of pre-assembled modules. The list of potential respondents included 235 persons. The fourth stage of the survey was to launch the final version of the questionnaire. A total of 36 valid responses were received. The results of the survey are entered in Excel format for analysis and graphical presentation.

The formal response rate was 15%. However, it was not realistic to receive answers from all as several organisations had more than one person listed, and the list covered a wide array of actors. We estimate that the response rate among realistic respondents was between 25 and 30%. The results are largely based on Norwegian companies, with a bias towards large actors in the construction industry and those with an interest in research and development. Reliability can be influenced by the selection criteria of respondents. However, the study can hopefully give indications of present thinking about 3D-printing, even though the quantifications are not based on a representative sample. Validity in the study was a main concern in the development for the survey and in the piloting with three companies.

4. Results about the use of 3D-printing

The results address two aspects of 3D-printing in construction. The first aspect is about present and expected degree of implementation, while the second aspect is about expected cost issues.

4.1. Implementation of 3D-printing

The questionnaire addressed the use and implementation of 3D-printing. Figure 1 indicates that most of the respondents had not used 3D-printing. Those who had used the technology had mainly used it for piloting and prototyping.

Figure 2 shows the expected areas of application of 3D-printing. Most respondents expected that 3D-printing would mainly be applied for small or complex parts, including decorations. However, some also believed in the production of building blocks.

Involvement in 3D-printing technology

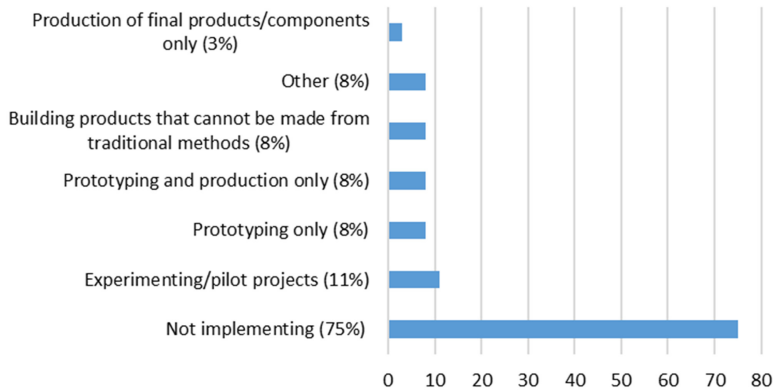


Figure 1.
Is Your Company
Involved in
3D-Printing
Technology?
N = 36 (More Than
One Alternative
Could Be Selected)

Expected primary area of 3D-printing

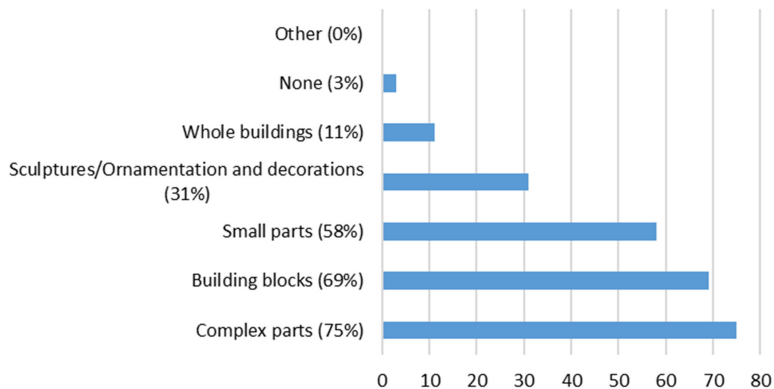


Figure 2.
In the Near Future (5
to 10 Years), What Do
You Expect to be the
Primary Area for
Application of 3D-
Printing Products in
Your Company?
N = 36 (More Than
One Alternative
Could be Selected)

Figure 3 indicate collaboration within the construction sector as a key success factor for implementation of 3D-printing, along with R&D funding.

Most of the respondents expect that it will take more than eight years for 3D-printing to be widely in use, as shown in Figure 4.

4.2. Cost issues

The survey also included questions about cost issues of 3D-printing. Figure 5 show that most respondents expected a high initial investment related to 3D-printing.

In spite of the expected high investment, a majority of the respondents believed that 3D-printing would eventually be cost efficient (see Figure 6).

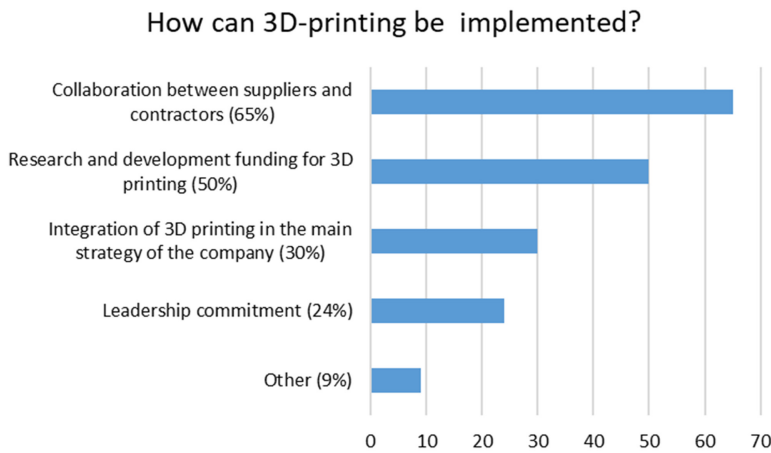


Figure 3. How Can 3D-Printing Technology be Successfully Implemented in the Construction Industry? N = 34 (More Than One Alternative Could be Selected)

