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AN INSIGHT INTO PROSPECTS AND CHALLENGES OF 3D PRINTING IN DEVELOPING COUNTRIES

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Abstract- The incorporation of 3D printing technique in construction demonstrates substantial promising opportunities for developing and under developing countries, that includes notable improvements in productivity, considerable cost minimizing, and eco-friendly construction provisions. This paper reviews the achieved milestones, prospects, and challenges linked with the integration of 3DP in the construction industry. Regardless of its benefits, such as reduced construction time and less material wastage, several challenges restrict its prevalent implementation. These challenges include high initial capital, lack of skilled labour, insufficient codes and regulatory frameworks, and technical risks related to material properties and printability. This review focuses the need of strategic resource allocation, organizing the training programs, and the establishment of regulatory guidelines. Emphasis is also placed on the importance of collaborative efforts between governments, academia, and industry stakeholders to encounters these challenges and utilize the full potential of 3DP technology in the construction sector.

Keywords- Additive manufacturing, Material optimization, Process efficiency, Regulatory challenges

1 Introduction

The construction industry is a key element of economic prosperity and societal development, but it also reflects one of the most environmentally adverse sectors worldwide [1]. Conventional construction methods are often overwhelmed by shortcomings, high capital cost, and notable carbon footprints, adding to approximately 40% of global carbon emissions. To counter these challenges, the introduction of additive manufacturing, most familiar by the term of 3-Dimensional Printing technology, unveils the transformative step towards sustainable and optimized construction practices [2]. 3D printing in construction encompasses the layer-by-layer addition of materials under computer control to create three-dimensional structures. This technique has numerous benefits, that entails lessened material waste, less manpower, and the ability to build complex designs that are not do-able with conventional methods. Regardless of these benefits, the implementation of 3D printing in construction, particularly in developing countries is difficult.

One of the crucial challenges is the high initial cost of 3D printing construction and the specific machinery and instrumentation required. Developing countries often face difficulties with limited finances, that makes it impossible to allocate resources in such advanced technologies. Furthermore, there is a shortage of skilled labor to operate and handle 3D printing machinery, thus impeding its general adoption. Moreover, regulatory and standardization issues pose substantial barriers. Many developing countries lack comprehensive regulations and standards for 3D-printed structures, leading to concerns about the safety, durability, and quality of these buildings [3]. Without preset standards, it is difficult for construction firms to obtain the necessary approvals and certifications, slowing the incorporation of 3D printing technology into mainstream construction practices. Regardless of all challenges and risks, the prospects of 3D printing construction are promising. It has the potential to resolve the issue of housing and infrastructure deficits that many developing countries face. For instance, 3D printing can notably shorten the construction times, accelerating emergency shelters and necessary infrastructure. Moreover, the environmental and economic benefits of reduced waste and carbon dioxide emissions are the main milestones towards sustainable construction, placing 3D printing as a promising option towards green building initiatives [4].

2 3D Printing Technology in Construction Industry

Additive Manufacturing is well known by the term of 3D printing technology. It encompasses modeling of any multi-dimensional object by adding material in layers according to 3D digital file. The first 3D object was developed in 1987 by 3D printing system [5]. 3D printing allows for more geometric freedom and complexity. The structural reliability of 3D-printed constructions depends on both the factors kept under consideration and overall print quality. Bond strength, deformation resistance and other strength parameters depends on equipment selection i.e., shape and size of nozzle, thickness of layer and layering time, pump speed, its printing time and printing path.

