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3D printing technology: Future of construction Industry

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ABSTRACT

This paper examines 3-D printing for architectural purpose and its characteristics and applications. The 3-D printing is being used for manufacturing building components as well as printing the whole building. The 3-D printing will be widely used to print houses by 2020. High rises building will be printed by 2025 with light-weight contour crafting technology. This paper also discusses the history of 3-D printing as well as future implications of it. Although still in its early days, 3-D printing offers various benefits. The 3-D printing is the sustainable solution over traditional techniques. This will be the future of construction industry.

Keywords : *3-D printing, Rapid prototyping, 3-D printed components, Additive manufacturing (AM)*

1. Introduction

The3-D printing is the computer-controlled sequential layering of materialswith the help printer to create 3-dimensional shapes. It is useful for prototyping and for the manufacture of geometrically complex design. The 3-D printing referred as additive printing or additive manufacturing (AM). It is a revolutionary production technique which is capable of creating solid objects from a digital file uploaded to a 3-D printer. The printer reads the file and lays down sequential layers of materials likeplastics, resins, concrete, sand or metals. It was first developed in the 1980's, but at that time it was a difficult and very expensive operation and had few applications. Since 2000, 3D printing has become relatively straight forward as well as affordable. It is Viable for a wide range of uses such as-product design component and tool manufacture, consumer electronics, metalworking, plastics, aerospace engineering dental and medical applications, footwear

The sale of AM machines or 3-D printers has grown rapidly now days. Since 2005, the domestic use of 3D printers has become practical as there are 3D pen available to create small object. A 3-D digital model of any itemcan be created, either by computer aided design (CAD) or using a 3-D scanner. The printer reads the design and lays down successive layers of printing medium which can be a liquid, powder, or sheet material, which are joined or fused to create the item. The process of printing can be slow, but it enables almost any complicated shape to be created, it depends on the technique adopted. Printing can produce multiple components at a time; also it can use multiple materials and can use multiple colours. Accuracy can be increased by a high-resolution subtractive process that reduces material wastage. [1]

2. History

Development of automated printing of entire buildings using slip forming techniques and robotic

assembly of components were pioneered in Japan. Robotic bricklaying was conceptualized and explored in the 1950's and related technology developed and automated construction began in the 1960s, with pumped concrete and isocyanate foams.

Early construction 3D printing development and research have been under way since 1995. Two methods were invented, one by Joseph Pegnawhich was focused on a sand/cement forming technique. It utilized steam to selectively bond the material in layers or solid parts but this technique was never demonstrated and implemented. The second technique, that isContour Crafting by Behrohk Khoshnevis, initially it was began as a novel ceramic extrusion and shaping method, which was an alternative to the emerging polymer and metal 3D printing techniques, and was patented in 1995.[2]

In 2005 Enrico Dini, Italy, patented the Monolite/ D-Shape technique, employing a massively scaled powder jetting/bonding technique over an area approximately 5m x 5m x 2.5m.

In 2008 3D concrete printing began at Loughborough University, UK, look to commercial applications moving from a gantry based technique to an industrial robot, it was then licensed And recently in 2014 Winsun (Shanghai WinSun Decoration Design Engineering Co) claimed to have printed 10 houses in a day each 200 m^2, however visual scaling from the photographs does not support the claim for the buildings size.

Since 2010, 3-D printing has become relatively straight forward as well as affordable. It can be used for variety of products in different fields.

Widespread use of light-weight contour crafting 3D printers to print houses will be a successful practice by 2020 and it will be used for high rises by 2025[3]

3. Methods there are two methods of 3 D printing for construction activities

This 3-D printing technology can be used for both manufacturing 3-D printed building components and to print the whole building.

