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State of the art of rebars problem in 3D printing of concrete in construction

Stadiul actual al soluțiilor de armare în imprimarea 3D a betonului în construcții

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Abstract. *Construction advances in 3D concrete printing boost design freedom, but reinforcement bars present obstacles. Incompatibility with 3D printing, positioning and accuracy issues, concrete adhesion issues, synchronization issues, and corrosion and fractures are major obstacles. To solve these problems, the use of fiber and other methods is necessary. Digital control and robotics improve printing accuracy, but the lack of standards makes study validation and comparability difficult. Since present techniques weaken automation and structural strength, rebar integration must be addressed. To improve 3D concrete printing, future research must combine materials science, mechanics, and robotics.*

Keywords. 3D concrete printing, reinforcement bars, Incompatibility, rebar integration

1 Introduction

Additive manufacturing (3D printing) has become popular across industries for its capacity to build complicated goods through bespoke designs and layer-by-layer procedures. As digitization advances, the construction industry has widely utilized AM technologies, especially 3DCP. **[1]** Concrete is a popular building material due to its compressive strength and adaptability. Energy-absorbing and ductile structural uses are limited by its brittleness and low tensile strength (TS). Reinforcement materials, especially steel bars, were recommended in the 19th century to overcome these restrictions. Steel's strong ductility and concrete-like heat coefficient increase tensile capacity and prevent bond failure. **[2]**

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Due to its anisotropic nature, 3D printed concrete needs reinforcement to ensure structural stability and integrity. **[3]** Current reinforcement methods for layer-by-layer printed concrete buildings cannot incorporate continuous vertical reinforcements, impacting structural integrity. Researchers are investigating methods that partially meet integrity criteria or supplement concrete printing. Vertical reinforcements injected during printing or post-installation, horizontal reinforcements extruded or put on printed layers, and reinforcement cages in printed formworks are proposed. **[4]**

The difficulties of integrating traditional rebar reinforcement into printed concrete structures hinders 3D Concrete Printing (3DCP). Manual steel reinforcement installation was laborious and unautomated in previous efforts. Continuous steel cables and 3D printed rebar offer little structural improvement over regular rebars. Thus, automating concrete printing and rebar integration remains difficult. **[5]**

Despite the importance of reinforcing, 3D-printed concrete structures with conventional steel bars are more complicated than traditional concrete buildings. **[3]** 3D printing's layer-by-layer deposition can disrupt rebar placement, weakening the bond and perhaps causing concrete slippage. **[6]** The goal is to create and apply 3D-printed concrete in construction, addressing technical obstacles using sophisticated reinforcement technologies. **[7]** Steel bars, especially when paired with other materials, can improve structural integrity through novel bidirectional steel mesh arrangements. **[8]**

2.Technologie

2.1 rebars problem and solved with fibers or other technic

2.1.1 Incompatibility of reinforcement bars with the printing 3d concrete process

3D-printed concrete is growing in research and business, but it lacks internal reinforcement. FRP reinforcement improves 3D printed concrete, but traditional production procedures limit on-site use. ZENG et al. use continuous fiber reinforced thermoplastic polymer (CFRTP) to create a 3D-printed concrete reinforcement (Fig 1). A study examined the tensile performance of 3D printed CFRTP bars and grids, then tested twenty-two concrete plates to see how loading direction and manufacturing type affected their flexural behavior. Performance is greatly improved with FRP reinforcement, with CFRTP reinforcement performing similarly. ZENG et al. recommend CFRTP reinforcement research to improve 3D printed reinforced concrete structures that blend concrete and FRP reinforcement (Fig 2). **[1]**

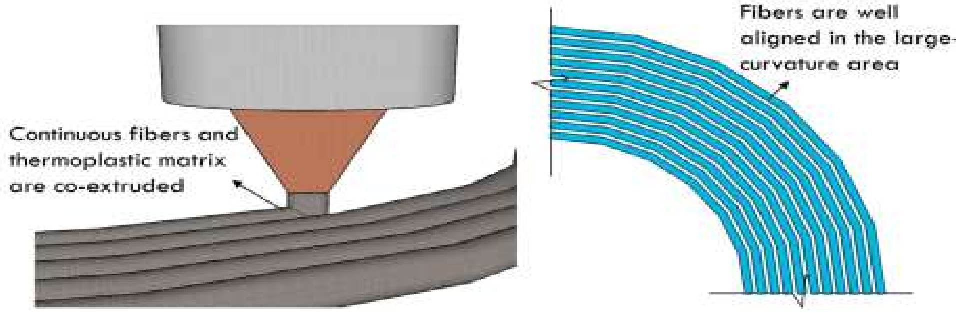

Fig 1 Continuous fiber reinforced thermoplastic polymer based on additive manufacturing. **[1]**

