3D PRINTING FOR EARTH CONSTRUCTIONS – REVIEW

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Concrete is the second frequently used material in our planet. Being the most consumed construction material for infrastructures and buildings, the demand for concrete is very high at present and expected to have the same significance in the future. On the other hand, conventional concrete could not be considered as an environmentally friendly construction material. This comes from the perspectives of reducing natural resources, high energy consumption, and produce a huge amounts of construction waste. 3D printing construction with earth materials provide the potential solutions to reshape the construction world and answering the current demands of sustainability, energy efficiency and cost in construction. This paper presents a review of 3D printed constructions made from earth materials benefits, limitations and current applications.

Keywords: 3D printing, additive manufacturing, earth materials, earthen construction

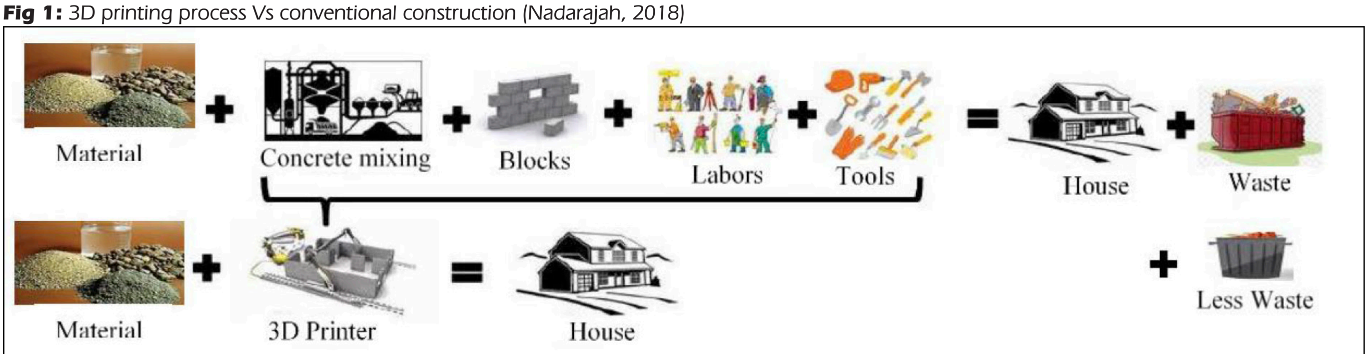
1. INTRODUCTION

Additive manufacturing also known as 3D printing was first developed in the 1980s, but at that time was a difficult and expensive operation and so had few applications. It is only since 2000 that it has become relatively straightforward and affordable and so has become viable for a wide range of uses including product design, component and tool manufacture, plastics, metalworking, aerospace engineering, dental and medical application and construction industry. 3D printing is a promising technology in construction work that can help improve the efficiency and minimize the errors of the construction and providing a matchless design freedom to designers and architects, as well as can help to optimize the structure shape by reduce the amount of the material used (Le et al., 2012, Lloret, 2015). This procedure is mainly used for minimizing the time and cost of the project (*Fig. 1*) (Nadarajah, 2018). Extrusion-deposition additive manufacturing is one of the most studied techniques. This method involves the use of multiple layers of concrete by a machine to create construction components or to print entire buildings (Lim et al., 2012, Perrot, 2016).

Constructions made from earth material are becoming more prevalent in today's energy-efficient homes and buildings. Their low ecological footprint makes them an ideal alternative to fossil fuels. At all stages of its use, clay doesn't require much energy. It can be reused, and it is easy to maintain. Also, due to its thermal inertia, mud constructions can help lower energy costs and provide a healthy indoor climate (Azeredo et al., 2008, Aubert et al., 2015). Although earth material is readily available, but its development is still limited by the high cost and the problematic durability. This issue is mainly due to the time needed for the material to harden and the labor cost to produce a good quality mud product. Many of research and experimental have been carried to improve the mix design made from earth material to have quick casting and good strength in the hardened state (Moevus et al.,2015, Landrou et al., 2017).

Digital manufacturing with earth materials could introduce the concept of traditional materials to our modern culture. This material could provide solutions to the issues of quality, cost, and efficiency. Although this technology is in its infancy, examples of digital manufacturing with earth materi-

Fig 1: 3D printing process Vs conventional construction (Nadarajah, 2018)



als already exist in the literature. Perrot et al. (2018) printed 3m wall made from earth material with addition of alginate to increase the strength as well as to improve the productivity. Dubor et al. (2018) tested the structural and environmental performance of full scale printed wall made of clay.

