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Automatic Construction by Contour Crafting Technology

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Abstract

Contour Crafting is a novel technology in construction industry based on 3D printing that uses robotics to construct free form building structures by repeatedly laying down layers of material such as concrete. It is actually an approach to scale up automatic fabrication from building small industrial parts to constructing buildings. However, there are little information about contour crafting (CC) in current use; present paper aims to describe the operational steps of creating a whole building by the machine reviewing relevant literature. Furthermore, it will represent the advantages of CC usage compared to traditional construction methods, as well as its applicability in construction industry.

Keywords:

Contour Crafting;
3D Printer;
Automatic Construction;
Traditional Construction.

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1- Introduction

Maslow, a remarkable American psychologist, has introduced the ‘Hierarchy of Needs’ in accordance with human necessities. The base of this hierarchy includes human physiological needs, i.e. food and accommodation [1]. However, in the beginning of 21st century, more than one million people have been living in poor accommodational conditions, and housing is still a major problem in many societies. Governments have always been trying to find a solution to change these conditions. The upcoming problem in traditional construction are construction methods currently in use. These construction methods are generally accompanied by compact, slow, and finally insufficient work to reach the goal. There are some other deficiencies in modern construction such as different building methods, building management problems, wasting and high consumption (in energy and material), high cost of current processes, and increase of environmental damages due to over activity of construction machinery [2].

It has been a long time that 3D printers have been utilized in manufacturing, as a strategy to hasten and automatize production, reduce workforce cost, and decrease waste materials. It was first in 1950s that probability measuring and brainstorming of 3D printers rang a bell to the scientist mind. In 1980s, the initial sketch of 3D printers was presented, namely rapid prototyping, and the first sample was built. The function of these 3D printers are COD-COM based which stands for Computerized Designing-Computerized Manufacturing. In other words, we are dealing with products which are designed by computers and are sent to assembly lines without human interference. To produce personal 3D printers, plastic is melted. Industrial 3D printers, able to print using metal, are built by liquid resins (SLA method), ceramic paste, and even nutrients. The main differences of these printers are surface flatness, dimensions accuracies, and also variety in of usable materials in outputs. Today, 3D modelling is common in different fields such as part manufacturing, industrial designing, robotics, aeronautic industries, and architecture. In the past, these modellings were presented as 2D images on monitors or papers, so as to enable people to gain an understanding of what designers have in their minds. It is possible to hasten time-consuming simulations, parts samples building, and also investigating the desirable model.

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Undeniable advantages of 3D printing in manufacturing industry, encouraged the scholars to scale up this technology in order to utilize it more in construction industry; in fact, this technology is used, instead of modelling, to build houses in real-life dimensions. Contour crafting, concrete printing, and D-shape are 3 methods of advanced mega-scale to 3D-print buildings, which is a basis in building all 3 additive fabrications in layers [3]. This paper pivots around contour crafting technology which is designed and registered by Professor Behrokh Khoshnevis (Head of CRAFT Institute in the USA). Contour crafting system is a lightweight movable 3D printer which can use various materials such as concrete, ceramic, metal, etc. It can load them in layers in building automatically without human manipulation. Currently, this machine is able to print all concrete, edge, insulation walls; in the inventor's opinion, its applicability will be widespread by 2025. Some of its advantages over 2 other technics of 3D printing of buildings are building faster, ability to use in situ, and creating smoother surfaces with higher quality. The key characteristic of CC system is having two trowels whose function will flatten the building material. In next section, the function of the mentioned machine in construction of a building will be thoroughly explained [2].

2- How Contour Crafting Machine Works

Flattening the needed space, a frame is dug for the foundation filled with concrete. Contour crafting machine accompanied by a piece of machinery on specific railroads will be put and moved next to the foundation (Figure 1). In order to access to each part in the 3D dimension space, the machine has to be able to move in all 3 X, Y and Z axes. The first axis (X) is made up of rails. Axis Y is created by the height of machine arm. When the arm is wide open, it will be 6 meters high sufficient to build a 2-storey building. The 3rd axis (Z) is made up of a horizontal bar which joins 2 arms [4].

