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TECHNO-ECONOMIC ANALYSIS OF 3D PRINTING OF CONCRETE FOR INDUSTRIALIZATION: A COMPARATIVE STUDY BETWEEN AAC BLOCKS AND 3D PRINTED ELEMENTS CONSTRUCTION

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ABSTRACT
Additive manufacturing, or 3D printing, of concrete is a disruptive technology with potential to transform the construction industry. To understand its techno-economic feasibility for industrialization, a comprehensive comparative study is crucial. This paper presents a detailed techno-economic analysis and comparative study of 3D printing of concrete. It includes an overview of additive manufacturing in construction, comparative study of printing techniques, material compatibility, printing speed, accuracy, and resolution. Economic aspects such as material, labor, and equipment costs, energy consumption, and environmental impact are analyzed. Potential applications in building construction, infrastructure development, and customized component fabrication are explored, along with techno-economic benefits and challenges. The paper concludes with key insights and recommendations for researchers, practitioners, and decision-makers. This study provides valuable guidance for understanding the techno-economic feasibility of 3D printing of concrete, facilitating informed decision-making and promoting its adoption in the construction industry for industrial applications.

Keywords: Additive Manufacturing, 3D Printing, Concrete, Techno-Economic Analysis, Comparative Study, Industrialization, Construction Industry, Printing Techniques, Material Compatibility, And Economic Aspects

1. INTRODUCTION
The use of 3D printing in the construction industry has gained significant attention in recent years due to its potential for revolutionizing traditional construction practices. In particular, 3D printing of concrete has emerged as a promising technique for industrialization, offering improved efficiency, sustainability, and design freedom. However, to fully understand the techno-economic feasibility of 3D printing of concrete for industrial applications, a comprehensive analysis is required. This paper presents a comparative study that aims to investigate the techno-economic aspects of 3D printing of concrete for industrialization.

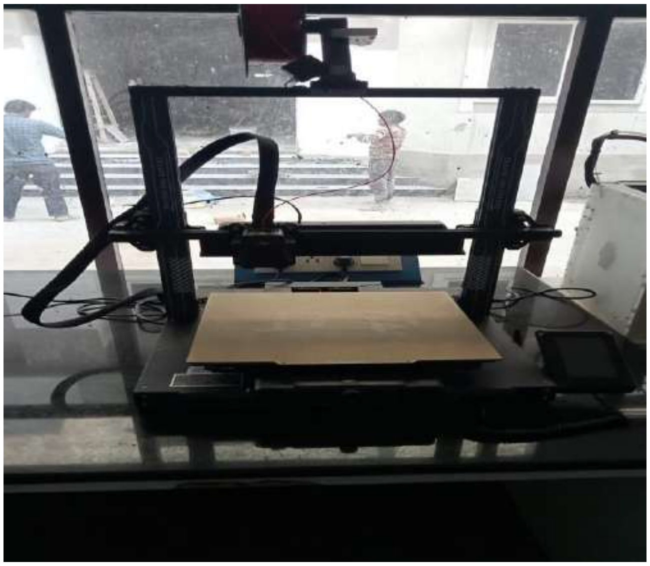

Fig:-3D printer using to prepare blocks

The paper begins with a brief overview of the current state of 3D printing in the construction industry, highlighting the growing interest and potential benefits of utilizing this technology for concrete-based applications. The advantages of 3D printing of concrete, including reduced material waste, increased construction speed, and enhanced design flexibility, are discussed in detail. The challenges and limitations associated with this technology, such as high initial investment costs, limited material properties, and lack of standardized guidelines, are also addressed.

Next, the paper presents a detailed techno-economic analysis of 3D printing of concrete for industrialization, comparing it with conventional construction methods. The analysis includes various aspects, such as material costs, labor costs, equipment costs, energy consumption, and environmental impact. Different 3D printing techniques, such as extrusion-based, powder-based, and binder-jetting, are considered, and their advantages and disadvantages are evaluated in terms of techno-economic feasibility.

Furthermore, the paper discusses the potential applications of 3D printing of concrete in industrial settings, such as construction of buildings, bridges, and infrastructures, and analyzes the economic benefits and challenges associated with these applications. The potential for customization and mass production using 3D printing of concrete is also explored, along with the potential impact on the construction industry as a whole.

This paper presents a comprehensive comparative study on the techno-economic aspects of 3D printing of concrete for industrialization. The findings of this study can provide valuable insights for decision-makers, policymakers, and researchers interested in adopting and implementing 3D printing of concrete in industrial applications, contributing to the advancement of this promising technology in the construction industry.