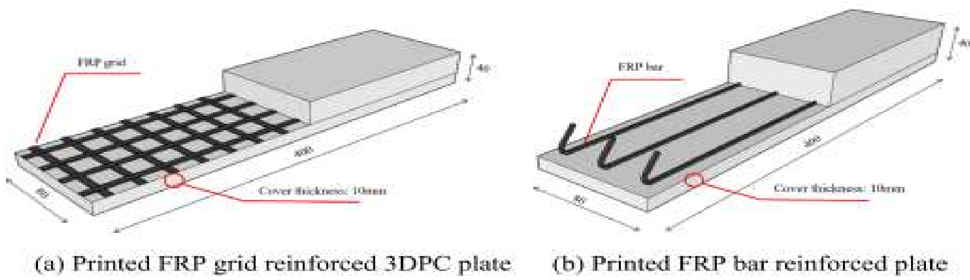

Fig 2 Schematic illustration of specimens. **[1]**

Due to environmental, resource, and economic considerations, AMIRTHARAJ et al. recommend alternate construction materials. Following IS and ASTM standards, they compare the mechanical characteristics of GFRP, CFRP, BFRP, and bamboo bars to steel. FRP bars fulfill strength standards but not the 200 GPa modulus standard with tensile strengths of 640 to 2136.9 MPa and elastic moduli of 34.2 to 140 GPa. Although pricey, stainless steel fits both criteria with strengths of 764–1116 MPa and moduli of 141–202.6 GPa. 250.3–370 MPa Bamboo tensile strength and 5.5–27 GPa moduli limit it to non-structural uses. FRP beams have equal ultimate loads to steel but more deflection and breaking. The research emphasizes the necessity for alternative steel bars that match structural performance and standard standards. **[2]**

SALAIMANIMAGUDAM et al. use CRITIC objective weighting, MABAC, and SAW multi-criteria decision-making to study reinforcing inclusion strategies for 3D-printed concrete structures. No reinforcement, conventional, micro, post-tensioned, and sync reinforcement are tested for automation, integration, time, and structural effectiveness. Automation and structural efficacy affect decision-making, with conventional reinforcement preferred above micro and sync reinforcement. The research warns against utilizing 3D-printed concrete without reinforcement due to poor structural performance and emphasizes computerized post-tensioned strengthening to increase structural integrity and efficiency (Fig 3). **[3]**

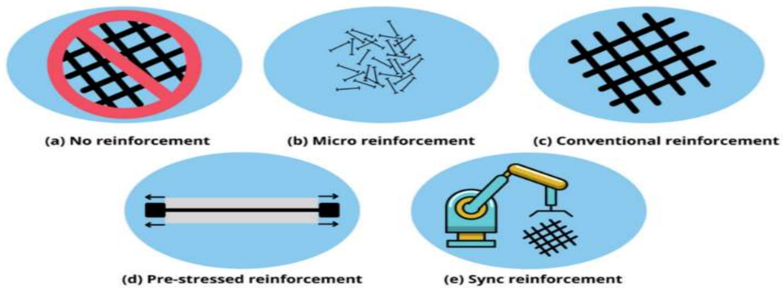

Fig 3 Types of Reinforcement Incorporation Method **[3]**

According to WANG et al. 3D printed concrete truss structures are lightweight and easy to manufacture, but reinforcement-concrete interfacial incompatibility affects structural dependability. Innovative 3D conical reinforcement improves load transfer efficiency and mechanical behavior. Performance of planar reinforcement ratio, conical reinforcement design, and shear-span ratio was tested on 10 beams. Compared to 2D techniques, final shear capacity increased 15% and post-peak deformation 40%. built updated finite element models to describe load transmission processes and a modified shear capacity calculation model that matched experimental results (Fig 4). **[4]**

