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Impact of Contour Crafting on Civil Engineering

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***Abstract*— This paper presents a general idea of how Contour Crafting Technology can change the Civil Engineering field, and how it is capable of changing our notion about construction process. It has been pointed out as a pioneer of a new era in the construction field due to the benefits that it can bring to the environment and to the construction process itself. This research has gathered and organized ideas in order to be a good source for later studies. Topics, such as features of Contour Crafting technology, concrete mixture for Contour Crafting finality, and a comparison between conventional construction method and Contour Crafting method are present in this research.**

Keywords—Contour Crafting; Housing Construction; 3D Printing; Additive Manufacturing; 3D Printed Concrete Properties; Construction Automation.

I. INTRODUCTION

3D printing technology is not a brand new discovery. It was created in the 1980s, but due to some main challenges, which will be explained later on this paper, it has not revolutionized the way we live yet (Lipson, Hod; Kurman, Melba, 1-5)[1]. It has shown endless possibilities of application. Areas, such as medicine, engineering, architecture, medicine and even cookery will be truly impacted by this technology. Imagine a world where the people can print everything that they need, where and when they need it. For example, food, cars, or even houses. Let's suppose that a professional needs a tool with a specified design to perform some function, and the market for some reason does not fabricate this tool with this specific design. In the 3D printing world, this person could easily make the design in a computer and just print out a brand new tool, which can attend his expectation.

It was named 3D printing but actually it is a manufacturing process, also known as additive manufacturing. Features, such as extreme accuracy, completely lack of wasting, safety, and versatility are what make this technology unique. The manufacturing in the US first took place in the 19th century, but before that, artisans made goods in a handmade process, which is slow and did not attend that time necessity [1]. By the time, some machines started to be invented and then used to substitute some of the human tasks. Nowadays, a big part of the human tasks was already substituted by computer integrated manufacturing process that has improved the production rate. However, as in 19th century, the way we do things now does not attend our time necessity because 21st century came with a new demand. We have 7 billion people living on this planet, and we are running out of natural resources. The way people live today does not contribute at all for this problem. The current manufacturing process has a harmful impact in the environment, in terms of waste and emission of contaminates. Additive manufacturing solves many of the most famous of today's problems involving transport, inventory, motion, waiting, over-processing, overproduction, and defects.

Nevertheless, due to its endless possibilities, the 3D printing technology can also be used for evil ends as other wonderful inventions were used in the past for warlike finality, such as airplanes, the use of the nuclear fission to design atomic bombs, etc. For example, with 3D printers, people could fabricate fire arms that cannot be detected by any detector because this kind of weapon might be printed out of any other material desired.

The team has chosen to focus on Contour Crafting (CC) technology, developed by Dr. Behrokh Khoshnevis, from USC (University of Southern California). "This technology consists in a "manufacturing process which uses computer controlled systems to repeatedly lay down layers of raw material such as concrete." [2]. In other words, this process is able to print out buildings in a matter of days. In this research, it is planned to study and organize information about Contour Crafting. The main topics within this paper are CC itself, 3D printed concrete properties and a comparison between traditional construction method and CC method.

II. CONTOUR CRAFTING

A. Applications

The CC technology applications are mostly within the civil construction area. In a not so far future, entire buildings, houses, precast components that can be assembled in field later on, emergency housing and in a further perspective, even space colonies can be built by this method.

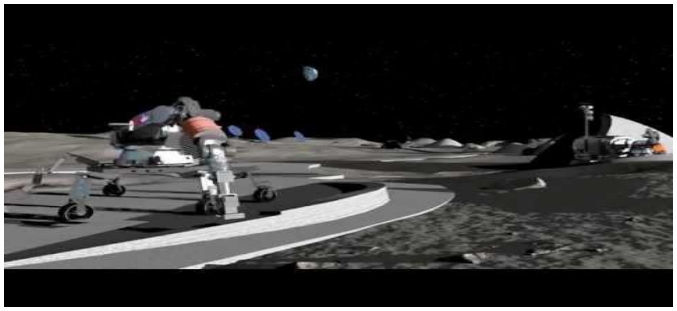

Fig. 1 Future Construction of a Space Colony

Fig. 2 House Built by Precast Concrete with CC Method

Source: Wikipedia

B. Mechanism

It consists on a machine that has the liberty of constructing without any kind of formwork. In this process, the design project is done in 3D design programs, such as AutoCAD or Revit. However, the CC machine interprets this project as a set of 2D layers that will be put together to form the 3D object. It pours concrete with a great precision, so it is able to print raw materials in a sequential process executed layer by layer.