This paper aims to show the possibility of merge the 3D printing technology with natural and locally found materials to produce more economic and eco-friendly constructions.

2. 3D EARTHEN CONSTRUCTION BENEFITS AND LIMITATIONS

2.1 Advantages

Concrete is one of the most plentiful man-made composite materials worldwide that has steadily reached its popularity since its inception. It is used in buildings, roads, highways, retaining walls, dams, bridges and other all types of civil construction work, the demand for concrete is very high at present and projected to have the same importance in the future. Nevertheless, traditional concrete could not be considered as an environmentally friendly construction material. This comes from the perspectives of depleting natural resources, high energy consumption, and construction waste disposal (Ismail and Ramli, 2013). Consequently, the necessity for the utilization of renewable and recyclable resources in concrete industries is of prime importance.

In this regard, one of reasonable alternative options is the use 3D printed construction with earth materials, additive manufacturing provides a matchless freedom of form for architects of concrete members, and this can lead to reduce the construction waste since the production and management of forms, can produce a large amount of waste, particularly in the case of forms for complex structures with assembly components that are utilized just a single time, as well as reduce amount of material used by using topological optimization concept and construction time and error. Meanwhile, the earth material can reduce the demand for conventional materials, since the major constituents of concrete are the aggregates and cement and the continuous mining create the shortage problem of the construction materials, as well as cement production process responsible of about 8% of the world‘s CO2 emissions (Chatham House, 2018). To avoid this issue, it is a quite important search for alternative materials, and earth material such as clay or mud could be a good solution, since they freely available. Erath materials also offers the benefits of natural insulation, fire protection, air circulation, low first cost, 100% recyclable structures, thermal flywheel effect, low greenhouse emissions, regulating the climate and providing a healthy Indoor environment.

Earthen construction can be utilized to build the affordable housing in low-income countries and disasters refuges using soil from the surrounding area. Natural disasters thing cannot be prevented by any technology leaving the victims homeless and exposed to the external actions. According to previous disasters refuges analyses, state that to build hundreds or thousands of refuges its take years (*Fig. 2)*. Utilization of 3D printing technology with the use of local materials for construction of the refuges, this can reduce the construction time to months and reduce the cost of materials and the cost of the project in half, since the refuges are temporary, its good alternative to save money throughout the construction process.

Fig. 2: Disaster shelters (Nadarajah, 2018)

2.2 Challenges

The use of concrete for 3D printing needs a specific type of concrete. The concrete mixture should flow like a paste and harden once it has been placed. The concrete should not set too quickly while in use, since this would block the nozzle and cause the printing process to be disrupted. As a result, the concrete’s open time is critical in the printing process. Extrudability, flowability, and open time are all concepts that are intimately related to concrete consistency and setting time. Therefore, specific qualities of concrete should be adjusted and adapted for printing in order to optimize it for 3D printing settings. Another issue with using Additive Manufacturing on a wide scale is the cost of acquiring infrastructure by building companies. The cost savings obtained from this technology mainly include savings in materials, labor and time, without considering the detailed costs of the 3D printer/robot, and necessary hardware, software, training, etc. As seen in Building Information Modeling (BIM), many construction companies, especially those in developing countries, have not yet implemented the Additive Manufacturing due to huge costs engaged for hardware, software and training, etc. (Aitbayeva and Hossain, 2020).

Moreover, because of the cost, insurability issues, and poor durability due to high water sensitivity, the development of earthen building is still limited. The high cost is primarily due to the high cost of labor and the time it takes for the material to solidify, as well as a slower production rate than the concrete industry. Having a mix design that allows for both rapid casting and appropriate strength in the dry state is problematic at the moment. Therefore, more researches are need to address these problems.

3. APPLICATIONS OF 3D PRINTED EARTHEN CONSTRUCTION

In the mid-2000s researcher from the University of Southern California, Dr. Behrokh Khoshnevis developed a process called Contour Crafting (CC) that prepare for the present day’s 3D Printing Concrete (Khoshnevis, 2004). Since that several researches are engaged in the expansion of large-scale 3D printers for the construction industry, the world has now witnessed many printed structures ranging from offices, houses, bridges, shelters and many more. 3D printed constructions with earth materials are presents in the following sub sections.