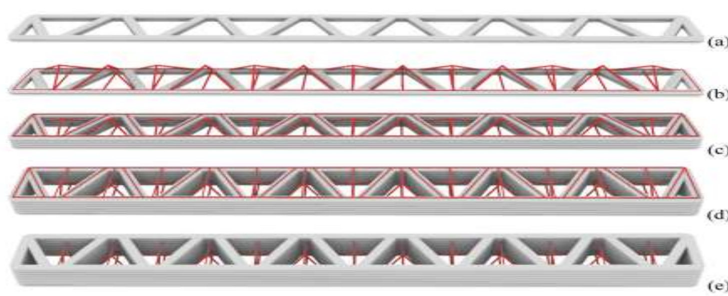

Fig 4 Key steps of 3D conical rebars reinforced 3DPC beam: (a) Print bottom concrete; (b) Lay 3D conical reinforcement; (c) Lay 2D truss reinforcement as needed; (d) Lay top 2D truss reinforcement and spot weld; (e) Print top concrete. **[4]**

Although 3D printing concrete (3DCP) promises more sustainability and productivity, automating the incorporation of rebar reinforcement presents difficulties(Fig 5). To address these challenges, DU et al. provide an automated robotic system in conjunction with Building Information Modeling (BIM) (Fig 6). They created a deep learning model and used Dynamo scripts to create printing routes that were optimized for rebar integration. The model achieved 92.5% accuracy in rebar recognition with a 2 mm location inaccuracy. The first real-world example of an automated system combining rebar with printed constructions utilizing BIM data was made possible by a centralized control system that allowed communication between gadgets like a camera and a robot arm. **[5]**

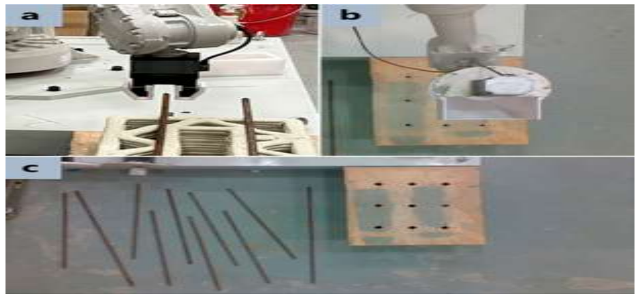

Fig 5 Experimental setup. (a) Gripper; (b) Concrete extruder; (c) Rebars and printing base. **[5]**

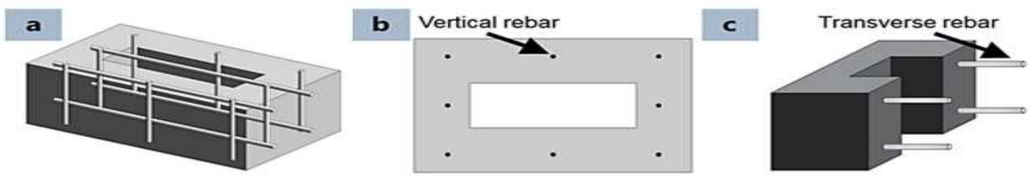

Fig 6 BIM model. (a) 3D view; (b) Top view; (c) Cross section view. **[5]**

Rebars and 3D concrete printing (3DCP) are incompatible because to bonding issues, reinforcement integration issues, and interface structural faults. Lack-of-fusion (LOF) in printed layers affects 3D printed concrete with integrated rebars structural integrity and performance.

3.2.2 positioning and accuracy of reinforcement bars in 3D concrete printing in construction

Digital construction production might benefit from 3D Concrete Printing (3DCP), but a lack of structural performance data hinders its use. Mechanical performance depends on reinforcement placement in printed layers and toolpath methods on concrete characteristics(Fig 7). LIU et al. study 3DCP beam flexural behavior with different reinforcement locations and toolpath techniques. Toolpath orientation perpendicular to reinforcement reduces shear and delamination failures and promotes flexural cracking, therefore it may be ignored. Steel reinforcement near the upper layers performs better flexurally than reinforcement toward the bottom (Fig 8). **[9]**

Fig 7 3D printed concrete beams process: a) printing of bed-surface layers b) placement of steel rebars c) printing of encasement layers. **[9]**

Fig 8 Three-point bending test of steel rebar reinforced concrete beams for a) rebar placed at bottom (TP∥-Bar@layer3 and TP⊥-Bar@layer3) and b) rebar placed at top (TP∥-Bar@layer6 and TP⊥-Bar@layer6). **[9]**

