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Development of a BIM-based automated construction system

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Abstract

Automation technology has advanced in industry, such as aerospace, ship building, automobile, etc. However, automation technology in construction has grown slowly, because the currently available automation technology and engineering technology may not be suitable for large scale construction products effectively and economically. This paper describes current additive manufacturing (AM) processes in construction which has the potential of application in the production of large structures. Based on the similar procedure, the paper explores a new BIM-based automated construction system (BIMAC) including composition of BIMAC, detail of execution setup, data issues, filling layer algorithm and shows printed example results, which are the highly customized building components. The further research about construction scale AM is presented. While still in its infancy, this research has the potential to improve the traditional construction methods, and solve problems like high accident, low quality, loss of skilled workers, and so on.

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Keywords: Additive manufacturing; concrete printing; automated construction process; Building Information Modeling; filling layer algorithm

1. Introduction

In recent years, advances in sensing technology, Numerical Control (NC) technology and the automatic driving system have led to improve the function and accuracy of automation system. Today, the automation systems have replaced humans in many complex, boring and dangerous industrial production activities. Industries, such as aerospace, ship building automobile, etc., has advanced Computer Aided Design (CAD) system modeling method and automatic assembly method [1]. However, the construction automation development lags behind other industries for decades. According to reports, construction industry is facing some serious problems as follows [2]: a)

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high accident rate at construction sites; b) Low quality of work; c) project management at construction sites is difficult; d) low labor efficiency; e) skilled workers have been lost.

Since the end of last century, in the United State and Japan, automation technology, in varying degrees, has been applied in the construction industry to solve problems such as productivity, quality, safety, high cost and the shortage of skilled labor [3,4]. Study of automatic construction is very active in Japanese construction industry, seeking solutions of the shortage of skillful workers. Many large Japanese construction companies have their own R & D center, and study new construction technologies by sophisticated equipment and a large number of staff. Taking Kajima Construction Company for example, the company spends more than $900 million annually on construction techniques and a large part of the investment is used for automatic construction like the robot system [4]. However, the robot system cannot detect and solve problems independently in real-time operation, leading to single task robots which are limited to a small construction area. In addition, most of the automation system requires many prefabricated parts, which means additional inventory, transportation and machinery cost. It will be expensive for using traditional automation technology to establish a fully mature automation system which can solve the problems of the construction industry [5,6].

Slow development of automation technology in construction has been due to the following reasons [7,8] :a) automation technology is not suitable for large scale construction products; b) automation technology is not suitable for conventional design approach; c) compared with other industries, the amount of the final output is rather less and the types are quite fewer; d) the limitation on materials selection; e) expensive automation equipment makes the automation technology unattractive; f) the introduction of automation technology make an impact to the traditional project management.

Construction industry needs to seek new automatic construction process to replace traditional manufacturing and assembly process, because the currently available automation technologies and engineering technologies are not enough to overcome these obstacles effectively and economically [6]. Today, a kind of new automatic process called as AM has the potential of application in the production of large structures. This process adopts the method of the whole building collaborative molding instead of the traditional architectural forms of girder, slab and column. In recent years, AM has been applied in automobile design, aerospace and medical industries, etc. [5]. However, most existing AM processes are only suitable for small and medium scale manufacturing parts, because they are unable to delivery many kinds of building materials and their material deposition efficiency is very low [9].

This paper discusses some automatic construction processes capable of manufacturing large building components. By analyzing the procedure of these large-scale AM techniques, a new automated construction system called BIMAC has been developed. The paper then describes the details of BIMAC, including execution setup, data issues, filling layer algorithm and result.

2. Additive manufacturing in construction

Lim introduced current construction scale AM processes capable of manufacturing large components in 2012 [10]: In the 1990s, Pegna developed an AM process using cement based materials [11]. The processes that are currently proposed and have already achieved the function of architecture printing, mainly include the Contour Crafting (CC) process form University of Southern California [12], D-shape process [13] form the British Monolite company and Concrete Printing process from Loughborough University [14].

Khoshnevis has led a team for long-term study of the CC process, and has suggest that it can be applied to the automatic construction of building works [12]. The CC process is a kind of AM using a trowel to achieve a precise and smooth surface of the printed output. With the CC process, it is possible to automatically build large scale architecture components, even the whole building. The cement mortar printing machine of the CC process has a nozzle of 15mm in diameter, and can print a wall of vertical layers of 19 mm in width and 13 mm in height with padding materials inside the wall, to print the end product with size >1m dimension [5,15-17].