# Sustainability in 3D Concrete Printing (3DCP): Literature Review

**Christian Felipe Bunch Acevedo**[1]

[1]International Management Master's program, Universidad de La Sabana;
christianbuac@unisabana.edu.co

**Abstract:** 3D Concrete Printing (3DCP) is a new construction method that has great potential to disrupt the construction industry. This paper is focused mainly on the sustainability discussions that are currently taking place in the academic space. A visual map of current publications was developed using VOSviewer and Scopus. With the use of this tool, three clusters and leading countries were identified as main topics for current analysis where authors are discussing the sustainability aspects of this technology.

**Keywords:** Literature Review, 3D Concrete printing (3DCP), Sustainability, VOSviewer, Scopus

## 1. Introduction

### 1.1 Context

In 2019, the International Energy Agency and the United Nations Environment Programme (2019) reported that overall, within the construction industry, both residential and non-residential, along with the estimated portion of the industry focused on manufacturing of the required building materials composed the largest energy use (36%) and $CO_2$ emissions (39%) for 2018. The remaining share of energy consumption and $CO_2$ emissions belong to the transport of materials and other external factors from the construction industry. Additionally, for reducing the carbon impact. In past years, the objective of improving the environment and producing low-energy buildings has led to advancement in renewable energy usage and

has given way to innovation in designs, materials, construction methodologies and new technologies (REN21, 2021; Shrubsole et al., 2019)

One of the most relevant and recent innovations in the construction industry involves the implementation of additive manufacturing (3D printers) for concrete printing of housing and other structures. The American Society for Testing Materials (ASTM) International (2013, p. 1) defines 3D printing as "the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology". In this case, the material used in 3D printing is concrete. This new application of 3D printing has great potential, as:

> The construction industry is one of the most inefficient industries; hence, 3D printing technology may disrupt the construction industry operationally and economically. Prior research has shown that complex large-scale structures can be produced with 3DCP technology, and besides introducing automation, the technology can have social and design flexibility benefits. (Khajavi et al., 2021, p. 2)

When trying to achieve a more sustainable construction, concrete is not the only material that can be used. Aggregate materials such as fly ash, geopolymers and recycled glass can be used in conjunction of concrete to decrease the carbon footprint of this construction method (Tay et al., 2019, p. 2). Additionally, Mohammad, Masad, & Al-Ghamdi discusses benefits of this technology in terms of safety on-site, reduction of environmental impact in the construction industry and flexibility in design processes (2020).

### 1.2 Research Problem

With the potential of 3D printing in the construction industry, research in several knowledge areas, such as engineering, business management, environmental sciences, or social sciences

is thriving. Each of them having a different perspective of this technology and finding benefits and challenges for their specific sectors. When reviewing the sustainability analysis of 3D printing used in the construction industry, limited literature that merges what is being studied in this sub-field exists.

### 1.3 General and Specific Objectives

The intend of this literature review is to visually explain a perspective of which aspects of sustainability in the 3D Concrete Printing (3DCP) in the construction industry are being studied and providing an insight on why these investigations are making this technology increasingly attractive for construction companies across the globe and how can these subjects be used for managerial purposes. Determining a base for future studies on the sustainability of 3DCP with a business perspective. Specifically, this paper intends to achieve the following objectives.

- Define a search equation to be used in Scopus to extract the relevant publications.
- Develop a visual map which contains the relevant terms being studied around 3DCP and sustainability.
- Define clusters that can summarize the map and provide a general approach to the main subjects being discussed by academics.
- Provide an insight on which are the latest aspects that surround sustainability being studied.
- Create a talking point for managerial understanding of current developments on 3DCP and its sustainability aspects.

