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Review

Additive construction: State-of-the-art, challenges and opportunities

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ABSTRACT

The present study has investigated to what extent additive manufacturing technologies can be successfully applied to the construction of large-scale structures. The central concept of additive construction was defined, and a systematic mapping study was performed in order to assemble relevant publications selected according to a well-defined set of criteria. Knowledge gathered from the relevant publications was organised into four main categories: material science, engineering, building design and market analysis. The lack of focus of material science research towards the characterisation and potential improvement of construction-related material properties has been emphasised. The evolution of technological solutions to deposit the construction materials from gantry solutions to more lightweight systems has been described. The governing parameters for deciding on the most appropriate solutions have been identified as the type of building component, the location for production, and the assembly technique. Benefits of additive construction for building design were shown to mostly address the perspective of end-users, but should instead be understood as the emergence of new opportunities and new constraints that will necessitate a greater degree of rational decision-making in the design phase. The relevant markets for additive construction were shown to be closely related to the inherent specificities of the project in question. This implies that additive construction can be successfully applied in connection with general housing projects only if housing in general changes to become more optimised and more individualised. It was concluded that additive construction has the potential to revolutionise the construction industry, its success depending on how the whole building industry is ready to tackle three challenges: the need for an architectural paradigm shift, the need for a holistic design process, and the need for rational designs. A list of suggestions for further research is provided, among them the development of tools for assessing the disruptive potential of additive construction in an objective and scientific way.

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1. Introduction

1.1. General background

Gartner [1], one of the world's leading information technology research companies, identified 3D printing both as “a rare example of a single technology that has become truly disruptive by itself”, and as one of the five emerging technology trends that are believed will significantly impact business during the period 2014–2019. 3D printers are currently claimed to be able to shorten design and development cycles, to improve communication and collaboration, and to resolve issues in the realm between of design and engineering [2]. Although 3D printing has discretely been applied in prototyping for many years, the term “3D printing” has now become a widely-used general term for additive methods, independent of specific technology, material and intended application [3]. New clothes, innovative medical implants, better-tasting pizzas, and futuristic houses are just some of the numerous media-heralded “3D printing achievements”.

In contrast, labour productivity in the construction industry has exhibited either a decline or stagnation over the past fifty years [4]. The causes are numerous and include factors such as labourers' resistance to change (due to excessively long-term payback), poor data interoperability, declining real labour costs (which tend to reduce investment in capital equipment), and high levels of turnover at the bottom end of the industry (which make it more difficult to implement new methods) [4]. Up until a few years ago, 3D printing applications in the construction industry were largely confined to the production of affordable architectural models. However, more recently, several spectacular attempts to 3D print complete houses have been the subject of much publicity.

The primary aim of this study is to investigate the extent to which 3D printing technologies can be successfully applied to the construction of large-scale structures. US President Barack Obama was reported to have said [5] that 3D printing is a technology with “the potential to revolutionise the way we make almost everything”. So, is 3D printing also capable of revolutionising the construction industry?

1.2. Definitions

In the present study the following definitions are used:

- “3D printing” refers to the various processes used to synthesise a three-dimensional object. The general process is as follows:
  - a digital 3D model is created by dedicated software, or by the scanning of an existing object,
  - an algorithm cuts the digital model into 2D slices, and
  - a “printer” prints the object, slice by slice, according to the dimensions of digital 3D model.

  In 2009, “3D printing” was defined more specifically by the American Society for Testing and Materials (ASTM) as “the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology” [6].

- The term “additive manufacturing” is preferred in this study because this concept is more generally defined by the ASTM as: “the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies” [6].
- “Construction” is here defined as a general term describing the act of generating large-scale structures whose purpose is linked to structural engineering. Such structures may include large civil engineering products such as houses, bridges, architectural pavilions and other types of building.
- “Additive construction” has a similar definition to “additive manufacturing”. It is described as “the process of joining materials to create constructions from 3D model data”. This means that the design, production and/or assembly processes should be digitally controlled at least to some extent.

1.3. Objectives

Additive construction represents the entire process of building a digital form (building design) from materials produced on-site (material science), which are then deposited according to a digital model (engineering). As is the case for any other new technology, the success of additive construction depends on both technological progress and commercial relevance.

The following questions are thus of major interest:

- What construction-specific material science challenges do we face?
- What structural engineering challenges come into play when scaling-up additive manufacturing?
- What building design opportunities emerge when using additive construction?