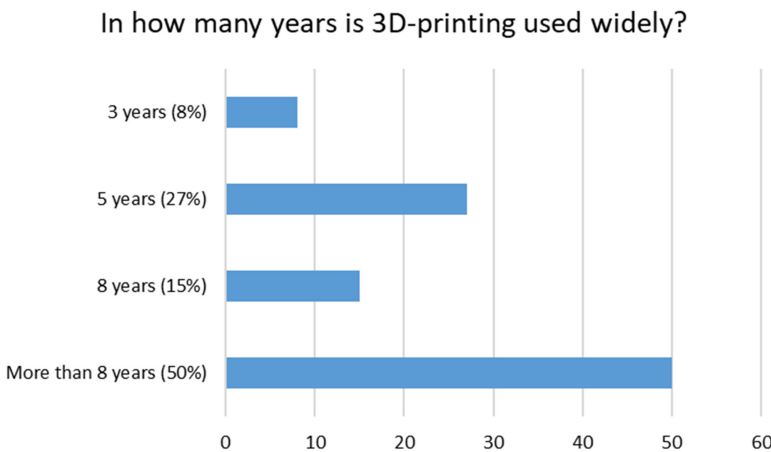


Figure 4. In how Many Years Do You Expect 3D-printing Technology to be Used Widely in Construction Projects? N = 36

Figure 5.
Do You Think
3D-printing
Technology
Involves High
Initial Investment?
N = 35

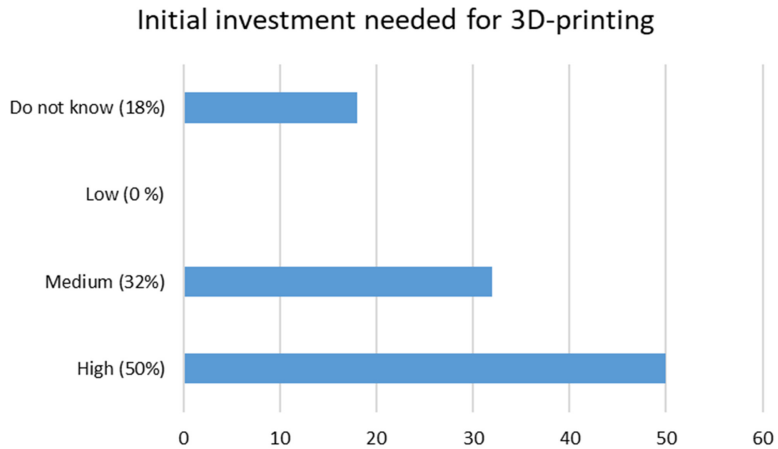
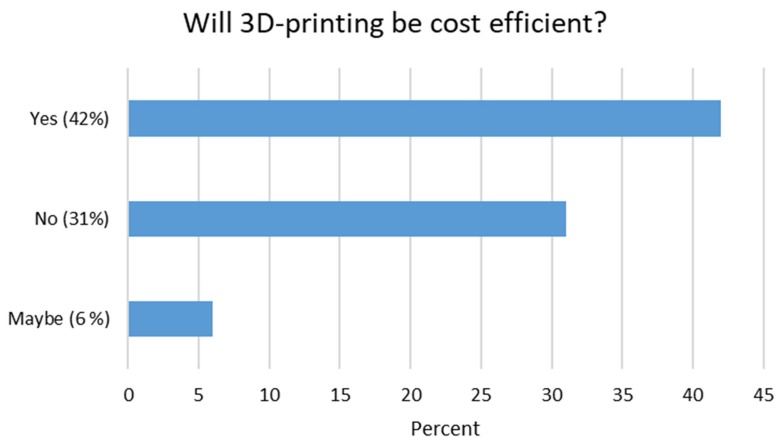


Figure 6.
Do you Think
the Use of
3D-printing
Technology in
Construction Projects
Will Be Cost-
Efficient?
N = 35



5. Conclusions

We have investigated the implementation of 3D-printing in the construction sector. The first research question addressed the status of implementation of 3D-printing technology in construction industry. Despite the positive expectations from 3D-printing technology, it has so far only been applied to a limited extent in the Norwegian construction industry, and mainly for piloting and prototyping. The study shows that 20% of the respondents use 3D-printing for prototyping, while a smaller part of the companies uses 3D-printing for ordinary production. In terms of materials, plastic and ceramic are now not only widely used in 3D-printing, but also a big development in 3D-printing of metals. In comparison, the study by [PWC \(2014\)](#) found that some years ago, 25% of manufacturing companies were involved in prototyping using 3D-printing. Our results imply that the Norwegian construction industry is behind but still on somewhat the same level as for manufacturing.

The second research question is related to expectations for 3D-printing in construction industry. The respondents expected not only high initial investments, but also that 3D-printing would prove to be cost efficient in the long run, with an implementation time of more than eight years. The reviewed literature was not conclusive about the future cost efficiency of 3D-printing (quite naturally, as the technology is in an early stage of development).

The companies in the survey believe that research and development funding for the 3D-printing technology along with collaboration between suppliers and contractors will facilitate its wide future implementation of 3D-printing in the construction sector. Regarding future use, the survey pointed to production of small or complex parts, including decorations as key potential applications of 3D-printing. This is in accordance to the literature, which highlighted the significant customisation opportunities, even though the literature also addressed uncertainty regarding the size of demand for mass customisation. Overall, the study conveys the impression of 3D-printing as a potentially interesting technology, especially for unstandardized construction components. The technology appears to still be at a testing stage. However, there is interest in the industry and we expect to hear more as the technology matures, and we gain more experiences.

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