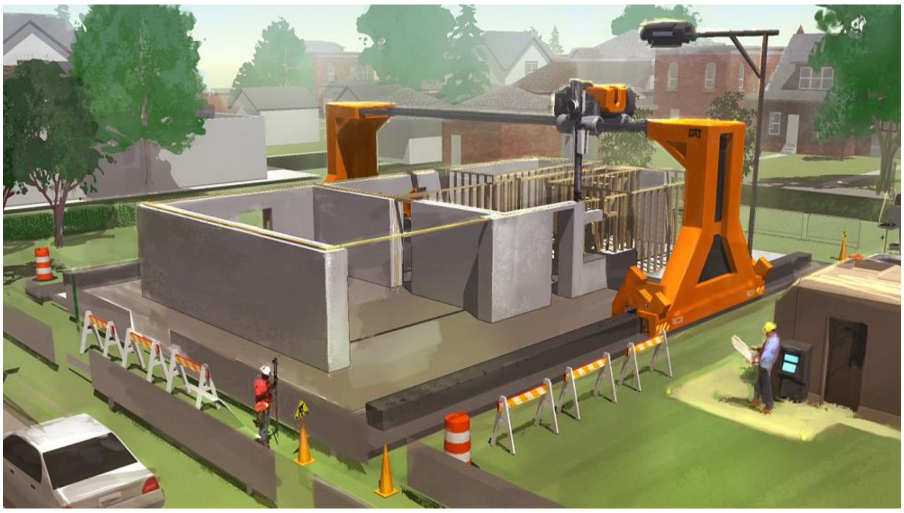

Figure 1. Outline of a working contour crafting machine [4].

Installing and preparing the machine, next step is the injection of the material which varies according to the project goal and building step. To construct an ordinary building, concrete paste will be an appropriate material injected into the front valve of the machine propelling one of its pumps to the nozzle orifice. In the end, concrete will enter to the 4-axis nozzle giving it too much freedom of movement (Figure 2). Arms have a unit of extrogene to carry materials from storage to head of nozzle and control the speed [4]. Arms are also equipped with a controlling trowel, which is able to move horizontally and vertically and also controls the slope, angle, and delicacy of geometrical shapes. Nozzles have 3 different heads which can create various shapes according to different external patterns [5].

Figure 2. Outline of CC machine nozzle equipped with 4 mobile axes [2].

The mentioned machine is capable of building both kinds of buttresses and standard walls. Nozzle can create some dented parts in the wall so as to incorporate pipe installations (Figure 3). Therefore, the first step is finished. The next step is about making upper parts of windows frames. This is done by the robotic arm. These arms are also responsible for installing the ceiling, which is prefabricated and looks like a chained plate. This plate folds and is placed via arms in its position and provides the space to build the upper storey (Figure 4). When the ceiling is built and installed and the upper storey in created by them machine, we can observe a completely printed house [4].

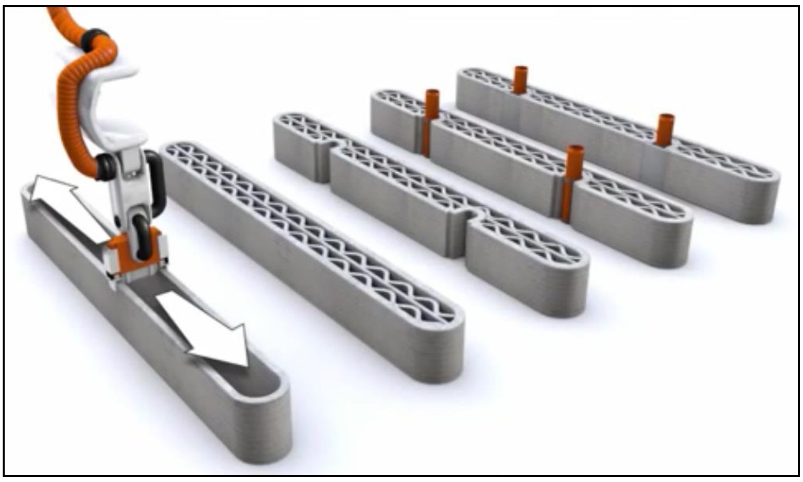

Figure 3. Schema of built walls by CC and placing the passages for the needed installations [2].