Fig. 3: *Gaia house (Gaia, 2018)*

3.1 Gaia house

WASP (World's Advanced Saving Project), an Italian company cooperated with RiceHouse that work in the field of sustainable building by the use of waste from rice production, to build Gaia, (*Fig. 3*), the first sustainable house model with earth material from the surrounding area and natural waste materials**,** coming from the rice production chain**,** aiming to achieve an efficient product from a bio-climatic perspective.

For the construction of Gaia, RiceHouse and WASP used vegetable fibers to create a compound that included 25% of on-site soil (30% sand, 30% clay, and 40% silt), 25% rice husk, 40% straw chopped rice, and 10% hydraulic lime. The muller was used to knead the mixture, which resulted in a homogenous and workable composite.

The Crane WASP printer was created with the goal of integrating natural ventilation, thermal-acoustic insulation, and plant engineering systems all inside the same space. The deposition of raw soil, rice production waste and straw are regulated by articulated weaves capable of giving both constructive firmness and geometric diversity throughout the wall's development. The precision and speed of 3D technologies enable the diversity of computational design in building practice, allowing for intricate geometries that are impossible to recreate with traditional construction systems. The printed area was 30 square meters with wall thickness of 40 cm, the production time was only 10 days due to its masonry, it doesn't need air condition or heating system, as it keeps moderate and comfortable temperature inside both in summer and winter.

Gaia is a high-performing module in terms of energy efficiency and indoor air quality, with approximately no environmental impact. (Gaia, 2018).

3.2 Tecla house

Tecla house (the name Tecla, a combination of the words Technology and Clay), is a new circular model of housing entirely created with reusable and recyclable materials, collected from local soil**,** (*Fig. 4*). The first model was designed by the Italian architecture studio Mario Cucinella Architects (MCA) and engineered and built by Italian 3D printing specialists WASP (World's Advanced Saving Project) by April 2021, becoming the world's first house 3D-printed entirely from a mixture made from mainly local earth and water.

The material consists of local soil mixed with water, fibers from rice husks and a binder. The house is made up of two modules up to 4.2 m in height, has an area of about 60 m^3. The house was built with 200 hours of printing, formed of two connected dome-shaped volumes with a ribbed outer wall that is made up of 350 stacked layers of 3D-printed clay with thickness 12 mm, with circular open on its roof allowing light to enter the house throughout the day. The clay is arranged in undulating layers that not only provide structural stability but also to act as a thermal barrier

The prototype was constructed using a multileveled, modular 3D printer that uses two synchronized arms, each with a 50-square meter printing area that can print modules simultaneously. Tecla was the first 3D printed building that constructed by using two printers at the same time, due to WASP software capable of optimizing movements, preventing collisions, and ensuring simultaneous operation.

Tecla was developed as part of an eco-sustainability research study that looked to bioclimatic principles and vernacular architecture and construction to produce low-carbon homes. By using this technology, housing modules can be built within 200 hours while consuming an average of six kilowatts of energy for 60 m^3 of natural materials and reducing typical construction waste. WASP founder, Massimo Moretti explains, "TECLA shows that a beautiful, healthy, and sustainable home can be built by a machine, giving the essential information to the local raw material,"(Tecla, 2020).

4. CONCLUSIONS

3D construction using soil materials may become one of the important innovations in the world of construction, that combines ancient building techniques with modern technology to form recyclable, low-carbon, climate-adaptable buildings. Take the benefits of additive manufacturing in terms of freely design, reducing construction time, cost and error, as well as take the advantages of the earth materials due to unlimited existing quantity and zero environmental impact.

Erath materials also offers the benefits of natural insulation, fire protection, air circulation, low first cost, 100% recyclable structures, thermal flywheel effect, low greenhouse emissions, regulating the climate and providing a healthy Indoor environment.

Earthen construction can be utilized to build the affordable housing in low-income countries and disasters refuges.

Fig. 4: Tecla house (Tecla, 2020)

Utilization of 3D printing technology with the use of local materials for construction of the refuges, this can reduce the construction time from years to months and reduce the cost of materials and the cost of the project in half, since the refuges are temporary, its good alternative to save money throughout the construction process.

Moreover, the earthen construction development is still limited, due to the insurability issues, and poor durability due to high water sensitivity. Further efforts are needed to safely print more economic-sustainable construction.

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