## 2. Methodology

## 2.1 Search Equation & Data extraction

To identify the articles that are referring to concrete 3D printing in the construction industry, a search equation which allowed to correctly filter the literature to be reviewed was necessary.

$$SE = \Big(ABS\big((3DCP\ OR\ \text{concrete 3D printing} OR\ \text{3D concrete printing} OR\ \text{concrete printing}) AND\ (Sustainability)\big)\Big)$$

$$OR\ \Big(KEY\big((3DCP\ OR\ \text{concrete 3D printing} OR\ \text{3D concrete printing} OR\ \text{concrete printing}) AND\ (Sustainability)\big)\Big)$$

$$OR\ \Big(TITLE\big((3DCP\ OR\ \text{concrete 3D printing} OR\ \text{3D concrete printing} OR\ \text{concrete printing}) AND\ (Sustainability)\big)\Big)$$

$$OR\ (AUTHKEY((3DCP\ OR\ "concrete\ 3D\ printing"\ OR\ "3D\ concrete\ printing"\ OR\ "concrete\ printing")\ AND\ (Sustainability)))$$

This equation considers the multiple terms that 3DCP is commonly referred to and constrains is exclusively to sustainability subjects. The limiter factors in the equation were “ABS”, “KEY”, “TITLE”, and “AUTHKEY”. These field codes guarantee that the search yields result from the abstract, keywords, titles, and author keywords. This is particularly useful as the visual map requires these terms to be included in the keywords of the extracted articles. Which narrowed down the results mainly from engineering studies. The resulting search equation was used in Scopus to retrieve the article keywords. Building a database to compare and identify the sustainability aspects surrounding 3DCP.

With the search equation was fully defined, it was used in Scopus advanced search, looking for the terms in article titles, abstracts, and keywords. From this search, 39 articles were identified and the bibliographical data was downloaded in .ris format.

## 2.2 Keyword co/occurrence analysis

The chosen software to process the bibliographical data retrieved was VOSviewer. This software creates a network between the data and creates visual maps to identify the clusters

that it generates (Van Eck & Waltman, 2020). For this case, a keyword co-occurrence methodology was chosen. This methodology relies on the number of times a specific keyword is mentioned in the bibliographic database, creating a visual cluster network with the co-occurrences.

From the 39 articles, 348 keywords were identified. To organize the data, a thesaurus was designed to adjust the bibliographic data which is later included in VOSviewer to create more organized and easier to interpret models. The thesaurus additionally removed the keywords "3DCP" and "sustainability" to ensure that clusters between research keywords were formed. Otherwise the visual map would revolve around these terms, negatively impacting the cluster generation.

In VOSviewer, the chosen co-occurrence method was Lin/Log modularity using a factor of attraction of 2 and a factor of repulsion of -1. Clustering used a resolution of 2.00 and a minimum cluster size of 65, with 100 random starts and 100 iterations. From the bibliographic database, 348 keywords with at least one occurrence were used for the analysis. From these settings, the resulting co-occurrence network is presented in Figure 1.

