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Experiment with carbon capture and sequestration technology with 3DPC structure

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ABSTRACT: About 7–8 percent of the world's carbon dioxide emissions come from cement production, which in turn comes from the building industry. 3D concrete printing (3DCP) is a new technology that has a lot of potential benefits, like less material waste and more design freedom. Nevertheless, the use of cement is still significant, which means that the environmental problems caused by traditional concrete are still present. A long-term strategy to lessen the negative effects on the environment is being explored in this project through the incorporation of carbon capture and sequestration (CCS) technology into 3D-printed concrete buildings. The project seeks to enhance material performance while minimizing CO₂ emissions during printing by exploring the use of alternative low-carbon materials like geopolymers, alkali-activated materials (AAMs), and recycled aggregates. To further lessen the environmental impact of 3D printed concrete, we also look at mineral carbonation and CO₂-enhanced curing as potential solutions. This study's findings show that 3D printing with CCS technologies and sustainable materials could drastically reduce construction-related carbon emissions without sacrificing print quality, performance, or longevity. In order to lessen the negative effects on the environment caused by the building sector, this study paves the way for 3D concrete printing methods that are less harmful to the environment.

I. INTRODUCTION

In comparison to previous years, the number of articles on 3D concrete printing is growing at a rapid pace. Analysis of the 3D printable mix's early age properties is the main focus of the research teams. These properties are critical for meeting the printing process's criteria. On the other side, research groups are working to enhance the 3D printed mixtures' hardness and durability characteristics. However, the aforementioned research assesses the features of constructions that are 3D printed. Note that high-performance concretes, which include a lot of cement and are bad for the environment, were the main material choice for 3D printing at first. However, the rheological properties of the printing mixture—an important process parameter—are positively affected by the increasing presence of binders. One of the leading causes of anthropogenic CO₂ emissions, the cement industry is responsible for massive quantities of the gas due to its production processes. The special character of the manufacturing processes, which result in high CO₂ emissions, is the root cause of this link. As of 2019, the cement and concrete sector was estimated to be responsible for approximately 10% of the world's CO₂ emissions from electricity consumption, carbonate breakdown, transportation, manufacture, and demolition. The cement industry is responsible for around 7% of the world's anthropogenic carbon dioxide (CO₂) emissions, making it a crucial player in this arena (IPCC report).

Cement isn't the only business with environmental problems; aggregate is another contributing element. The pumping technique often requires the use of just fine aggregate in 3D printed concrete. Similarly, the aforementioned aggregate is almost depleted. Aggregate is the most volumetrically used material in concrete, it should be highlighted. There have been permanent alterations to the ecosystem as a result of the mining of this material.

The whole field of civil engineering is now focusing more and more on sustainability considerations. This idea incentivizes businesses and academics to find long-term solutions for 3D printing materials. These previously mentioned difficulties have been addressed in existing research on multiple occasions. Conclusions and new lines of inquiry must still be considered, though. In this article, we will take a quick look at the material and technological components of 3D printed concrete's sustainable approach. A fresh path for research is laid forth by the work that has been presented. Cementation material printing via extrusion is the sole subject of this article.

1.2 Problem statement

3D concrete printing's (or 3DCP) meteoric rise has brought forth some exciting new developments in the building sector, especially with regard to material efficiency and design versatility. Significant environmental problems,

however, are preventing the broad use of 3D printed concrete. Because of the energy required to produce them, traditional 3D printing technologies rely significantly on high-performance concretes containing a high proportion of cement, which are a big source of CO₂ emissions worldwide. Another factor that contributes to irreparable environmental damage and the loss of natural resources is the usage of fine aggregates, which are necessary for the pumping process in 3D printing.

The environmental impact of both the material production and the 3D printing process has not been fully addressed by the current crop of sustainable 3D printing materials, including low-carbon cements, alternative binders, and recycled aggregates. In addition, there is a lack of study on the environmental sustainability of 3D printing mixes over the long term, and most of what is available focuses on how to improve their rheological, early-age, and toughened qualities.

