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UTILIZATION OF 3D PRINTED CONCRETE IN CIVIL ENGINEERING: REVIEW

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ABSTRACT: 3D Printing, which is an automated production process that allows for layer by layer control, has surged in popularity in recent years. For decades, the technology has been utilized in the manufacturing industry, and it is currently being used to print houses and villas in the construction industry. The construction industry may benefit from technology in terms of increased customization, shorter construction times, fewer workers, and cheaper construction costs. Three dimensional printing (also known as additive manufacturing) is a cutting-edge manufacturing process that can produce complex form geometries without the need of tooling, dies, or fixtures from a three-dimensional computer-aided-design model. Because of the significant benefits of producing working prototypes in a reasonable amount of time with minimal human involvement and material waste, this automated manufacturing technology is being employed in a wide range of industries. On the other hand, a more recent application of this technology to the built environment looks to improve our regular building processes while reducing the need for human resources, costly capital inputs, and additional formworks. The scientific interest in employing 3D printing for building and construction has risen in recent years. This study evaluates the most recent research trends in the field by evaluating papers from 2011 to 2023. Finally, this research paper gives a brief outline of future work that may be done to increase the capabilities and printing quality of current systems.

Keywords: Construction Industry , Automation , Concrete 3D Printing, Sustainable Construction, Additive Manufacturing

1 INTRODUCTION

3D printed concrete is a unique sort of concrete that can be produced layer by layer using a 3D printer without the use of formwork or a vibration process. It's a revolutionary manufacturing technology that's currently being used in a variety of industries. New design options and more efficient, resource-saving building procedures can be generated if the potential of this technology is used to large-scale construction. Interdisciplinary study on additive manufacturing for use in the building sector. Many construction structures have been successfully created utilizing 3D printed concrete technology, with some of them achieving real-world applications. 3D concrete printing is a construction technology that may fabricate a predesigned building part in 2D layers on top of each other, resulting in a 3D model when the layers are doubled. There is no requirement for formwork or subsequent vibration because the concrete is poured from a printing nozzle.[1,2,3,4] Contour Crafting (CC) is a concrete printing process that has a lot of promise for enhancing building procedures and methodologies. CC uses robots to create items layer by layer; it is utilised for small-scale industrial parts and has been recognized as the only approach capable of providing components large enough for construction. Several firms have been experimenting with various

3D printing processes and technologies. ICON, a US firm, has proved its 3D printing expertise by manufacturing 10 houses in under 24 hours for a total cost of $5000 constructions. Architecture has developed the world's biggest 3D printer, which creates a stone- like substance from sand and a chemical binding agent. 3D concrete printing aims to improve construction on several levels: it shortens the construction process by eliminating some time- consuming processes in the traditional method; it lowers project costs by reducing waste and overproduction, as well as labour costs; and it provides flexibility in building structural shapes that aren't possible to build with traditional methods.[4,5,6,7]

A Massachusetts Institute of Technology team led by Emanual Sachs patented 3D printing in 1989. An important milestone in the development of 3D printing technology was reached in the 1990s when Charles W. Hull from the United States created a Rapid Prototyping system that can produce produced parts. Every country has been implementing strategies and policies to encourage 3D Printing technology since the early 21st century. The Chinese government also places a high value on 3D printing research and application. Three-dimensional printing was emphasised in 2012 by the Ministry of Science and Technology's National High-Tech Research and Development Plan As of 2015, the Ministry of Industry and Information Technology of China officially announced the Promotion Strategy for National Additive Manufacturing Industry, which is a unique promotional plan for 3D Printing technology in China for the first time ever. "Innovation, coordination, green, development, and sharing" are the five development concepts outlined in China's 13th five-year plan, which calls for the construction industry to emphasise the concept of green development, focus on new-type construction industrialization, deeply integrate information technology, as well as update and upgrade the industrial chain of construction [8,9,10]