3.1 By using 3 D printed building components for construction

There are components which are used in construction and proved to be very effective. Some of the examples of 3-D printed components are below:

3.1.1 Cool Bricks

Creative frontrunners in the 3-D printing industry developed a design element called Cool Brick. It uses water to cool homes in hot and dry climates. The method used for Cool Brick is called evaporative coolingcombines a wood screen, or mashrabiya, and a ceramic vessel filled with water. Cool Brick is 3-D printed porous ceramic as shown in Fig.1. The bricks can be set in mortar to have an entire wall, each brick absorbs water like a sponge and is designed as a three dimensionalpattern which allows air to pass through the wall. As air moves through the 3-D printed brick, the water that is held in the micro-pores of the ceramic evaporates, bringing cool air into an interior environment, lowering the temperature using the principle of evaporative cooling. The bricks are modular and have an interlocking design, and stacked together to make a screen. The 3-D pattern creates a strong bond when set in mortar. The shape of the brick also creates a shaded surface on the wall to keep a large percentage of the wall's surface protected from the sun and cool down the temperature which will improve the wall's performance[4].

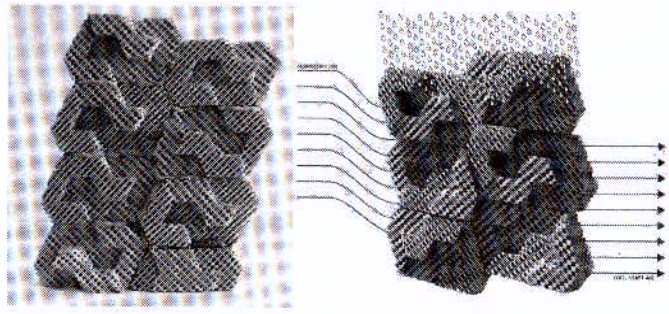

Fig.1. Sample of cool bricks

3.1.2. Poly Bricks

Polybrick is developed by the Sabin Design Lab. It is the first mortarless, 3-D printed wall assembly as shown in Fig.2. It will allow for the production of

ceramic wall assemblies that are robust and high strength. The printed bricks are fired to decrease any possible warping and shrinkage. They are then dipped in a satin glaze and fired once again at a higher temperature to create a vitrified shell. The bricks are cost effective, require less labor and maximize the efficiency of the process by using low cost materials.

Polybrick functions using tapered dovetail joints like those used in woodworking and the tapered sides of the bricks are then oriented in walls to maximize the structural strength of the finished edifice. The system includes geometric manipulations and exchanges built into the algorithms connecting the individual component which will allows this aggregative system to have the accurate taper angle to ensure gravity does work to intact bricks with each other [5].

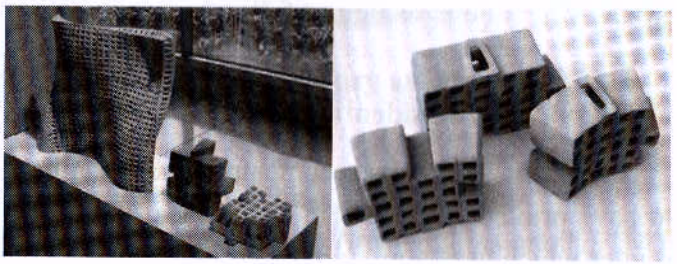

Fig. 2. Samples of poly brick wall

3.1.3. Pixel stone

For pixel stone, 3-D printer specifically designed to print brick façades. It actually prints pixels or small brick cubes which can be in single colors or mixes. Those cubes are pumped into a mixer and remix them according to color, then extrude them through a hose in a digitally designed pattern as shown in Fig.3 As the printer extrudes the bricks, it also bonds them together in Pixel stone [6].

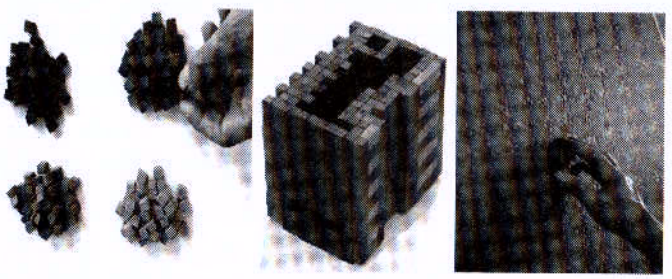

Fig.3. Samples of pixel stone and wall

3.1.4. 3-D printed structural steel building components

Arup Company produced a new design method for creating "critical structural steel elements" for tensile structures. This structural unit will give a whole new direction for the use of 3-D printing in construction industry. The technique will allowproduction of bespoke structural pieces more efficiently and is expected to reduce waste and costs. It is made up ofmaraging steel. Each ofthese member are 14 cm tall prototypes is produced at just under half the size of a real node as shown in Fig.4. It has been put through preliminary material tests. The single component is 75% smaller and 40% lighter than conventional steel members [7].