Due to its lightweight and quick manufacturing, reinforced 3D printed concrete (3DPC) truss structures are becoming popular load-bearing systems. Unfortunately, their reinforcing design and structural performance are little understood. The WANG et al. process includes topology optimization, reinforcement design, and structural performance assessment for 3DPC truss beams to improve design approaches (Fig 9). This technique optimises tension and compression struts for weight reduction and stress transmission depending on printing limits. Stress flow analysis determines reinforcement that makes unreinforced trusses load-bearing and ductile. Tests and finite element model simulations show that topology optimized 3DPC truss beams may increase strength-to-weight ratio by 94% while retaining failure deflection-to-weight ratios equivalent to reinforced concrete beams (Fig 10). **[10]**

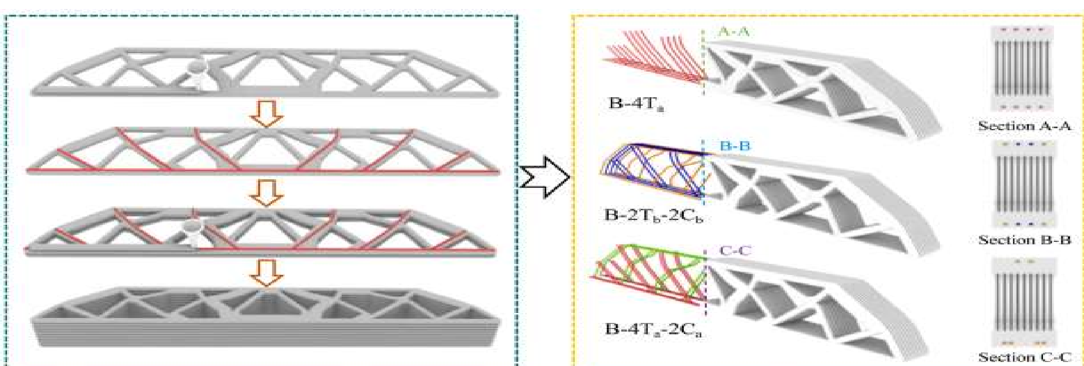

Fig 9 Specimens fabrication process and design. **[10]**

Fig 10 Reinforcement placement for different configurations. **[10]**

In 3D concrete printing, automation and structure integration are key problems for reinforcement bar positioning. An autonomous robot system uses BIM to generate paths and a deep learning model to recognize rebar. **[5]**

Reinforcement bar integration in 3D concrete printing (3DCP) involves placement, bonding, and automation issues. These challenges must be addressed to improve printed component structural integrity and performance.

3.2.3 Limited adhesion between steel and printed 3d concrete in construction

LIU et al. describe spray-based 3D (S-3D) concrete printing method for synchronous reinforced concrete construction. Reinforcement is included into S-3D printed 2.5D rebar concrete design by the authors. They found that 2.5D rebar mesh improves early stiffness, ductility, strain propagation, and ultimate load capacity of printed concrete slabs by 19.04%–81.12% compared to 2D mesh. This approach proves S-3D printing reinforcement and automates large-scale rebar concrete buildings(Fig 11). **[6]**

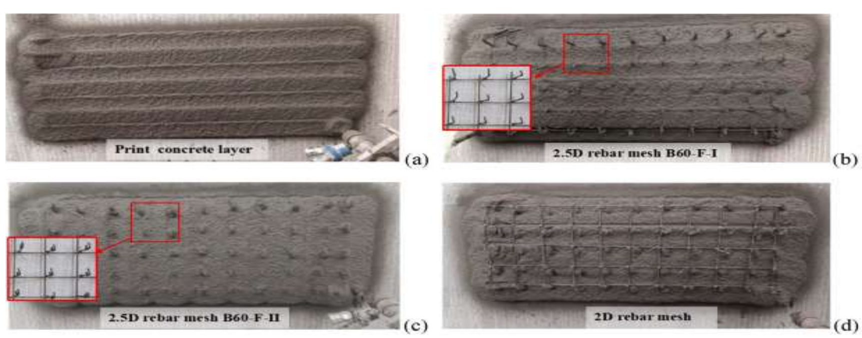

Fig 11 Process of printed concrete slabs with different types of hooks. **[6]**

SHAHZAD et al. used a validated finite element model to study steel reinforcing bar pull-out in 3D-printed concrete (3DPC). The study examines concrete-to-concrete contacts' peak load, slide behavior, failure causes, and damage criteria. Mold-cast specimens had a 9.38% greater load-bearing capacity than interlayer and 25% above interstrip 3D printed specimens, while 3DPC has lower starting stiffness. Print angle decreases from 0° to 30° and increases to 90°, when peak load is highest. For stress concentrations, specimens at 30° have the most damage, while those at 90° have the least. Peak load capacity increases with layer size, and specimens with a 50 mm bond length perform best, providing valuable insights for future 3DPC modeling of concrete surfaces (Fig 12). **[11]**

