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Review

A critical review of the use of 3-D printing in the construction industry

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ABSTRACT

3-D printing, which is an automated production process with layer-by-layer control, has been gaining rapid development in recent years. The technology has been adopted in the manufacturing industry for decades and has recently been introduced in the construction industry to print houses and villas. The technology can bring significant benefits to the construction industry in terms of increased customization, reduced construction time, reduced manpower, and construction cost. A few isolated products and projects have been preliminarily tested using the 3-D printing technology. However, it should be noted that such tests and developments on the use of 3-D printing in the construction industry are very fragmented at the time of the study. It is therefore necessary for the building and construction industry to understand the technology, its historical applications and challenges for better utilization in the future. A systematic review shows that 3-D printing technology, after years of evolution, can be used to print large-scale architectural models and buildings. However, the potential of the technology is limited by the lack of large-scale implementation, the development of building information modeling, the requirements of mass customization, and the life cycle cost of the printed projects. It is therefore expected that future studies should be conducted on these areas to consolidate the stability and expand the applicability of 3-D printing in the construction industry.

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1. Introduction

The construction industry has been recognized as one industry that consumes considerable amount of resources and poses significant environmental stresses. According to Klotz et al. [42], buildings consumed 36% of the total energy used, 30% of the raw materials used and 12% of potable water consumed in the US. The industry has also

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been challenged for poor performance on productivity. For example, Nasir et al. [59] compared the labour productivity of 20 countries and found that the US showed the worst performance with an annual compound rate of −0.84%. The low productivity issue has also been found in other developed countries, such as UK [1], Singapore [49], and Hong Kong [51].

Over the past few decades, studies on construction innovations have been conducted to address the productivity, environmental, and other issues in terms of two forms. One form of construction innovations is a response to external needs (e.g. the clients' needs) and the other form of construction innovations originates from other industries [31]. However, as Tidd et al. [70] pointed out, the main emphasis for innovation strategy in the construction industry is to use technology from elsewhere to reinforce other competitive advantages. This is one of the reasons why the construction industry is viewed as a low-tech industry with low levels of innovation [31].

The image of the construction industry may be changed as the industry has been actively participating in the 3-D printing business. According to Berman [9], 3-D printing employs an additive manufacturing process whereby products are built on a layer-by-layer basis, through a series of cross-sectional slices. The term 3-D printing can also be applied to office or consumer versions of rapid prototyping machines that are relatively low-cost and easy to use [17]. The global 3-D printing materials market value was US$165m in 2013 and is expected to increase at a rate of 20% per year to US$410m in 2018 [69]. From the construction point of view, buildings are also products that have the potential to host 3-D printing. There have been many attempts in the construction industry to use 3-D printing to increase customization, reduce construction time, and improve affordability. For example, major contractors (such as Foster and Partners in London, UK) now have a suite of modeling equipment and 3-D printing process to print 3-D architectural models [13]. Other than creating 3-D models, 3-D printing has also evolved to produce large (>1m) structures using contour crafting, which extrudes the internal and external skins of the wall that are later backfilled with a bulk compound similar to concrete [38].

However, it should be noted that the research relating to the application of 3-D printing in the construction industry is still in its infancy. Many new experiments have been conducted in the construction industry to explore the full potential that 3-D printing can bring to the construction industry. However, these experiments are very fragmented. A critical review of the history and current development of 3-D printing in the construction industry is therefore needed. This paper therefore aims to (1) review the concept and characteristics of 3-D printing in the construction industry, (2) review the applications of 3-D printing in the construction industry, and (3) discuss the challenges of using 3-D printing in the construction industry and hope that by addressing these challenges, better utilization of the technology in the future can be expected.

2. The definition and characteristics of 3-D printing in the construction industry

According to Bogue [10], 3-D printing is an automated, additive manufacturing process for producing 3-D solid objects from a digital (i.e. CAD) model. In other words, in a 3-D printing process, the 3-D CAD model will be sliced into a series of 2-D layers, which will later be deposited by the printer to construct the model.