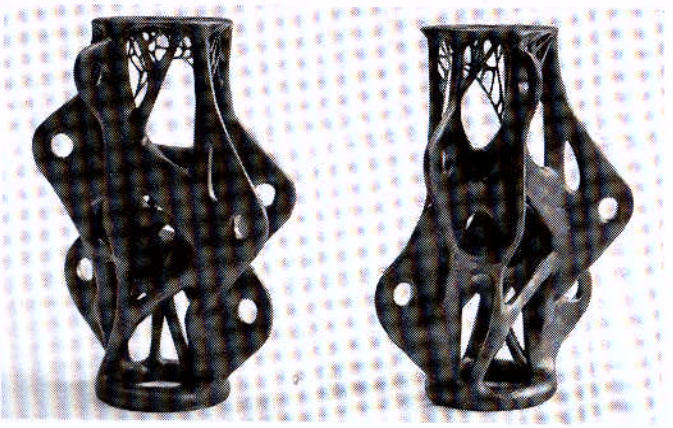

Fig.4. 3-D printed tensile member

3.2 By printing whole building with the help of 3-D printer

The 3-D printer technology is developed by Professor Behrokh Khoshnevis from the University of Southern California, which can be used to build a whole house or a component, layer by layer, in a single day. It offers the potential to automate the construction of a complete house including services like electrical, plumbing, drywall and insulation. It is a computer controlled process. In which file of the drawing is loaded to the software and according to that computer will instruct the giant robot to print the object (Fig.5). The giant robot featuring arms and extrusion nozzles, a computer-controlled gantry system moves the nozzle back and forthand prints hollow wall with a zig zag pattern inside to provide reinforcement which leaves

space for insulation (Fig.6,7). Using this process, a single house as well as housing societies, each with a different design, may be printed in a single run, with all the services embedded in each house.The chief advantages of the 3-D printing process over existing technologies are superior surface finish andthe greatly enhanced speed of fabrication.

The potential applications of this technology are in emergency, low-income, and commercial housing. The technology willpotentially reduce energy use and emissions by using a rapid-prototype or 3-D printing process to fabricate large sub-components.This fabricates the parts in large pieces. The structures are then assembled on-site, complete with steel reinforcements and insulation This process saves between 30 and 60 % of construction waste, and can decrease production times by between 50 and 70 %, and labour costs by between 50 and 80 %. also using recycled materials resulting in a construction method that is both environmentally forward and cost effective [8].