Recently, 3D printing has advanced considerably and can now be done with a variety of materials, including plastics. Formerly used just to create physical models for stakeholders to review, 3D printing is increasingly being utilized to construct complete buildings, including homes and office complexes. An important milestone in the development of 3D printing technology was reached when the University of Southern California's "Contour Crafting" project demonstrated how layered extrusion technologies may be used in large-scale structures. 3D concrete printing is ideal for both digital building on-site and prefabrication. These new technologies, when combined with digital planning, can pave the path for Construction Industry 4.0. When it comes to changing building practices, digitalization and automation of essential production processes represent the most viable option.[11,12]

A typical 3D concrete printer has a nozzle head movement of up to 475 mm in the X direction, 650 mm in the Y direction, and a printing base of up to 750 mm in the Z direction. This is accomplished by using 300 Servomotors to control linear screws. A screw-type extruder may be driven by a 660 watt servo motor. The concrete printer will be controlled by software, which mechanical engineers may find more useful. The use of software such as SolidWorks or Inventor is critical in the production of printed concrete. Some of the software used in CNC milling machines is not open source, although it is useful for designing structures. The stereo- lithography files are converted to G-code instructions by an open source slicer programme. The goal of contour crafting is to make the surface of the concrete pouring out of the nozzle easier to work with. A new nozzle with trowels that follow the outer edge is required to accomplish this in the concrete printer. The trowels should also be able to generate an angle based on the form of the printed item, allowing for the printing of slanted walls. During the fill cycle, the trowels should not come into touch with the concrete paste. Lund University in Sweden came up with the notion of printing concrete with the aid of a robotic hand, as seen in Figure 1. This software- controlled robotic hand increases the precision of 3-D printed structures.

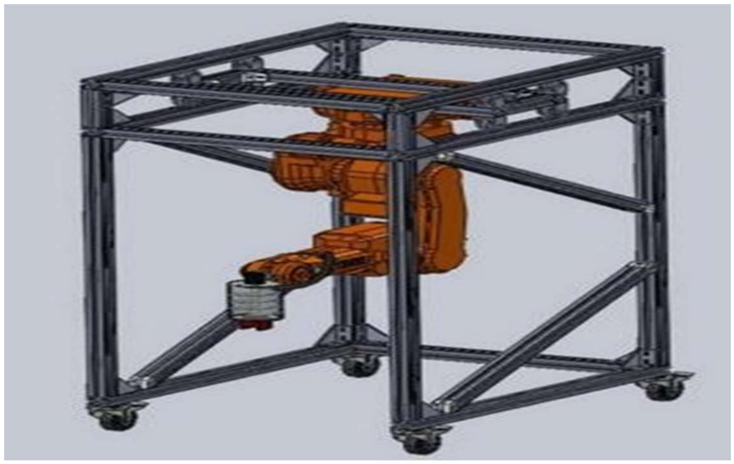

Figure 1 : Prototype of robotic hand presented by lund Univesity, Sweden

Figure 2: 3D Printing Of Concrete. Mixture

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Figure 3: 3D Printing in Layers (Source of Image : Softpedia News)

Figure 4: COBOD BOD2 3D House Printer - Gantry Type; Developed by Printhuset Company, Denmark

2. PARTICLE BED 3D PRINTING

2.1. CATEGORIZATION

Using a computer-generated 3D model, particle-bed 3D printing produces free-form structures. To build a product, consecutive cross-sectional layers are used, as in other additive manufacturing processes.

The printing method consists of two repeating labour steps: (1) applying a layer of dry particles and (2) selectively depositing a fluid phase onto the particle packing using a print head or nozzle to bind the particles. Finally, in a de-powdering process, non-bonded particles are eliminated. After the printing process is completed, infiltration or heat treatment can be used to increase the product's strength and durability.

For the manufacture of concrete components using particle-bed 3D printing, there are three major strategies: (1) printing the component directly with cementitious material, (2) printing a formwork that is filled with typical fresh concrete and then removed, or (3) printing a permanent formwork that creates a composite with the poured concrete

- **SELECTIVE BINDER (CEMENT) ACTIVATION**

The particle bed in the selective binder activation process is made up of a dry combination of extremely fine aggregate (usually sand less than 1 mm) and binder. Cement is used as a binder in the construction of concrete components. Spraying or jetting water or a water-admixture solution into the packed particles activates the cement locally, producing a cement paste matrix surrounding the aggregate particles.