II. LITERATURE REVIEW

- **Environmental Challenges and 3D Concrete Printing**

Among the many advantages of 3D concrete printing include shorter building timeframes, more design freedom, and less material waste. Nevertheless, cement remains an essential component, much like in conventional concrete manufacturing, and its use is associated with increased energy consumption and greenhouse gas emissions (Mehta, 2016). Because of its high cement content, high-performance concrete—the material most commonly used in 3DCP—has a negative impact on the environment. Another environmental worry is the demand for fine aggregates in 3D printing, which is becoming worse due to the scarcity of these materials and the irreparable harm they create during extraction (Aïtcin, 2016).

Alternatives to conventional cement, including as geopolymers, alkali-activated materials (AAMs), and recycled aggregates, have been the primary focus of research into sustainable 3DCP materials. These substitutes try to lessen the impact of carbon dioxide emissions without sacrificing or improving the material qualities needed for 3D printing. 3D concrete printing has the potential to significantly reduce carbon emissions if these materials are used (Khan et al., 2018).

- **Securing Carbon Emissions from Concrete**

There is hope for a solution to the environmental problems caused by CO₂ emissions through the use of CCS technology in the cement and concrete sector. Carbon capture and storage, or CCS, is the process of removing CO₂ from the air by collecting it where it is produced and then storing it in a stable form. Incorporating carbon dioxide (CO₂) into newly mixed concrete causes it to react with calcium silicate minerals, resulting in the formation of stable carbonates; this process is one of the most studied CCS methods used to produce concrete. Curing speeds up this process by incorporating CO₂ into the material (Gartner, 2016).

Carbon dioxide (CO₂) accelerated curing is a further possible CCS approach for 3DCP. This method involves either injecting CO₂ into the curing chamber or embedding it in the printing material while it is being 3D printed. By improving the carbonation process, this not only reduces CO₂ emissions but can also increase the concrete's strength and durability (Purnell et al., 2017).

- **Eco-Friendly Substrates for Printing Concrete in Three Dimensions**

Sustainable 3D printed concrete research has focused heavily on investigating low-carbon materials. An eco-friendly substitute for conventional cement, geopolymers are produced from waste items such as slag or fly ash. According to research (Davidovits, 2008), these materials offer better or equivalent mechanical qualities, less carbon dioxide emissions, and longer lifespans.

AAMs, or alkali-activated materials, are an additional viable option. The process of creating AAMs involves using an alkaline solution to activate alumino-silicate materials like slag, fly ash, or metakaolin. According to Palomo et al. (2014), these materials have the potential to produce 3D printed concrete with 80% less carbon dioxide emissions than Portland cement. Additionally, 3D printed concrete that uses recycled aggregates might lessen the need for raw materials, which in turn helps to lessen the environmental toll of aggregate mining (Shao et al., 2020).

- Difficulties and Paths Ahead

Combining carbon capture and storage with 3D printed concrete could have several advantages, but there are a number of obstacles that need to be overcome first. The rheological behavior of environmentally friendly materials is a major obstacle. The printability and performance of materials like geopolymers and AAMs in 3D printing might be impacted by their flow characteristics, which differ from those of standard cement-based concrete (Le et al., 2020). Another unanswered topic is whether or not carbon sequestration methods can scale to accommodate massive 3D printing projects. To optimize these approaches for industrial-scale applications, further study is required, while laboratory-scale experiments have showed encouraging results.

Another thing to think about is how much it will cost for sustainable 3D printed concrete materials. This is especially true for ones that use CCS technology or alternative binders. Although the environmental benefits of these materials are obvious, their widespread use may necessitate new developments in material processing and ways to reduce costs, as they are sometimes more expensive than regular concrete (Haszeldine, 2009).

III. PROPOSED METHODOLOGY

One new area that has great promise for reducing construction-related carbon emissions is carbon capture and sequestration (CCS) technology for 3D-printed concrete buildings. To improve environmental performance and tackle global climate change problems, this strategy is being integrated with sustainability concepts. We'll take a closer look at this technology, dissecting it to see how 3D-printed concrete buildings can be used for carbon capture.

The Impact of Concrete Production on Carbon Emissions

A considerable amount of the world's carbon dioxide (CO₂) emissions come from the conventional method of making concrete. Cement, an ingredient in concrete, is a significant carbon dioxide (CO₂) emitter. The chemical reaction (the breaking down of limestone to create lime) and the energy-intensive manufacturing process both contribute to the release of carbon dioxide into the atmosphere throughout the cement production process.