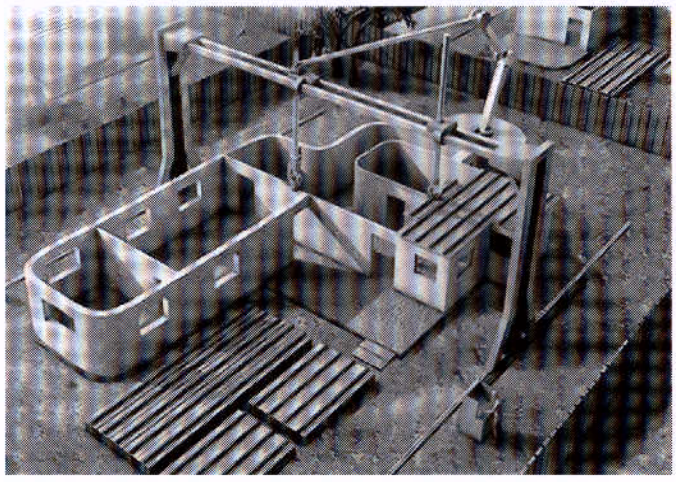

Fig. 5. 3-D printer

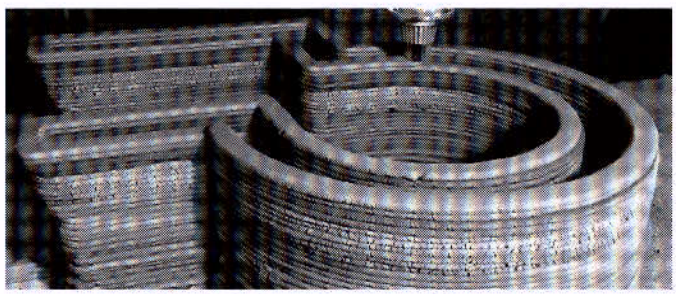

Fig.6. 3-D printed wall section

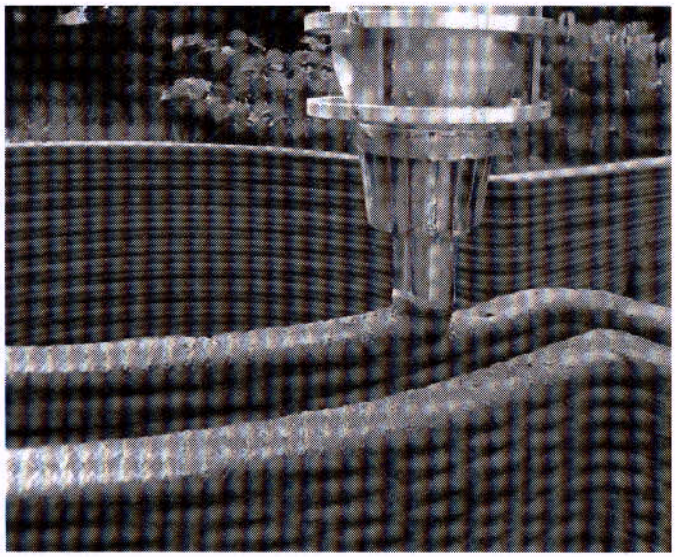

Fig. 7. 3-D printed wall in zigzagging pattern

4. Examples of 3-D printed building

The 3-D printed building examples in the world are discused in this section as follows.

4.1 3-D Printed Residential Building, China

In March 2012, Chinesecompany WinSun claimed to have printed 10 houses in 24 hours, using a 3-D printer which uses a mixture of ground construction and industrial waste and material such as glass and tailings, a base of quick-drying cement mixed with a special hardening agent. Win Sun has further demonstrated the capacity of this technology with a five-storey apartment building and a 1,100 square meter villa, complete with all interior services as well as elements inside and out as shown in Fig.8. This villa is on display at Suzhou Industrial Park.

The 3-D printer array is developed by Ma Yihe. This printer stands 6.6 m high, 10 m wide and 40 m long. It fabricates the parts in large pieces, then the structures assembled on-site and completed with steel reinforcements and insulation in order to fulfill the official building standards. Overall, the villa costs around $161,000 to build. Using recycled materials in this way, the structuredoes not needvarious materials. Due to this construction method that is both environmentally friendly and cost effective. [9]

Fig. 8. 3-D printed five story apartment building

4.2 The 3 D Canal House, Amsterdam

The 3D Canal House, Amsterdamis another 3-D printedproject. It is 13 room demonstration houses. The project team built a 3D printer; The printer creates wall components from material likebioplastic mix of plastic fibers and 80% plantoil. Wall components are then interlocked together and filled with bio-concrete to provide structural strength. This technology can be one of the most sustainable solutions in construction industry.