- **SELECTIVE PASTE INTRUSION**

The particle bed in this example is made up of aggregate particles with an average diameter of 5 mm and no binder. The binder paste, which is made up of cement, water, and admixtures, is

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sprayed over the particle bed using nozzles. To make components with appropriate strength, the cement paste must fill the gaps between the particles.
In compared to other building additive manufacturing processes, the particle-bed. The choice of shape is nearly unrestricted with 3D printing processes. Due to the mechanical stability of the dry packed particles, inclined constructions, overhangs, arches, vaults, hanging beams, and cantilevers may be easily produced. Another benefit of this technology is its high manufacturing resolution, which is useful even for large-scale items. Resolutions as low as 0.1 mm are achievable depending on particle size. Furthermore, the length of time it takes to produce anything is unaffected by geometric complexity. The printing space constrains component size, which is a key disadvantage of particle-bed 3D printing.

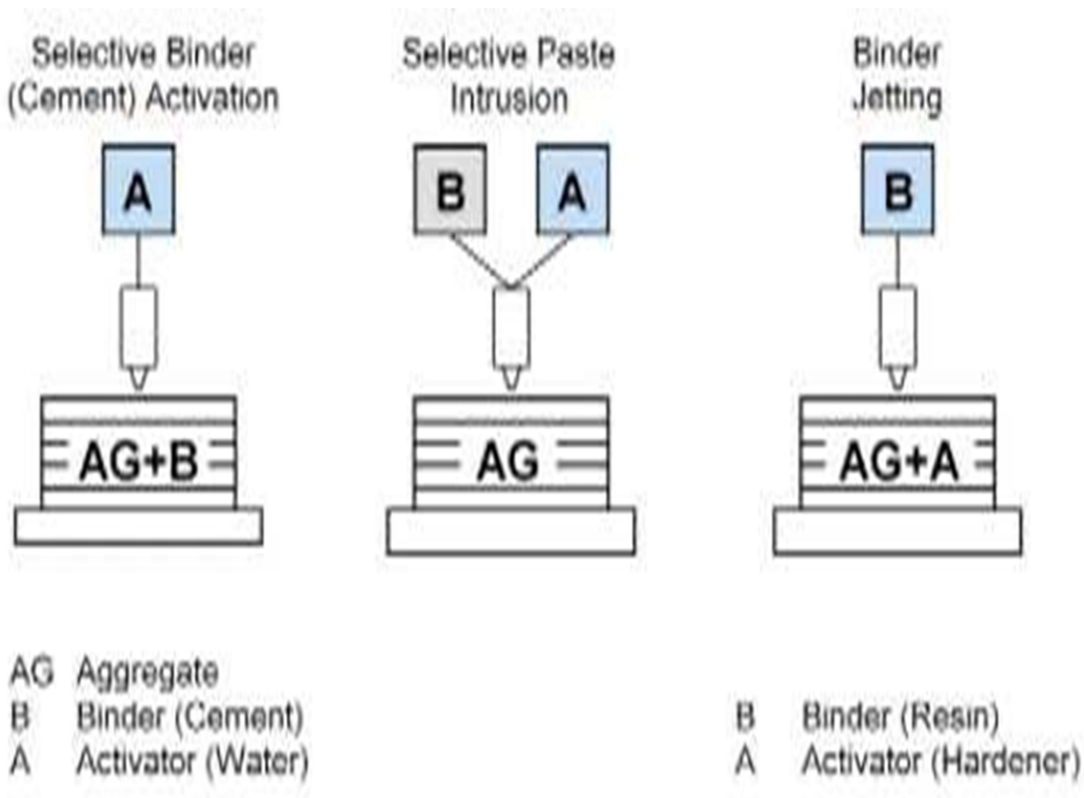

figure 5: particle bed 3D Printing methods

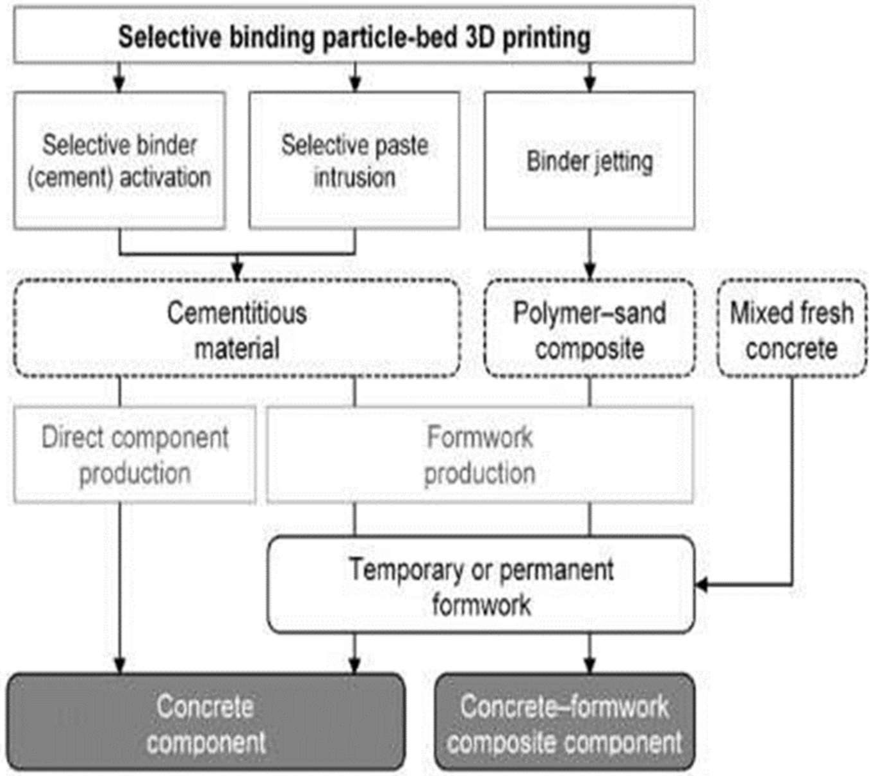

Figure 6: Classification Of Particle Bed 3D Printing

Furthermore, in terms of manufacturing costs and environmental assessment, the additional process step required to remove non-bonded material after printing, as well as the potential of recycling this material, must be addressed. As a result, it appears that this technology is destined for highly automated manufacturing in a precast plant. It is critical for the non-bonded material to be entirely recyclable in terms of environmental effect.