Using 3D Printing for Building Projects

The use of large-scale printers and 3D printing technologies in the construction industry allows for the layer-by-layer creation of structures, usually out of concrete or specific combinations. Several benefits may be available using this approach: Less material waste: Unlike conventional building processes, only the precise amount of material required is printed. One advantage of 3D printing is the design versatility it provides. Unlike traditional methods, it allows for the creation of detailed, personalized shapes. Energy efficiency: The accurate deposition of materials during 3D printing has the potential to lower energy consumption. The utilization of traditional concrete mixtures—which are carbon-intensive—in 3D printed products is still an issue.

Using 3D-Printed Concrete with Carbon Capture

- Concrete's Capture of Carbon

Making changes to the concrete mixture is the initial step in lowering the solution's carbon footprint: Concrete undergoes a natural process known as carbonation, in which it absorbs CO₂ over time. Use of less energy-intensive geopolymer cements or alkali-activated materials, which can sequester more carbon as they cure, is being considered as a way to improve upon this natural process, according to recent research. Materials With Carbon Infusions: Carbon dioxide (CO₂) is being investigated by several businesses as a potential concrete curing agent. Injecting carbon dioxide gas into new concrete causes it to react with minerals, creating solid carbonates; this process is called CO₂ mineralization. The concrete then stores the CO₂ it contains. By incorporating this step into 3D printing, the produced structure can have less of an effect on the environment.

- CCS Methods for Making Concrete.

The process of Direct Air Capture (DAC) was: Direct Air Capture is an attractive technique for large-scale carbon capture and storage since it removes CO₂ directly from the air. The CO₂ that is collected can subsequently be utilized in the making of concrete or even injected into rock formations to be stored for the future. The point source capture technique is useful for removing CO₂ emissions from factories that produce them in large

quantities, such as cement factories. One possible use for the collected CO₂ is in the production of 3D-printed concrete, although it can also be stored for later use.

- **Eco-Friendly Staples and Supplies.**

To lessen concrete's impact on the environment, scientists are increasingly looking for binders other than Portland cement: Geopolymers are binders that use industrial by-products like slag or fly ash, which are less carbon intensive than cement.

The direct use of carbon dioxide in the production of carbonated cement has the potential to transform waste carbon dioxide into a valuable commodity. A number of businesses have begun testing this method. Bio-concrete: Alternatives based on biological materials are also being studied; in this case, certain bacteria are utilized to boost the carbonation process in concrete, which aids in carbon sequestration and keeps the structure intact.

- **3D Printing Closed-Loop Systems.**

It is possible to capture and utilize the carbon emissions that are produced during the manufacturing of concrete or 3D printing in a closed-loop system. Injecting collected CO₂ emissions from the 3D printer or the curing process back into the manufacturing cycle to capture them in the finished product is one possible implementation of such a system.

A Carbon Capture Approach with a Sustainable Methodology 3D-printed concrete buildings could use a sustainable carbon capture sequestration technique in the following ways:

1. **The Design Process:**

Making Eco-Friendly Decisions Architects and engineers can maximize material efficiency during the design phase of a 3D-printed concrete structure by reducing the volume of concrete required while maintaining strength and stability. The use of generative design software, which aids in the creation of structures with optimal use of materials, could make this a reality. **The Selection of Low-Carbon Materials:** Consider geopolymer concrete, recycled aggregates, or carbon-reduced cement as low carbon substitutes for traditional concrete.

2. **Getting the Materials Ready:**

Carbon Sequestration in the Compound: Incorporate carbon capture methods, such as CO₂ mineralization or CO₂ curing, into the 3D printing material preparation process directly. This aids in lowering the project's total carbon emissions right from the bat. One way to improve the carbon sequestration potential of the aggregate materials used in 3D printing is to pre-treat them with CO₂.