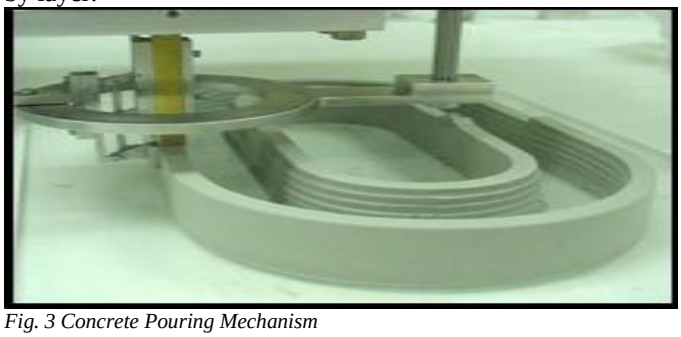

Fig. 3 Concrete Pouring Mechanism

Source: Wikipedia

Even though it sounds very simple, there are many adjustments that are still needed to be made before its application in the real world. The inventors (Dr. Behrokh Khoshnevis and other researchers) have come up with a new set of procedures in order to manage this technology on a real construction site. As the conventional construction procedure, standards must be created to regulate the management and use of Contour Crafting.

One of the points that were difficult to surpass was creating a concrete mixture that could match the needed properties, which are buildability, stiffness, and strength, that are going to be discussed later on (3D Printed Concrete Properties topic). The concrete should be able to lay down correctly, remaining in position when poured, to be stiff to support the layers that will be poured sequentially, and to reach enough strength to support the structure.

C. Guaranteed Quality

As everything is executed by computer, there is a small possibility of failure. The quality of construction depends mainly on the quality of its workforce. If a computer is set to follow commands, for example to print a building, it will not get tired or give excuses for failure.

Over the years it has become obvious that the more computers are used in the production of something, the less failures happen on the process of manufacturing. Besides doing a great job, it reduces risks and brings safety.

D. Social Impact

One of the first impacts of Contour Crafting on construction site would be the decreased number of workers. With almost all the steps of construction being guided by a computer, just a few technicians would be needed to manage the machine.

In addition, the labor will depend more on mind work than on arms work, so the people involved should be able to run this system correctly, with good management and computer skills. This could bring women and elderly people to the construction site, what is very unusual nowadays.

Finally, we all know that construction industry has the biggest number of work related fatalities. Unfortunately, this fact might ruin this area's image for future workers. However, Contour Crafting can reduce work injuries and fatalities to almost zero.

E. Sustainable Character

Our planet is running out of raw material, due to its irresponsible use by people. Contour Crafting is an environment's friend because it wastes no material at all. In addition, it does not bring noise, dust or make harmful emissions to the environment.

F. Future perspective

All the major industries of the world work mostly with automated systems, except construction industry. However, it has inevitably changed, and Contour Crafting is a potential agent of this transition. Can you imagine, on the future, that all the steps for building an apartment (since the first project until the last repair) will be executed by computers? It would be utopic in a recent past, but today it is unavoidable to happen.

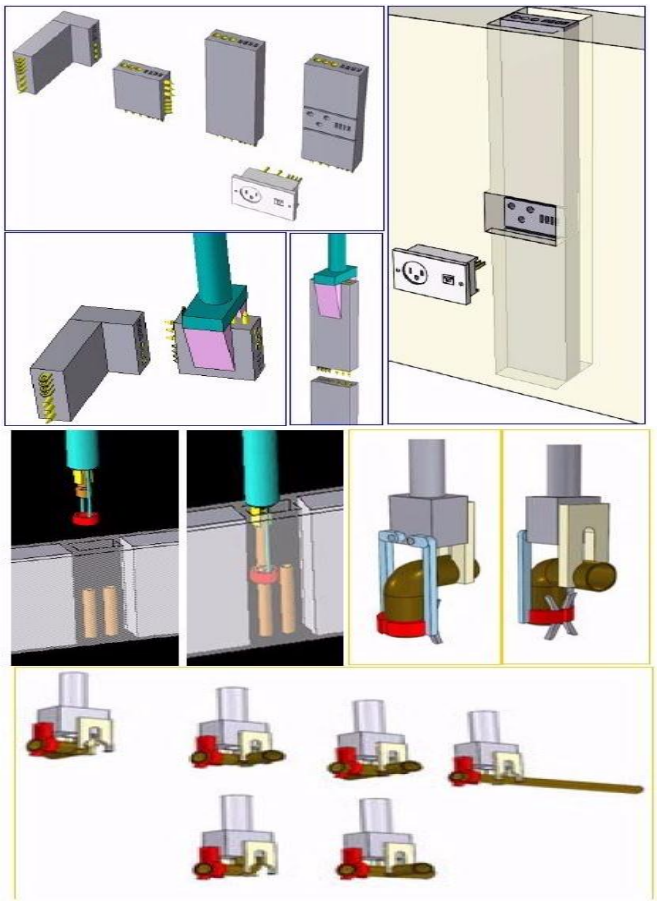

Fig. 4 Electrical Modules and Assembly Process

Fig. 5 Plumbing and Assembly Process

Source: Reference [3].