2.2. REVIEW OF LITERATURE

The first powder-bed based additive manufacturing techniques were developed in 1986, and they utilized lasers to sinter metal, plastic, polymer, or ceramic powders to create solid things. Sachs et al. at MIT developed a 3D-printing process that uses fluid binders to selectively bind particles in a powder bed to create ceramic components in 1993. All of these approaches, however, were created with the intent of producing tiny items (such as prototypes) rather than full-scale civil engineering projects.

Pegna proposed the idea of printing solid components for the first time in 1995. He proposed the use of layer-by-layer selective deposition of Portland cement for free-form building. Hollow elements were created. The components were created by layering a matrix material (sand) and selectively covering it with a reactive chemical (cement) Using several masks, we were able to apply the cement selectively. After each layer was crushed, the reactive agent was activated by injecting water vapour at air pressure between them. Six months after manufacturing, the compressive and tensile strengths, as well as the E- modulus, were measured. [13.14]

An ESA (European Space Research and Technology Centre) initiative is intended to employ D-Shape with lunar dirt to create components for a lunar colony. Granular material was combined with crushed metal oxide (e.g. MgO) and placed in 5 mm layers in the experiments. A reaction of the metal oxide with magnesium chloride (MgCl2) in the "water salt" binder resulted in selective binding. An exothermic process produces Sorel cement, just as it does in Sorel cement.[15]