2. LITERATURE REVIEW

P Krupík(2020) 3D printers as part of Construction 4.0 with a focus on transport constructions said thatthe 4th Industrial Revolution, also known as Industry 4.0, encompasses rapid advancements in digital and technical fields. This paper focuses on 3D printers as part of Construction 4.0, specifically in transportation infrastructure. A SWOT analysis is conducted to identify strengths, weaknesses, opportunities, and threats in this context. The current state of 3D printing technology is evaluated, acknowledging existing limitations and roadblocks. While 3D printing is still in the research and development stage, it is expected to play a significant role in Construction 4.0. However, achieving the ideal future scenario depicted in the diagram below will require further progress and time.

Zhu Jianchao (2017) 3D printing cement based ink, and it's application within the construction industry: This article discusses how 3D printing technology is the key driver of the third industrial revolution, following the advent of automation and mass production. The study focuses on cementitious-based materials for construction and employs a qualitative method using literature studies and in-house research findings. The article highlights the strategy for developing an optimal mix design that meets the requirements of the 3D printing process and overcomes current limitations. It emphasizes the need for further research to develop higher-strength printing materials for multi-story buildings without additional steel reinforcement. The study also suggests that SAC cement is more suitable for 3D printing mortar due to its quicker setting time and stronger early strength. The paper recommends the use of a combination of retarder and accelerator for comprehensive time setting control, with the type and quantity depending on various printing conditions.

3. RESEARCH METHODOLOGY

The research methodology is designed to provide a systematic and rigorous approach to conducting a comprehensive techno-economic analysis and comparative study of 3D printing of concrete for industrialization. It ensures that the research is based on sound principles and practices, and the findings are reliable and valid.

Selection of Comparative Study Framework: A comparative study framework is selected to evaluate and compare different 3D printing techniques for concrete. The framework is chosen based on its relevance to the research objective, and it may include factors such as working principle, advantages, disadvantages, potential applications, material compatibility, printing speed, accuracy, resolution, material costs, labor costs, equipment costs, energy consumption, environmental impact, and techno-economic benefits and challenges.

Data Collection: Data is collected from various sources, including research articles, technical reports, industry reports, and other relevant publications. The data may include technical specifications of 3D printing techniques, material properties, cost data, and other relevant parameters needed for the techno-economic analysis.

Data Analysis: The collected data is analyzed using appropriate statistical and analytical methods. Comparative analysis is performed to evaluate and compare the different 3D printing techniques based on the selected comparative study framework. The techno-economic aspects, including material costs, labor costs, equipment costs, energy consumption, and environmental impact, are quantitatively analyzed and compared.

Results and Findings: The findings of the data analysis are presented in a clear and concise manner, using tables, charts, and other visual aids. The results are interpreted and discussed in the context of the research objective and the existing literature.

Limitations: The limitations of the research methodology, such as the availability and accuracy of data, assumptions made in the techno-economic analysis, and other potential limitations, are acknowledged and discussed.

The global construction industry heavily relies on concrete as the primary building material, but it faces various challenges. One of the major challenges is the high cost of construction, with formwork alone accounting for over 75% of building expenses in cities like Sydney, according to a study by the Boral Innovation Factory. Another challenge is the significant amount of waste generated during construction, especially from shaped formwork that is eventually discarded, contributing to the construction industry's overall waste production. However, 3D printing technology is gaining popularity in the construction sector due to its potential to reduce various project-related aspects such as design, materials, costs, and time. The concept of 3D printing was first introduced by Charles Hull in 1984, and it involves creating physical objects layer by layer using numerical data in STL format. 3D printing allows for lighter objects with multiple functions as it uses minimal material. The construction industry is responsible for nearly 80% of the world's garbage, and traditional concrete casting into formwork can limit architects' design flexibility due to the cost and constraints of formwork. Additionally, the slow pace of construction, safety concerns, and sustainability issues in the current construction methods are also challenges. The use of 3D printing technology in concrete construction has been gaining momentum as it offers potential solutions to these challenges. Unlike traditional subtractive manufacturing methods, 3D printing is an additive manufacturing process that converts 3D models into material components laye by layer, which can revolutionize the construction industry.