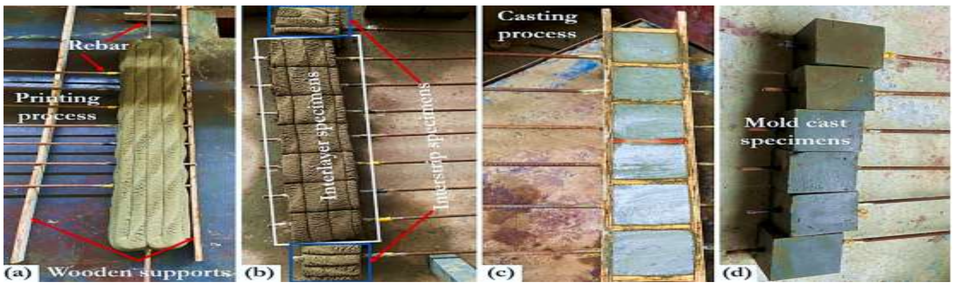

Fig 12 Printing and casting of specimens: (a) 3D printing and rebar placing process; (b) 3D-printed specimens; (c) casting of mold cast specimens; and (d) mold-cast specimens. **[11]**

According to CAO et al., 3D-printed concrete without reinforcements, especially vertical reinforcement, is problematic. They recommended injecting high-flowability material to join reinforcement segments to build a mortar reinforcing mesh in-situ(Fig 13). This flexural testing method used parallel and interlaced epoxy-coated steel fibers in beams. In-situ mesh outperformed independent reinforcements in flexural strength by 123.6%. The high-flowability epoxy filled concrete gaps during fabrication, proving multi-directional reinforcement integration in 3D-printed concrete structures and the practicality of 3D printing (Fig 14). **[7]**