Contour Crafting has also been pointed as problem solver for spatial issues. It is very expensive to send matter to space stations, but is not it possible to use a 3D printer to make everything that the stations need there? Yes, it is possible.

G. Challenges and Limitations

One of the first challenges of CC machine for the future would be its mobility. Due to its size and weight, the machine has to be attached to another machine that would be able to move it.

Second, the difficulties of the environment. How these machines would surpass the issues of the environment, such as unleveled ground, weather impacts, etc. There are some researches with great ideas to improve this issue, such as a machine suspended by cables oriented by a Cartesian system [4].

Third, the cost is still an obstacle to develop this technology because of its recent discovery. The maintenance fees for these machines are also very expensive. If CC development had more support from sponsors, maybe it could be developed faster.

Finally, the great challenge of the construction industry will be adapting to the transition between conventional construction and CC method. One of the CC technology limitations is the fact that it is not compatible with conventional design (very complex reinforcement systems). In addition, there is a great necessity of making a standards of management of this kind of construction. How is it going to be handled? How are the materials going to be replaced? These are some questions to be answered in the coming years.

Fig. 6 "Complicated Construction Practice Hard to Be Automated"
Source: Reference [5].

III. 3D PRINTED CONCRETE PROPERTIES

A. Workability

"The ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is called workability." [6]

The workability on 3D printed concrete is a critical factor on Contour Crafting. The layers first poured have to support the layers that will be poured sequentially but also cannot cure very fast causing bond problems between the layers.

B. Extrudability

"Extrudability relates to the ability to transport the fresh concrete through a hopper and pumping system to a nozzle where it must be extruded as a continuous filament." [7]

The concrete mixture used in this process needs to have a good extrudability rate; otherwise it is going to create concrete clog points inside the 3D printer machine, causing delays and maintenance necessity. It is known for every professional on construction that once you start pouring concrete you only should stop when the labor is done. This kind of problem is unacceptable on the construction site.

C. Curing

"Curing is the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. This process results in concrete with increased strength and decreased permeability. Curing is also a key player in mitigating cracks, which can severely affect durability." [8]

Due the fact that CC construction has accelerated rhythm, its curing must be speeded up as well. However, this high velocity should not be too fast to the point of harming the bond between the layers. To reach this precise curing speed, many techniques may be used, for example thermal and chemical ones. [9]

D. Mixture

"Concrete is a mixture of several components in certain proportions which goes by the name of concrete mix design

on construction language .The mix ranges depends on the application necessities." [10]

The mixture designs for 3D printed concrete are not cheap or easy to come up with. Many researches going on in the CC area are committed to study and improve the mix designs. Therefore, the perspective is to decrease the cost of the materials. For example, usually, the size of the aggregates should not be over 2 mm, and most part of the times, additives like superplasticizer, retarder, accelerator, and polypropylene fibers are needed, and they are very expensive. [7]

E. Strength

"Compressive strength may be defined as the measured maximum resistance of a concrete specimen to axial loading. It is generally expressed in megapascals (MPa) or pounds per square inch (psi) at an age of 28 days." [6]

As all the other kinds of concrete, the printed concrete must be able to hold the weight of the structure. In this point, the printed concrete has shown an excellent strength average rate. The authors believe that it is due the small size of the aggregates, causing a reduction of avoids in the concrete. The less number of avoids, the higher compressive strength rate.

IV. CONVENTONAL CONSTRUCTION METHOD VS CONTOUR CRAFTING METHOD

A. Cost

Conventional Construction: In the traditional method, there is a high cost of production because of the quantity of materials, labor, waste, and time. In addition, sometimes it becomes even higher due to the complexity of projects. For example, during extreme weather conditions, the construction process has to slow down significantly because of the employee's incapacity to work in these conditions, which would not affect a CC machine. Delays on project's execution raise costs.

CC Method: Contour Crafting is an alternative that can decrease about four times of the construction cost because of its simplicity, materials' saving and short time productivity (10 houses in one day, for example). In addition, it can give more liberty to design projects that might be easily done without much difference (in terms of cost and feasibility) from simple projects.