4.3 Office building, Dubai

Office building in Dubai is world's first functional office building built by using three-dimensional printer technology as shown in Fig.9. This building cost €125,000. It was opened for operation in May 2016. This project is also called as'Museum of the Future'which comprises of area around 250 m^2 space (2,700 ft^2). Structure is divided into 3 models (P3, P2 and P1). The largest P1 can print objects up to 16m x 9m x 2.5m costing around €12,000. Other components are printed using a variety of materials, including metal, plastic and concrete. A 3D printer was used to print whole building in a special cement mixture, layer by layer. Overall it took a total of 17 days to print the building at a cost of about $140,000, after that the interior and exterior design details were added. It needed minimum professionals and workers. It saves50 percent on normal labour costs.[10]

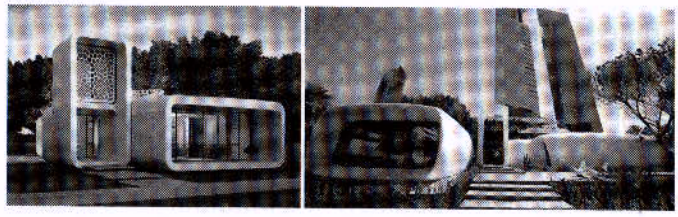

Fig.9. Office building at Dubai

5. Potential Implications of 3-D Printing for the Home Building Industry

Although still in its early days, 3-D printing could offer the various benefits. It has Onsite or factory applications. 3-D printed products only use as much material as needed to form them. That indicates it need lesser resources, also less waste is generated. 3-D printing has low carbon emission and low embodied energy than conventional construction method. There is reduction in transportation costs if products are printed on-site. The cost of transporting the printer can be expensive due to the size of printers currently needed for construction. 3-D printing has potential to create more accurate and interesting designs as 3-D printing can achieve shapes that conventional techniques cannot achieve. It lowerslabour costs. There is reduction in cost of customized design. With 3-D printing; it costs the same to create one item as to produce thousands. Also there is reduction in health and safety risks if 3-D printing can be used to produce assemblies. Now this technology can be used for much larger scale constructions, such as bridges and even sky-scraper printer is designed to produce a complete shelter using vernacular materials, such as mud, clay and natural fibers. 3-D printing also can potentially be used to create housing in disaster areas or areas where emergency housing is needed.

5.1 Future of 3-D printing in construction

The construction industry has already been adapting to the digital revolution with Building Information Modeling (BIM) and smart technologies, alongside a stronger commitment to leaner and greener construction. This all stands the sector in good background for emergence of 3-D printing as smart infrastructure, efficiency and environmental responsible construction technology. BIM is at the heart of the 3-D printed building movement providing the software to control the design and construction process. Combining robots with the use of 3-D printed building components will make easier to create buildings with different shapes. Normally the single story building would take eight months with 160 workers on the site, with 3-D printing technology; same structure can be completed with only eight workers on site, within 12 weeks. There are many benefits of this technology such as quicker construction, less labor, lower cost, less wastage of material, efficient and accurate design as well as greater control and customization to create a leaner, greener, smarter building. So, it is fair to say that the invention of 3-D printed buildings has made it easy to predict the future of construction [11].

5.2 Challenges to be overcome

It is more expensive than conventional construction due to high cost of 3-D printer and lack of awareness in the industry about 3-D printing technologies and applications. Currently, limited materials have been used, although research and experimentation is underway with printers which will be capable of using multiple materials to produce more complex assemblies. 3-D printers can be large and so it is difficult and costly to install on site. 3-D printing incurs more up-front costs to create the digital model that will result in safe, cost-effective products. Printers are currently slow compared to conventional construction, although they can be operated 24 hours a day, seven days a week. The potential of a disruptive impact on the type of skills and labour needed to design and build homes. 3-D printing will significantly affect on the labors who works on wages. In future there are challenges in front of researchers to overcome several aspects like capacity of using different material as well as cost and size of printer.

6. Conclusion

The key conclusions drawn are as follows:

1. The analysis shows that the use of 3-D printers for construction purpose will be the most suitable technology in coming future.
2. With the use of this technology, construction job will be easier and simpler as it take less time, less labour, minimum wastage in material, more accuracy in construction.
3. 3-D printing technology has much potential and it will be one of sustainable solution in construction industry.
4. Although this technology is in its early stages, there are various researchestaking all over the world in every field.Further research will help to overcome the current issues related to 3-D printing technology as well as it will create the awareness about 3-D printers used construction purpose in different manners in whole world.

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