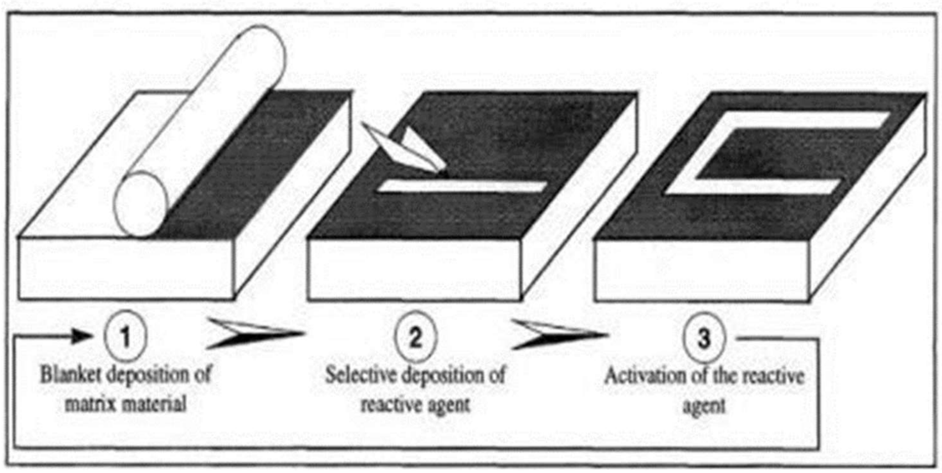

Figure 7 : Layer By Layer Selective Deposition of OPC

Similarly, the Viridis 3D initiative creates moulds for the foundry sector using an industrial robot. A combination sand application and print head system on the robot spreads silica sands with layer heights ranging from 0.2 to 0.5 mm. A modified furan binder holds the particle bed together. Without curing, the material's strength is at 1.2 MPa. The material acquires a strength of 2.6 MPa after curing [16]

Gibbons et al. utilized cementitious composites in conjunction with piezoelectric printer technology to create 0.1 mm layer thickness specimens in order to improve the resolution and robustness of the green structures, organic modifiers such as carboxymethylcellulose, polyvinylalcohol, and glycerol (up to 5% by weight) were added to the powder and/or liquid. Aside from the admixtures, quick hardening cement was the major component of the powder, while demineralized water was the main component of the liquid reactant. The powder's particle size distribution was compared to a proprietary basanite-based 3D printing powder. 4-point flexural tests on specimens with a cross-section of 21 x 21 mm2 were used to determine flexural strength. After 26 days of immersion in water, the specimens had a flexural strength of
2.2 MPa and 0.8 MPa after one day. After the printing procedure, the specimens' w/c ratio was around 0.2, and their density ranged from 960 kg/m3 to 1300 kg/m3. [17]

Tan, M. J. (2019). examines. 3D concrete printing applications that employ recycled glass as the fine
aggregates. A paucity of attention has been paid to the rheology of recycled glass in concrete, which is critical to its performance in 3D concrete printing despite the fact that numerous research have been conducted. Recycled glass concrete has a less mechanical strength than conventional cement, but its flow characteristics are superior. But it's important to find a balance between mechanical strength and flow ability when designing the mix design. To increase its build ability and mechanical strength, future study will focus on optimizing the mix design utilizing a mixture of sand and recycled glass, changing the grade of recycled glass particles, and adding accelerators.[18]

Panda, B., & Tan, M. J. (2018). presented the research that Mortar was created with a new material design and new characteristics for use in 3D concrete printing. To construct complicated architectural and structural components, 3D printing uses extruded materials that are placed layer-by-layer, unlike conventional casting, which requires formwork and human interaction. Three early-age characteristics of the 3D printed geopolymer material include extrudability, shape retention, buildability, and thixotropic open time (TOT). In a systematic experimental method, five alternative geopolymer mix designs are evaluated to determine the optimum printable mix, which will then be utilised to print a 60-centimeter-tall freeform structure on a concrete gantry printer to confirm the formulation's performance.[19]

Muthukrishnan, S., & Sanjayan, J. (2021). found that following are two ways for improving build ability:
(1) Additives used at the initial mixing of concrete (2) An intervention to improve build ability at the print head (set-on-demand). The first approach is the most frequently researched, yet it has an impact on pump ability. Until the mix reaches the print-head, this technique has little effect on its pump ability. Finally, the potential of a novel set-on-demand technique is discussed. [20]