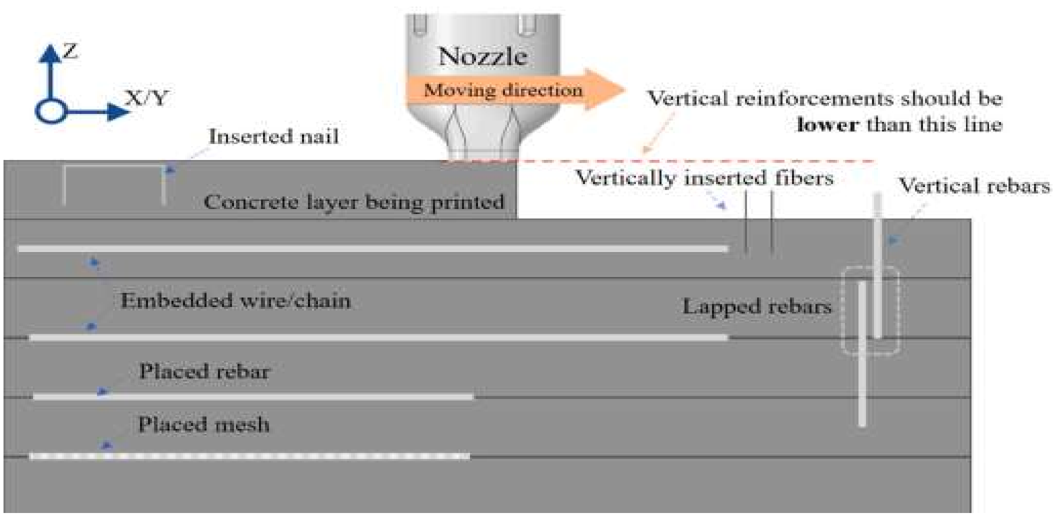

Fig 13 Current post-reinforcing techniques and reinforcement positions **[7]**

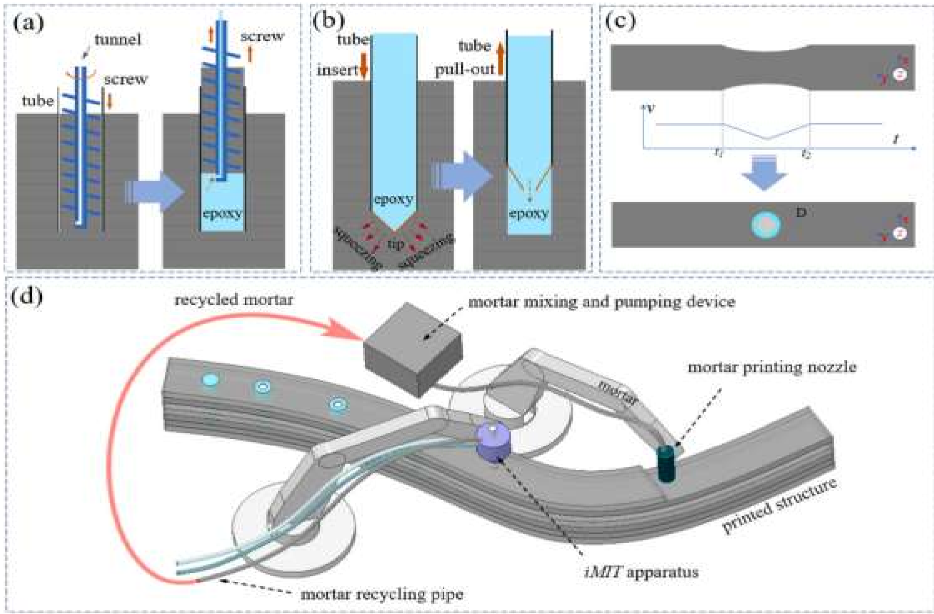

Fig 14 Illustration of the hybrid printing and reinforcing system. (a) tube insertion method, (b) mortar dispersing method, (c) mortar geometry control, and (d) demonstration of the mortar dispersion and recycling. **[7]**

Mechanical and chemical interactions at its contact limit steel-printed 3D concrete adherence in building. This is crucial for improving the performance and longevity of hybrid structures incorporating both materials.

<u>3.2.4 Difficult synchronization between printing and rebar in 3d printing concrete in construction in construction</u>

Steel cable bonding in fresh mortar and 3D printed beam flexural behavior.

LIU et al. use steel wires in printed mortar strips to enhance concrete printing path-following. They tested mortar bonding with 0.5 mm, 1 mm, and 1.5 mm steel cables using pull-out and four-point bending (Fig 15). 0.5 mm and 1 mm cables maintained buildability within open-time restrictions, while 1.5 mm cables bounced off the mortar, impairing reinforcing feasibility. Bonding strength was 1.4–2.4 MPa, lower than concrete reinforcement. Flexural strength increased up to 90%, and ductile fracture modes were detected. This method shows that 3D printing can improve reinforcing methods (Fig 16). **[12]**

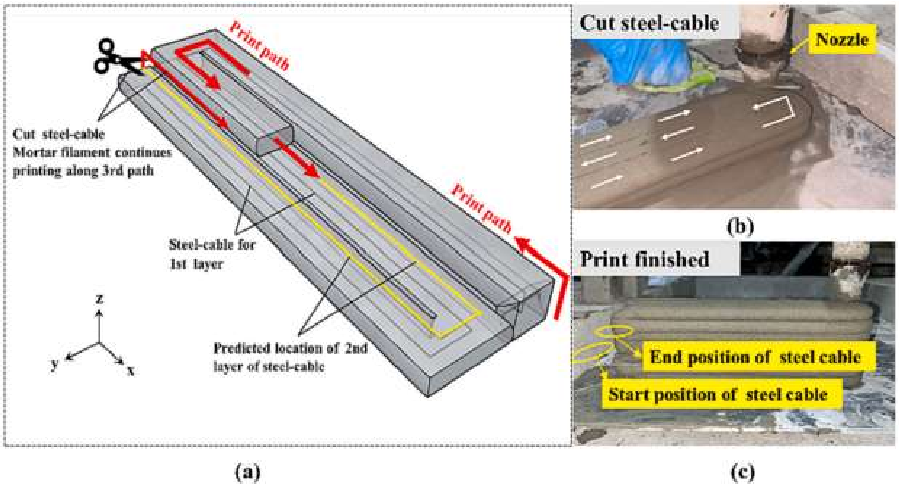

Fig 15 Print Path Schematic for four-point bending test specimen (a) Printing path; (b) Cut steel cable; (c) Finish printing **[12]**