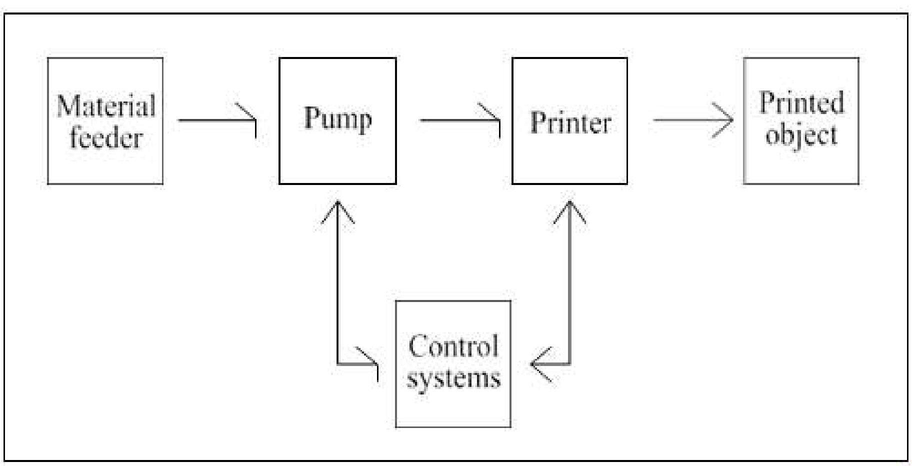

Figure 2: Schematic diagram of the printing process.

4. MATERIALS AND METHOD

Portland cement (conforming to IS 12269 (2013)), Class F fly ash (ASTM C618-17a (2017)) and silica fume (conforming to ASTM C1240-15 (2017)) were used in this study. Their specific gravities are 3.1, 2.6, and 2.2, and their oxide compositions are shown in Table 4.1. Chemical compounds include PCE-based superplasticizer and methylcellulose-based VMA (Viscosity Modifying Agent). VMA is used in liquid form (34% solid content) and in powder form. In addition, polypropylene fibers with a length of 12 mm and a thickness of 40 microns are used. Nanoclay, which is known to give shape stability to extruded products, is used as a rheological modifier with an average particle size of 1.5-2 µm and a specific gravity of 2.29 (purified palygorskite) (Voigt et al., 2010; Kazemian et al. ., 2017) . .

The specific gravity of fine aggregate, quartz dust, and two grades of quartz sand (called sand 1 and sand 2) are 2.76, 2.68, and 2.64, respectively. For granular materials, particle size was determined using laser diffraction (for portland cement, fly ash, and quartz dust) and sieve analysis (for quartz sand). The particle size distribution for silica fume was obtained from the factory, as ultrasonic testing for laser diffraction was not possible.

4.1 Mixing Procedure:

A Hobart planetary mixer made the mixer easy. Water is first added to the mixing tank with superplasticizer. The premixed dry ingredients are added gradually for 2-3 minutes with the rotating blade at low speed. For mixtures with VMA, mixing was stopped after 5 min and VMA powder was sprinkled into the mixture before continuing mixing. About 15% of the water mixture is kept in the nanoclay mixture. Nanoclay was dispersed in this water using a hand-held high speed blender and added to the mixer after 5 minutes of suspension. As a result, the blades are rotated at 365 RPM for 25 minutes and each batch has a concrete volume of about 6 liters.

4.2 Performance of AAC Blocks:

Dimensional Check:

Dimensional check was carried on site for physical dimensions of AAC blocks to compare with 3D printed concrete blocks.

Figure 3: Dimesional check on site for AAC Blocks

Water Absorption Test:

Figure 4: Water Absorption in Laboratory for AAC Blocks

Compressive Strength:

Figure 5: Compressive Strength for AAC Blocks

Extrudability:

It refers to the capacity of the concrete to be extruded out of the nozzle. This is assessed on the basis of the distance over which the paste can be printed without blocking the nozzle. Also, the printed paste should be clear of cracks separations.

Compressive strength:

The concrete's target strength is calculated using 5x5 concrete cubes and BS 1881-116:1983. Since the structure is printed in layers rather than in its whole, strength is very crucial. The desired strength and strength growth should be high since the printing process just takes a few minutes and setting time should be taken to be immediate.

Flowability:

The slump flow test is a method for determining flowability. An upside-down cone is used to disperse the concrete. The amount of time needed for the mixture to spread by a particular diameter is measured, and the rate of flow may then be calculated. Greater flowability and workability are correlated with a readily expanding mixture.

Buildability:

Concrete's buildability is its capacity to solidify before a further layer of concrete is poured over the previously applied layer. The number of layers that might be built without the lower levels significantly distorting allows for an evaluation of the buildability. Each print session should produce an object with at least 20 layers.

Open time:

In essence, the amount of time that has occurred since the water was added to the combination is its open time. The concrete shouldn't quickly solidify while printing because it would clog the nozzle and stop the operation in its tracks. The printing process therefore relies heavily on the concrete's open time.