The construction process of structure by 3D printing technology has three main steps [1]. The design step involves the preparation of 3D model using computer aided design (CAD) software. This design can be obtained by 3D scanning of the existing object. This CAD model is then converted into stereolithography file. The STL file is then imported into slicing software that splits the model into multiple thin layers and gives programming G-code file which has detailed instructions for parameters for every layer to be printed. The 3D printer deposits material layer by layer in accordance with the G-code instructions in a bottom – up sequence. Numerous materials like ceramic, metal, resin, and plastic can be used in this technology. Post - processing of the final object may need curing, painting or other finishing procedures. D – shape or powdered based printing machines are used in the concrete construction. In a powder - based system, four major parts controls the whole system. A thermal head is coupled with a robot and two hose pumps. The concrete material is supplied by the first pump, while the accelerator is supplied by the second and micro-controller controls all the three parts. In Gantry based system, a peristaltic pump is connected to the thermal head which is controlled by using a four-degree of freedom mechanism. The printer head is attached to the vertical arm, it has a nozzle attached to it, which is usually composed of steel. The nozzle size and shape depend on the selected technique. Predominant techniques used in 3D printing technology for concrete structures are counter crafting, Powder Jetting method [3], and 3D printed formwork methods [6].

3 Attainment in Developed Countries

Notable 3D printed buildings are constructed worldwide which reflects the potential of this technique. In Wellington, USA, Printed Farms marks a significant milestone, comprises a covered area of approx. 10,000 sq.ft. Apis Coir constructed a 38 m^2 house in Moscow in 24-hours which had a unique shape. That shape was chosen to manifest its adaptability to construct any building shape and 50-70% cost reduction was reported as compared to conventional block wall method. During the construction of mentioned buildings, severe winters followed by -35 degree Celsius was recorded and the 3D printable mixture was workable only till -5 degree Celsius, so additional insulations were done. Similarly, the same reputed company constructed Office of the Future in Dubai which was reported to reduce the construction cost by 50-70 percent, waste reduction by 60 percent and labor expense by 50-70 percent. Pedestrian bridge in China is one of the milestones of 3D construction which highlights its capability to adapt to structures other than housing. In this project, 33% cost reduction was reported mainly due to the elimination of moulds and reinforcing bars. Some other examples of such structures are given in Table 1 given below.

Table 1:Notable projects in 3D printing construction [5], [6], [7], [8]

S. No	Buildings	Countries
1	Printed Farms Equestrian Facility	Wellington, Florida, USA
2	Detroit's First 3D Printed Home	Detroit, Michigan, USA
3	Wildfire-Resistant Home	Redding, California, USA
4	3D-Printed 5 story building by Win sun Company	Jiangsu Province, China
5	Florida's First 3D Printed House	Tallahassee, Florida, USA
6	Office of the Future	Dubai, UAE
7	12-meter-long bridge	Amsterdam
8	Pedestrian Bridge	Shanghai, China
9	The Lewis Grand Hotel Suite	Philippines
10	Apis Cor House	Russia

4 Prospects and challenges for 3D printing in developing countries

AM Technique have promising prospect along with challenges as well. Viability of this technique can be seen in seven major categories that includes material, manpower, process efficiency, logistics, sustainable construction, structural strength and cost. It offers rapid prototyping, reduced waste, less time in one dimension, adaptability to any geometrical design and less manpower but also coupled with multiple risks and challenges. If cost of structure is considered it includes three major dimensions i.e., material, manpower and facilities. 3D printing will reduce the labor demand and remedial