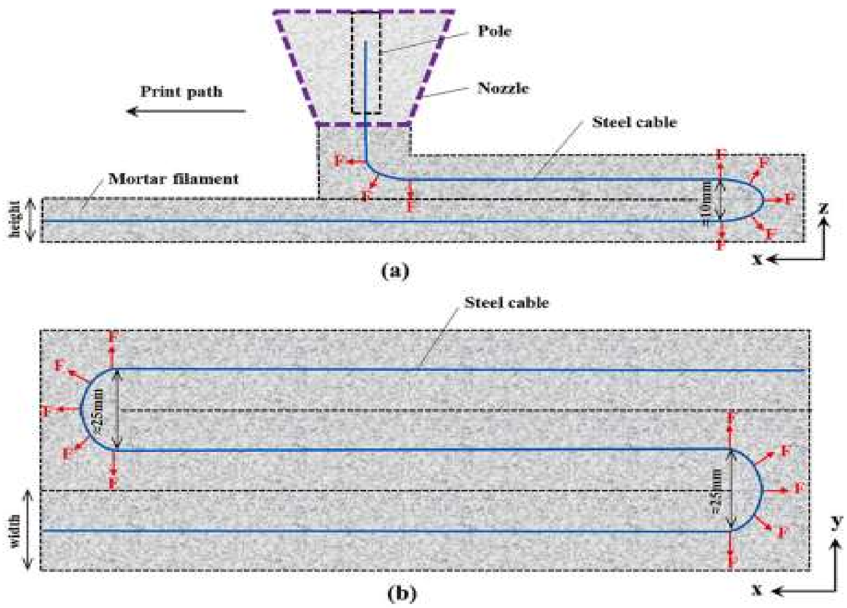

Fig 16 Schematic of bending resilience of steel cable at turns in print path (a) xoz plane; (b) xoy plane **[12]**

The buildability and flexural properties of 3D printed recycled mortar reinforced with synchronized steel cable under different reinforcement ratios.

LIU et al. used 30% recycled sintered brick powder in their mixture and modified their printing apparatus to enable synchronized reinforcing of 3D printed mortar with steel cables(Fig 17). It was discovered that the ideal range for open time was 10 to 40 minutes. About 2 to 2.5 MPa of binding strength existed between the cables and mortar. Multiple fractures appeared at mid-span during failure, and flexural strength saw a rise of 172%

to 357 percent. Within a 12% inaccuracy of test data, a flexural strength adjustment formula produced results(Fig 18). **[13]**

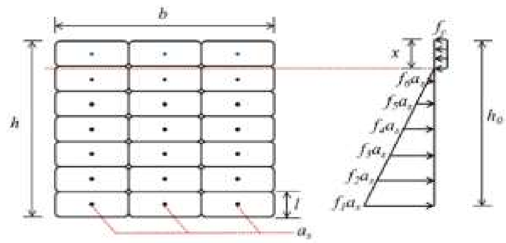

Fig 17 The stress diagram of the bending section. **[13]**

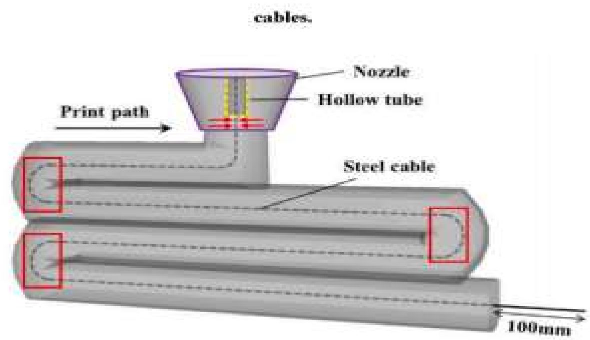

Fig 18 Schematic diagram of steel cable reinforcement printing process (red wireframe shows anchoring formed by steel cable at turning and climbing). **[13]**

In 3D concrete printing, rebar placement and printing synchronization affect structural integrity and efficiency. The ultimate structure's performance depends on the incorporation of reinforcement materials.