Depending on the technologies used in the 3-D printing process, there are five main types of 3-D printing processes. The first type of technology is called stereolithography, which usually includes a perforated platform, a container of a liquid UV-curable polymer, and a UV laser [54]. Based on the layers extracted from the CAD model, a beam of laser is used to trace the bottom layer of the model on the surface of the liquid UV-curable polymer, which will cause the polymer to harden. The perforated platform will then be lowered and the second layer will be traced and hardened by another beam of laser. The process

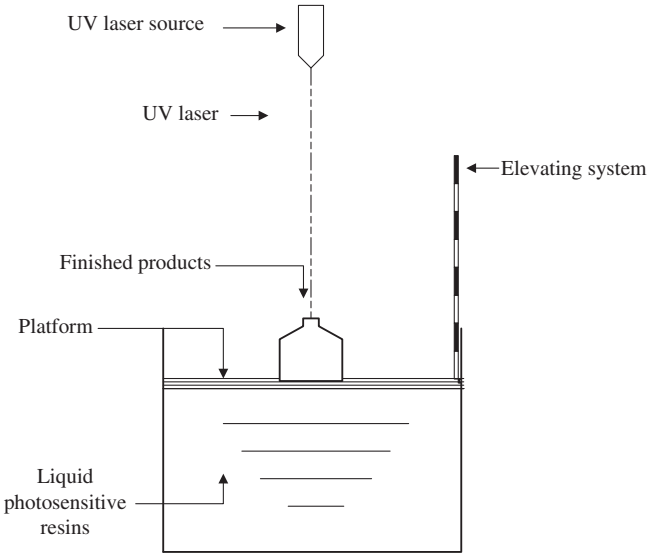

Fig. 1. An illustration of the components and processes in stereolithography.

will be repeated until the 3-D model is created (see Fig. 1). According to Kang and Cho [35], the development of suitable and affordable resin materials for stereolithography is a main barrier to implementing the technology as the current photo-curable resin costs from $80 to $210 per liter.

The second type of 3-D printing technology is usually referred to as fused deposition modeling (FDM). It has three components: a printer head, printing material (e.g. polymers and synthetic stone), and support material. Printing material is firstly fed to the printing head, which will later moves in X- and Y-coordinates to deposit the material to print the first layer of model extracted from the CAD model. Similar to stereolithography, the base will then move down for the printer head to work on the second and other layers. Once completed, support material will be removed (see Fig. 2). In recent years, metals can be used as the print material in FDM. However, the main disadvantages are the limitation of the material to low-temperature and low-strength alloy as well as the possibility for oxidation during the printing process due to the lack of a controlled environment [55].

Another type of 3-D printing process is usually referred to as inkjet powder printing process which uses glue or binder to bond successive

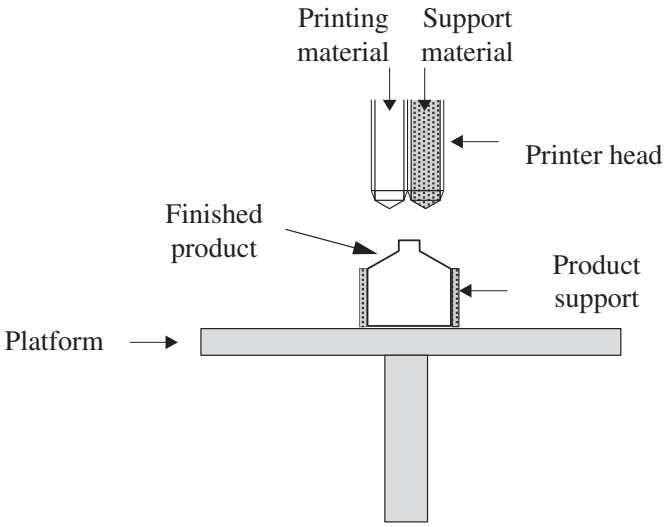

Fig. 2. An illustration of the components and processes in FDM.