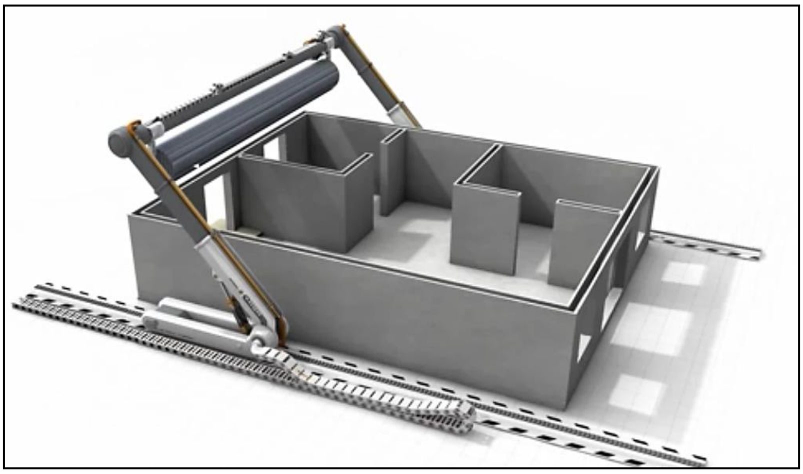

Figure 4. The ceiling installation step by CC machine [2].

It is worth noting that the capability of CC machine is not only restricted to walls printing in building houses, but also to strengthen the walls placing electrical installations and also painting houses in the range of the mentioned machine activities.

3- Configuration Types of Contour Crafting

Different kinds of this machine can be used in accordance with the objectives and necessities of building projects. Figure 5-A demonstrates a typical machine which can be substituted for mobile houses, and fulfill our urgent needs for accommodations. In Figure 5-B, a single robot can be observed which is used to build a customized residential house. To build larger buildings, multi-nozzle machine is used whose nozzles all can work simultaneously (Figure 5-C). We can also have climbing machines to fulfill our needs to access any height. The tower type of the machine having swerving wheels is the newest version of 3D constructing printers. This device facilitates house building and consequently makes it more economical, not necessarily cheaper (Figure 5-D) [6, 7].

4- Advantages of CC Technology over Traditional Construction

4-1- Cost Reduction

Compared to traditional construction methods, this technology is expected to reduce the costs considerably, including investment, project management, workforce, and material costs (Table 1).

4-2- Increasing Architectural Flexibility

In common construction, it is usual to expend a great deal of money on architectural flexibility. In Prefab construction, cost reduction will cause decrease in architectural flexibility. Emergency construction, the cheapest strategy among all methods, has the least architectural flexibility; however, CC technology has one advantage, i.e. by spending as little money as emergency method, the architects will enjoy higher flexibility, even more than the traditional ones.

4-3- Environmental Effects

Traditional construction necessitates the use of different machinery, totally consuming a great deal of energy and releasing too much CO2 into the environment. Using CC machine which works on electricity, the emission rate of CO2 decreases remarkable yearly in proportion to construction industry. Figure 6 illustrates comparatively energy consumption and CO2 emission by CC and traditional construction methods [8].