3.2.5 Rebar durability problems (corrosion, coating, fractures) in 3D-printed concrete for building.

Steel bars in reinforced concrete corrode in severe situations, reducing structural longevity. Using a phase field technique (PFM), YUAN et al. examine how corrosion morphology, cover thickness, concrete strength, heterogeneity, steel bar diameter, and aggregate content affect concrete damage. They found that corrosion morphology and concrete heterogeneity considerably impact durability and damage susceptibility. Concrete strength has little influence, although lesser strength increases cover failure risk. Cover thickness and steel bar diameter hardly affect durability and failure. While aggregate content does not correlate with longevity, aggregate distribution greatly affects it. For concrete structure engineering and durability evaluation, the study provides crucial information. **[14]**

ZHANG et al. report that concrete 3D printing is a major technology in the construction industry's focus on digitalisation and sustainability. The durability of 3D printed cement-based materials (3DPCM) remains unknown, preventing its usage in load-bearing constructions. **[15]** ZHANG et al. tested 3DPCM durability in 15 labs in 13 countries for water absorption, carbonation, and chloride intrusion. Water absorption tests show bulk porosity, whereas carbonation and chloride tests show local flaws (Fig 19). Cast samples had more water penetration than ordinary concrete, but equivalent carbonation and chloride resistance. Anisotropy hampered 3DPCM longevity, although better mixture design and processing helped. Carbonation depth measurements revealed cold connections in three cross-section geometries due to printing variations. We also suggested methodological changes for future study. **[15]**

Fig 19 Sacrificial anodic cathodic protection structure schematic **[15]**

WANG et al. claim that corrosion of steel rebar shortens the lifespan of reinforced concrete structures and poses a safety concern to structural engineering. The research examines passivation and corrosion mechanisms, focusing on chloride ion penetration and concrete carbonization. It suggests methods for extending concrete's lifespan, such as strengthening protective coatings and rebar's resistance to corrosion. The research also describes required corrosion testing methodologies and uses X-CT to analyze steel bar corrosion byproducts and interfaces. It emphasizes corrosion studies and microstructural qualities and suggests further study. **[16]**

TAHERI-SHAKIB et al. study how pit distribution influences concrete pore architecture and crack propagation during galvanostatic accelerated corrosion. One sample had bigger, scattered pits, whereas the other had smaller, concentrated pits. X-ray CT, SEM, EDS, and Raman spectroscopy showed that bigger pits formed only iron hydroxides, while smaller pits formed both oxides and hydroxides. Crack patterns differed significantly: samples with dense pit distribution exhibited cracks from pore closeness to reinforcing bars and wider outward-diffusing cracks, whereas samples with less pits had a different crack pattern. Also, elemental mapping showed increased corrosion product concentrations near fissures, suggesting water movement into the concrete matrix. These studies help improve infrastructure longevity by enhancing concrete degradation knowledge. **[17]**

According to CADENAZZI et al. rebars made of hemp fiber-reinforced polymer (HFRP) are a sustainable substitute for glass fiber-reinforced polymer (GFRP) and carbon steel (CS) in concrete reinforcement. After testing the mechanical properties and sustainability of HFRP rebars, the study concludes with a simulated tensile test that shows HFRP's tensile strength is superior to GFRP and on par with CS 235, but with somewhat less stiffness. Graphene fiber integration might improve mechanical properties. For applications requiring moderate strength and endurance, HFRP rebars are economical, lightweight, and environmentally benign. Large-scale production trials and long-term durability studies in challenging settings are required to support the use of HFRP rebars in infrastructure projects. **[18]**

ZHAO et al. emphasize the importance of selecting the right coating technology and ensuring quality control for effective anti-corrosion protection. China recommends two or three layers with defined kinds and thicknesses, whereas international standards are less specific. Long-term stability is improved by multilayer systems 82% chloride ion penetration resistance and 50% mass loss reduction from freeze-thaw cycles. Cross-border projects require standardized suggestions and quality control systems to increase coating technology applicability and dependability due to national standard differences. **[19]**

Conclusion

Innovation in materials for 3D concrete printing is revolutionizing the construction sector by improving productivity, offering greater architectural freedom, and enhancing durability. However, for this technology to become a reliable and widely adopted standard, it is essential to continue research on several critical aspects such as interlayer strength, durability, material reinforcement, mixture stabilization, and process standardization. Addressing these technical and scientific challenges is crucial to enable 3D concrete printing to evolve from an emerging technology to a fully mastered and sustainable solution for the future of buildings. This transition could transform not only construction methods but also the standards that underpin the modern construction industry.

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