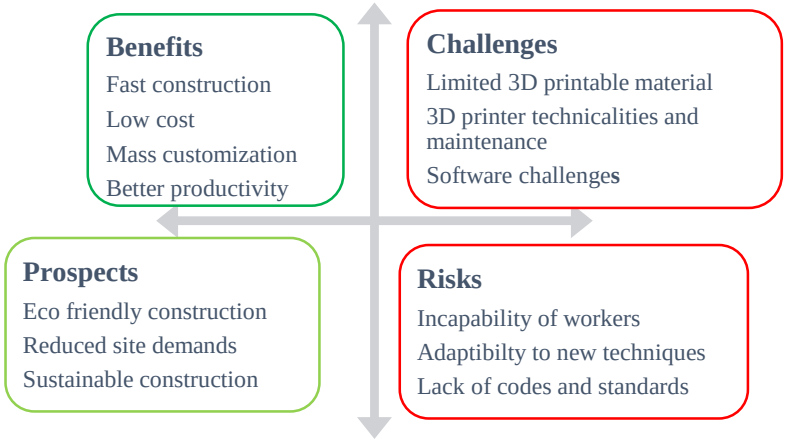

Figure 1: SWOT Analysis of 3D printing construction

works. Therefore, to evaluate this technique, it is desirable to calculate the financial performance in the whole process including all factors. Printability, buildability and open time are major concerns when material is considered while 3D printer itself comes with numerous challenges i.e., scalability and geometrical limitations [9]. Similarly, unskilled labor and inadequacy of knowledge also hinders the adaptation of the technique. Lack of codes and standards makes 3D printing questionable. It allows to complete large-scale project in less time but printing too quicky can also affects the strength [10]. Optimization of materials, expertise while maintaining speed is a delicate balance between benefits and challenges. Need of the hour is to create a standardized procedure and specify the design steps, standard codes and practices and construction guidelines which would give every organization a direction to stimulate research for the gaps so that implementation can be promoted. To effectively summarize the benefits, prospects and challenges, SWOT analysis of this technology is given in Fig.1.

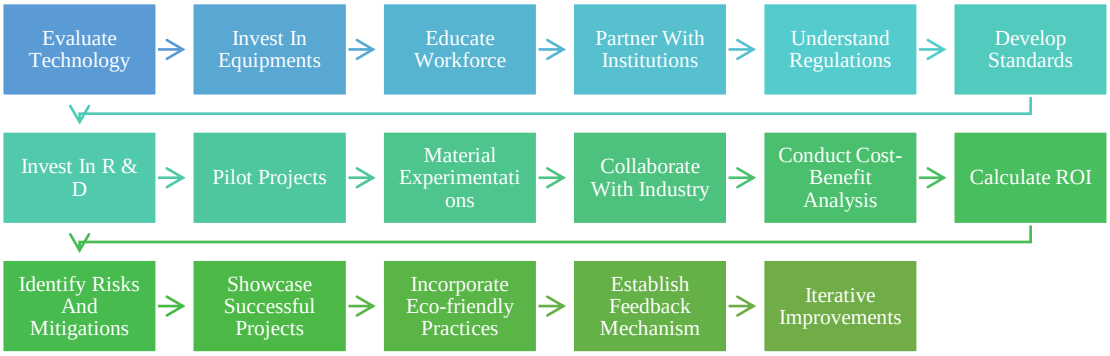

Figure 2 : Guidelines for adoption of 3D printing technology

5 Guidelines for adoption of 3D printing technology in construction industries

Diversified models have been designed to better understand different attributes that may affect the implementation process of 3D printed construction. The technology-organization-environment (TOE) framework is the most consistent framework

that covers all the aspects that should be considered for the adaption of innovative technology at organizational level [11]. Technological dimensions include evaluation of technology, material experimentation and exploration, developing standards and codes while Organizational dimensions comprise of cost-benefit analysis, collaboration with industry, training programs, invests capital in equipment's related to 3D printing. Environmental aspects have life cycle assessment, identification of risks and mitigations, incorporation of eco-friendly practices [12]. Fig.2 explains the adoption guidelines under the light of TOE framework.

6 Conclusion

The application of 3D technology in construction has a high potential for bringing down construction time and ultimately reducing manpower, therefore indicating clear cost and resource savings. However, the applicability of this in multi-story buildings is not clearly assessed. With this, comprehensive analytical studies are needed to evaluate life cycle assessments using BIM, which would enable one to understand the environmental impacts and the actual project costs associated with an emerging technology. Steel has a significant impact on the cost of concrete structures. Accordingly, the study of methods of enhancing 3D buildings that are printed using steel or otherwise has to be conducted. Moreover, the design and construction criteria for this technology still remain to be developed. Proper codes and rules need to be drawn up if this technology is to be used practically.

Its implementation could affect the employment circumstances. But there are chances of new fields yet to be explored for developing 3D printing equipment and exploring materials to be used in this technology. Overall review concludes that legislative and economic perspectives still need to be explored.

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