5. EXPERIMENTATION AND DESIGNING

Using a 3D printer supplied by a digital file that explains the specifics of the thing, three-dimensional (3D) printing is a cutting-edge approach for creating objects. It is also known as rapid prototyping (RP), layer manufacturing, additive manufacturing (AM), additive fabrication, additive processes, direct digital manufacturing, and solid freeform fabrication. Materials including plastics, metals, concrete, sand, or resins are used in this printer.

Researchers explored various 3D printer designs, building techniques, and materials in order to advance this technology for the fabrication of structural elements and/or complete structures.

In this study, the most recent advancements in 3D printing techniques are reviewed. By contrasting the price of concrete for a Multipurpose Hall that was constructed conventionally with the price if it had been constructed using 3D printing, the impact of 3D printing is examined. Software called Revit is used to create the model.A modern analysis of advancements in 3D printing techniques is presented in this research. A comparison of the concrete cost of a Multipurpose Hall that was constructed traditionally with the cost if it had been constructed using 3D printing is used to examine the effects of 3D printing. Revit software is used to create the model.

Selected Case Study:

The conventional construction of a Multipurpose Hall is analyzed, including examination of architectural and structural designs from Greater Amman Municipality for material costs comparison with 3D printing. The hall is a one-story structure made of concrete and stone, with a traditional shape and a total area of 350 square meters (m2). The aim of applying 3D printing in this public building is to achieve cost savings and shorter construction time. The Revit modellingprogramme is used to represent each zone of the building based on its function, including concrete works, interior walls, and exterior walls above ground level, with determination of materials and estimated costs.

Concrete Works:

For the external walls behind the stone, 20 MPa concrete compressive strength is employed. With a concrete compressive strength of 25 MPa, reinforced concrete (RC) is utilised for slabs on grade and stairways. Columns, slabs, beams, and stairs are all made of RC components with a concrete strength of 30 MPa.

External Walls:

The outside wall of Multipurpose Hall is a typical wall made up of a 17 cm layer of concrete, a 10 cm plastered hollow cement block wall, 3 cm of extruded polystyrene insulation, and 5 cm of stone cladding.The outside wall of Multipurpose Hall is a typical wall made up of a 17 cm layer of concrete, a 10 cm plastered hollow cement block wall, 3 cm of extruded polystyrene insulation, and 5 cm of stone cladding.

Table 2: Comparative study of quality parameters

Parameters	3D Printed Blocks	AAC Block
Basic raw Materials	Cement, fly ash ,water and Geo polymer	Cement, lime ,specially grinded sand
Production process and set up	Using 3D printer with Nozzle size 2cm (200 mm)	Produced only in well-established plant equipped with steam boiler and high pressure auto claves
Dry Density kg/m3	900	750
Compressive strength	5.47 N/mm2	3.25 N/mm2
Usage	Non Load bearing blocks	Non Load bearing panels and blocks
Aging	Gains Strength with age (like Conventional Concrete)	No aging , Loses strength if not protected against humidity
Cost	1,13,383.00	1,36,615.00
Eco friendliness	-Pollution free -Consumes fly ash (an hazardous industrial waste material)	-Pollution free -Wastage will be more

6. CONCLUSION

- The study indicates that water retentivity plays a pivotal role in governing the flow and extrudability of the concrete mix during the intricate process of 3D printing. The collected empirical data is useful not only for anticipating and averting possible phase separation problems, but also for optimising concrete mix designs for increased dependability and efficiency in the intricate process of large-scale 3D printing initiatives in the construction industry.
- The study acknowledges the importance of mechanical characteristics and porosity in guaranteeing that structures produced through 3D printing not only fulfil but also surpass the requirements set forth by conventional building techniques. The research makes a significant contribution to the continuous endeavour to validate and optimise 3D printing technology for wider implementation in construction practises by thoroughly assessing these properties aspects.
- The incorporation of a continuum mechanics and thermodynamics-based model is a complex and all-encompassing method of modelling the 3D printing process. This model ensures the accuracy and stability of the printed layers by acting as a reliable tool for predicting and addressing problems associated with layer deformation. The study advances our understanding of the complex dynamics involved in 3D printing and

offers useful insights for improving the technology by including these simulation studies into the research framework

- The study resides in its ability to support strategic planning and well-informed decision-making for upcoming building projects. Construction sector stakeholders are provided with a comprehensive grasp of the economic environment related to 3D printing, which enables them to balance the possible benefits against the drawbacks. This thorough knowledge will help architects, engineers, and project managers make well-informed decisions about using 3D printing technology in their projects. They can take into account factors like long-term sustainability, efficiency gains, and project timelines, in addition to immediate costs.

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