TABLE I. COMPARISON BETWEEN CONVENTIONAL CONSTRUCTION METHOD AND CONTOUR CRAFTING, IN TERMS OF COST

COST	IF USING CONTOUR CRAFTING
Financing	- Reduce project length - Control of time to market
Materials	- Wasteless process - Decrease material cost
Labor	- Significantly reduced labor and related cost

B. Labor

Conventional Method: Besides being one of the most hazardous industry, Construction nowadays has become overpast because it still depends mainly on the man force. One of the challenges of Civil Construction industry today is to find well-qualified workers because most of them still need to be trained, causing additional costs and schedule delays. In addition, its labor is very expensive because of the big number of workers that it brings to the construction site.

CC Method: The great advantage of this technology is the use of few workers at the construction site. Only specialized people (computer and management skills) would be required to operate the machine. Due to this fact, not only men would be able to work in construction, but women and elderly people as well. In conclusion, CC machine does not get tired, does not give excuses of failures, and does not need to be trained. In contrast, it might work 24 hours a day, thus it speeds up the job schedule.

Fig. 7 High Number of Worker at a Normal Construction Site

Fig. 8 Almost no worker at a CC Construction Site

Source: Wikipedia

C. Safety

Conventional Method: Construction industry is the most hazardous of major industries. One of five worker deaths in 2013 were in construction, according to the United States Department of Labor. The causes of deaths "were falls, followed by struck by object, electrocution, and caught-in/between" [11]. Every time that a mega construction is being built, the human loss is very high. For example, the construction of Hoover dam (in the Colorado River) took life of more than a hundred of workers.

CC Method: With Contour Crafting, work injuries and fatalities are reduced to zero because of the very safe method of construction. As it has a low number of workers and a computer executes almost everything, it does not bring any danger to the construction site.

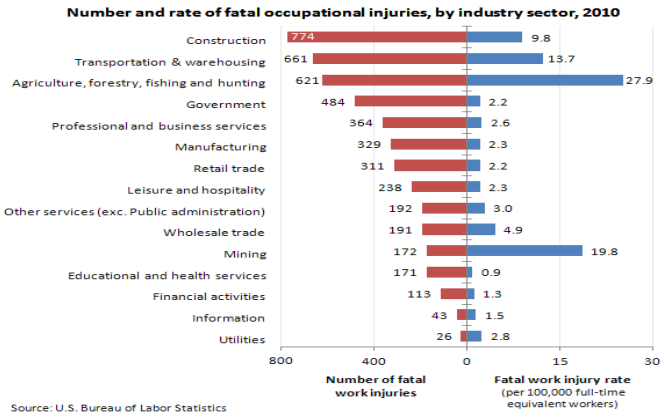

Chart 1 Number and Rate of Fatal Occupational Injuries, by Industry Sector, 2010

D. Sustainability

Conventional Method: This method is very harmful to the environment. First, it pollutes noisily the environment. Second, it also emits many harmful toxic materials, which are dangerous for the whole environment (soil, air, people and animals), such as dust. Finally, the number of wasted materials is very high. Usually, the quantity of materials used to make a building could easily be enough to build one more building, but the wasting does not make it possible.

CC Method: Due to its accuracy, Contour Crafting technology provides construction without waste, being considered as environmental friendly and a sustainable process, consequently. In addition, it does not make any noise, besides of being a fast process. It uses less material, less energy for all construction activities and less transportation of material, equipment, and people.

E. Productivity

Conventional Method: Construction today can last months, and even years. It is liable to schedule delays and work failures. For example, when the concrete is poured, it cannot be stopped until the job is finished, forcing workers to spend a long time at the construction site, which causes loss of productivity because human beings get tired. In addition, the use of formwork is a big factor that causes delay in job's flow because it requires a lot of labor to work with forms.

CC Method: With Contour Crafting, 10 houses can be built in a single day, or even more. This method does not use formwork, which is a shortcut in the construction time [7]. Computers execute everything in the construction, so it might be as much as 50 times faster than conventional method. In addition, this method is very accurate to execute its assigned commands, so it is able to make its jobs faster.

V. CONCLUSION

The world has walked more and more in destination to automated systems. In the future, computers will make all the processes of major industries. It also includes construction industry. There will be a time when all the steps of buildings will be performed by machines. For example, design, plumbing, reinforcement, and electrical systems would be made by CC technology.

Another point of Contour Crafting is that it has a great productivity, building houses in a matter of hours, without wasting any material. In addition, its cost can be much lower than the conventional method cost because CC uses less workers and materials. This new technology is an environmental friend, which does not pollute or cause any evil effect to our environment.

However, even with all its benefits, Contour Crafting has some challenges to overcome. First, CC developers should study how this technology would be managed at a construction site. Second, it is necessary to see how people would react to this transition between conventional method of construction (many workers, wasting and fatalities) and the automated construction method (less workers, wasting and more safety). Finally, the great challenge is to overcome the current cost barrier of this technology. The authors believe that the more this technology is developed, the cheaper it will become to be applied in the reality.

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