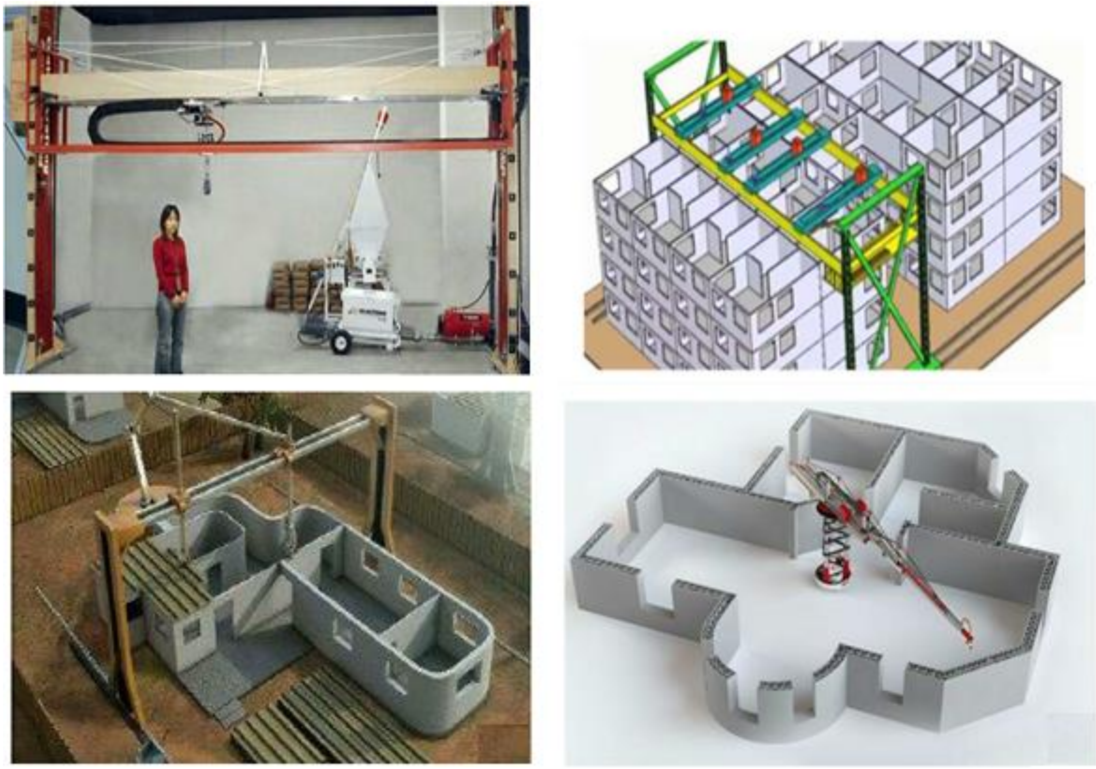

Figure 5. Different types of configuration of CC machine [6, 2].

Table 1. The effects of CC technology application on decreasing each part of building projects costs.

If automated by CC	Due to	Portion
Short project length and control of time to market will dramatically reduce this cost	Financing	20%-25%
Will be a waste-less (lean) process	Materials	25%-30%
Will be significantly reduced	Labour	45%-55%

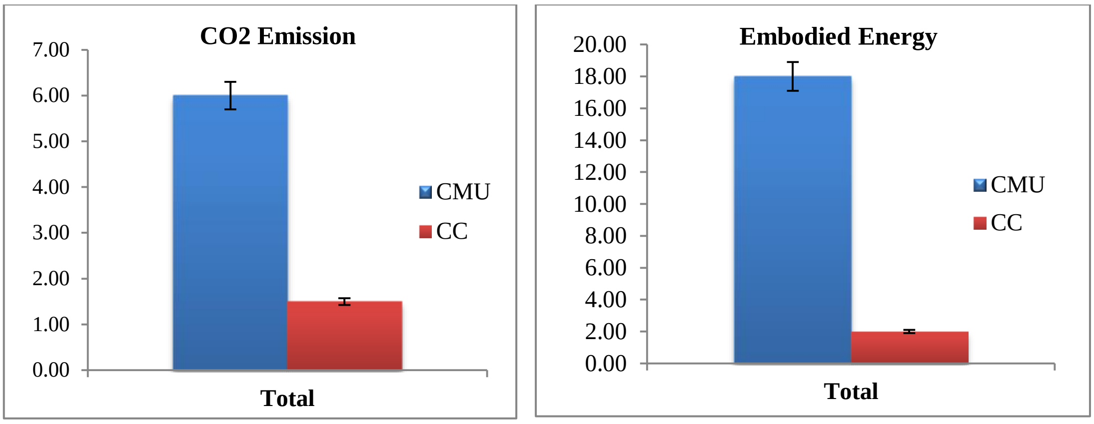

Figure 6. Energy consumption and annual CO2 emission during CMU (Concrete Masonry Unit) Construction and CC (Contour Crafting) [8].

5- CC Practical Potentials in Construction

CC machine is designed in such a way to adapt to various materials, and support the building process of modern complicated structures and also ancient labyrinthine buildings [4]. Moreover, this technology is expected to hasten the serialization of houses, mass production, and estates development. In a comprehensive study on 15 different countries in 2015, it was indicated that China is one of the best choices to pass the CC usage act in the building process, and currently, building projects are developing by CC method in this country [9]. Furthermore, the inventor of this modern design hopes that using this technology will soon be an influential step in resolving housing problems in Iran. The range of the application of this technology has also reached the aeronautics industry. NASA is using this technology to build essential tools for astronauts, such as landing pads, shelters, protection walls, reflecting walls, probes landing places and paths [10].

6- Conclusion

Since there is increasing in tendency towards automation of building industry like other manufacturing industries, CC-technology-based automatic building is expected to stabilize its place in building industry enjoying benefits such as hardworking reduction, cost decrease, architectural flexibility improvement, and environmental positive effects. However, there are some concerns regarding social effects of this technology and its influence on work system and the related jobs, but, seemingly, socio-economical improvements of the mentioned technology will obliterate its negative effects.

7- Acknowledgement

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