3. **Real-Time Carbon Capture in the 3D Printing Process:**

Set up mechanisms to collect carbon dioxide gas that is released while the printer is working. Other carbon usage technologies like carbonation could make use of this acquired CO₂. **Energy Efficiency:** To further decrease the project's carbon impact, employ renewable energy sources like solar or wind power to run the 3D printers. After the building is printed, add CO₂ to the curing atmosphere to promote improved carbonation. This can help sequester more carbon in the concrete and is the fourth method for post-construction carbon sequestration.

4. **Tracking the Removal of Carbon:**

Create means of tracking the quantity of carbon dioxide (CO₂) absorbed and preserved by the 3D-printed concrete. The effectiveness of the carbon capture method can be demonstrated with the use of this data.

5. **Discussion of Obstacles and Plans for the Future.**

The use of 3D-printed concrete for carbon capture and sequestration has great promise; yet, there are still numerous obstacles to overcome: **Scalability:** Prior to their potential large-scale application in building, numerous carbon capture technologies are still in the experimental stage and may require more optimization. A higher initial investment may be required for projects that use carbon capture technologies, use alternative materials, or make use of sophisticated 3D printing methods. Environmental advantages and regulatory incentives might eventually outweigh these expenses. Clear standards and certifications for low-carbon concrete products, especially those involving CO₂ sequestration, are necessary for the construction sector to guarantee that these approaches meet safety and quality standards.

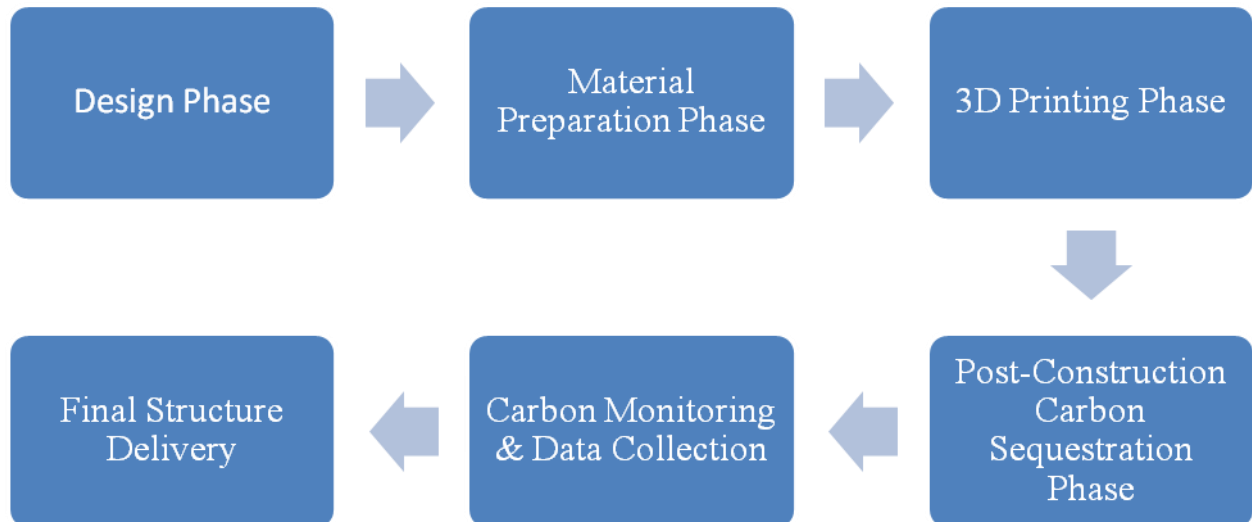


Fig 1. Flowchart of methodology for project.

IV. CONCLUSION

One promising way to lower carbon emissions associated with construction is to incorporate carbon capture and sequestration (CCS) into 3D-printed concrete. Through the use of CO₂ mineralization, low-carbon binders, and effective design techniques, this method preserves structural integrity while improving sustainability. Continued research and policy support can assist mainstream this technology, making construction more environmentally friendly and climate change resilient, despite obstacles like cost and scalability.

Notwithstanding its potential, there are still issues with scalability, high startup costs, and the requirement for rules and standards that apply to the entire sector. Making 3D-printed carbon-sequestering concrete a common solution in the building industry will need addressing these problems through ongoing research, technical developments, and legislative assistance. In the end, this creative strategy advances the battle against climate change and opens the door for more economical and environmentally responsible construction methods.

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