Zhu, B., Nematollahi, B., Pan, J., Zhang, Y., Zhou, Z., & Zhang, Y. (2021). investigated For the production of concrete columns, 3D concrete printing of permanent formwork is used. Using several mixtures for the manufacture of permanent formworks, the effect of different hydroxypropyl methyl cellulose (HPMC) contents (0, 0.0003 and 0.0006 by mass of binder) and water-to-binder (W/B) ratios (0.27, 0.29, and 0.31) on rheological properties, structural build-up, and mechanical performance was investigated. Following that, three concrete columns were built utilizing the printed concrete as the permanent formwork and tested in compression with varied longitudinal steel reinforcement ratios (0.0 percent, 1.9 percent, and 2.5 percent). At the junction of the cast-in-place concrete and the printed concrete permanent formwork, good bonding was observed. [21]

Sanjayan, J. G., Jayathilakage, R., & Rajeev, P. (2021). found in their research that in order to meet these competing needs, active rheology control using vibration is used. With varying amounts of nanoparticles in the mix, the effects of vibration frequency and acceleration on rheological properties of concrete were investigated. The active rheology control via vibration was demonstrated in buildability tests using 3D printers. When vibration rheology control was applied, the mechanical characteristics of the printed structures were also observed to improve.[22]

Ko, C. H. (2021). presented a study of their investigation using a research technique. The fundamental concepts of AMoC are first introduced. The difficulties of AMoC are then addressed, including hardware, material properties, control, and design. Finally, solutions for dealing with the difficulties are explored. Hardware, material, control techniques, manufacturing process, and design are all factors that influence the success of AMoC. In order to achieve a successful computer-aided design (CAD)/computer-aided manufacturing (CAM) integration and deliver CAD and CAM benefits to the architectural sector, these challenges must be considered early in the design phase. Objects are built layer by layer in three- dimensional (3D) printing. As a result, the additive technique (such as toolpath) and material characteristics have an impact on printing output (such as tensile strength and slump). Despite the fact that earlier research have attempted to enhance AMoC, the majority of them have focused on the manufacturing process. However, a successful implementation of AMoC in architecture must take into account the limits and constraints of concrete 3D printing. So far, there has been little study into the possible problems of using AMoC in design from a construction lifecycle viewpoint .[23]

3 CONCLUSION

With the approach of constructing superstructures to creating the most affordable building, building components and engineering methods have grown exponentially through time. When compared to traditional building methods, 3-D printing of concrete allows for more precise, cost-effective, and timely completion of projects. Because of geographic considerations in various regions, the quantity of mixing should be adjusted correspondingly. This approach, on the other hand, necessitates specialists from a variety of fields, including civil, mechanical, robotics, and computer science, which might lead to difficulties. It may, however, be resolved with minimal effort. We concluded from our literature review that printing concrete may be used as high-performance concrete. The flexural, compressive, shear, and tensile strength of concrete changes depending on the mix ratio. With the addition of fibres and activators

to concrete, the strength of the concrete rises; nevertheless, the concrete's flow ability should be maintained until the design is completed. Concrete may be printed in a variety of forms and styles.

3D printing is growing increasingly popular each year. Because of the limited obstacles that it now faces, the technology's benefits cannot be overlooked. Because standard blueprints are incompatible with 3D printers, the entire design process must be handled differently, which necessitates expertise and experience. The future influence of new technology in the sector of building is critical. The information era is now underway, and its key traits will unavoidably pervade all elements of future design.

The majority of concrete 3-D printing research has so far been experimental, with little emphasis on computational simulations of the process, and there is even a scarcity of published material on simulation and modeling. Computational modeling would allow for the design and optimization of 3-D printed cement-based parts on a variety of sizes and materials, resulting in more long-lasting and cost-effective solutions. Computational modeling will continue to advance, and integrating computational models with experimental studies will aid in the maturation of 3-D printing technology in concrete.

Finally, due of its high demand, 3D building printing is a promising field. According to the information presented above, construction 3D printing is cost effective, and it improves, greenifies, and secures the construction process. The authors' conclusion to compare the two types of machines is an excellent example, because the end product provides a general image of 3D printing for those who are new to this fascinating field.

Declaration of Competing Interest : The authors declare that they have no any conflict of interest.

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