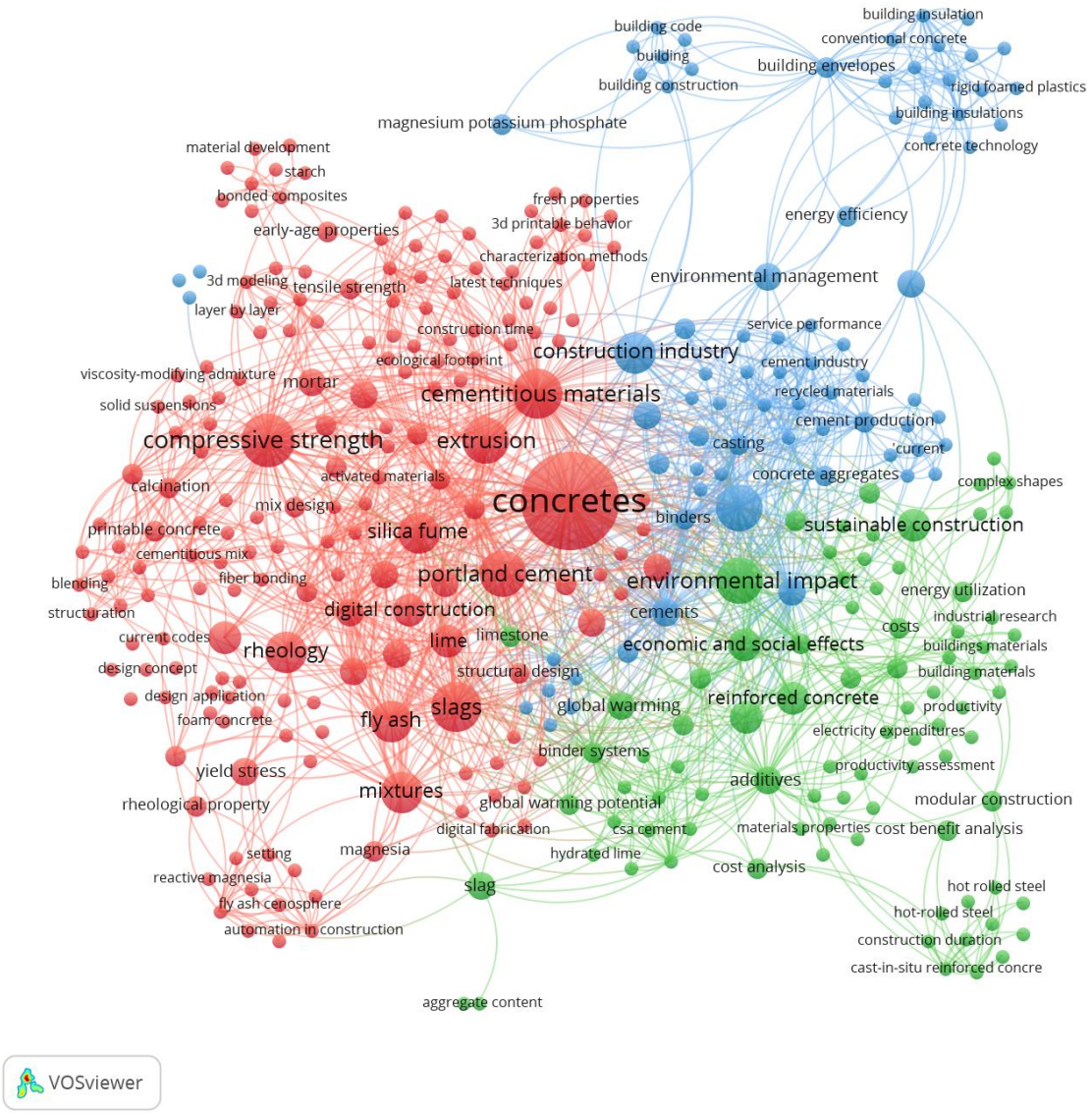


**Figure 1.** Keyword Co-occurrence Network Visualization for 3DCP Keywords

The parameters mentioned above resulted in three clusters which were color-coded and were summarized on Table 1. The terms “3DCP” & Sustainability were removed to clean up the map and provided direct connections between the identified keywords. Cluster 1 integrates the mechanical properties of concrete and cementitious materials, along with their behavior

when used for 3D printing. Cluster 2 includes the environmental, social, and economical aspects of this technology. Cluster 3 has two main factors, the Life-Cycle Assessment (LCA) and the construction industry. This cluster is focused generally on the industry.

| Cluster No. | Color | Description | Main Keywords |
|---|---|---|---|
| Cluster 1 | Red | Mechanical properties of concrete and cementitious materials | Concretes, compressive strength, rheology, extrusion, performance assessment |
| Cluster 2 | Green | Environmental, social, and economical aspects of sustainability in 3DCP | Environmental Impact, sustainable construction, economic and social effects, cost analysis, architectural design |
| Cluster 3 | Blue | Life-Cycle Assessment (LCA) and construction industry | Life cycle assessment, construction industry, cement production, environmental management, environmental performance |

**Table 1.** Co-occurrence clusters generated in VOS Viewer using Lin/Log modularity method

Additionally, VOSviewer provides an overlay visualization where it shows the introduction of new concepts across a timespan. Figure 2. Shows the earliest date identified for the discussion about sustainability on 3DCP being 2016, where the discussion revolved around increased productivity, design and construction among others. A rapid interest in the sustainability surrounding 3DCP is reflected on the color coding of the overlay visualization having recent developments on all three identified clusters. Figure 3. Identified that studies about the sustainability around 3DCP have been increasing ever since. As of May 2022, there have been 39 publications on this subject. Figure 4. Geolocates the source country of these

publications based on the contact address or publisher's address. The publication count distribution can be seen on Table 2.

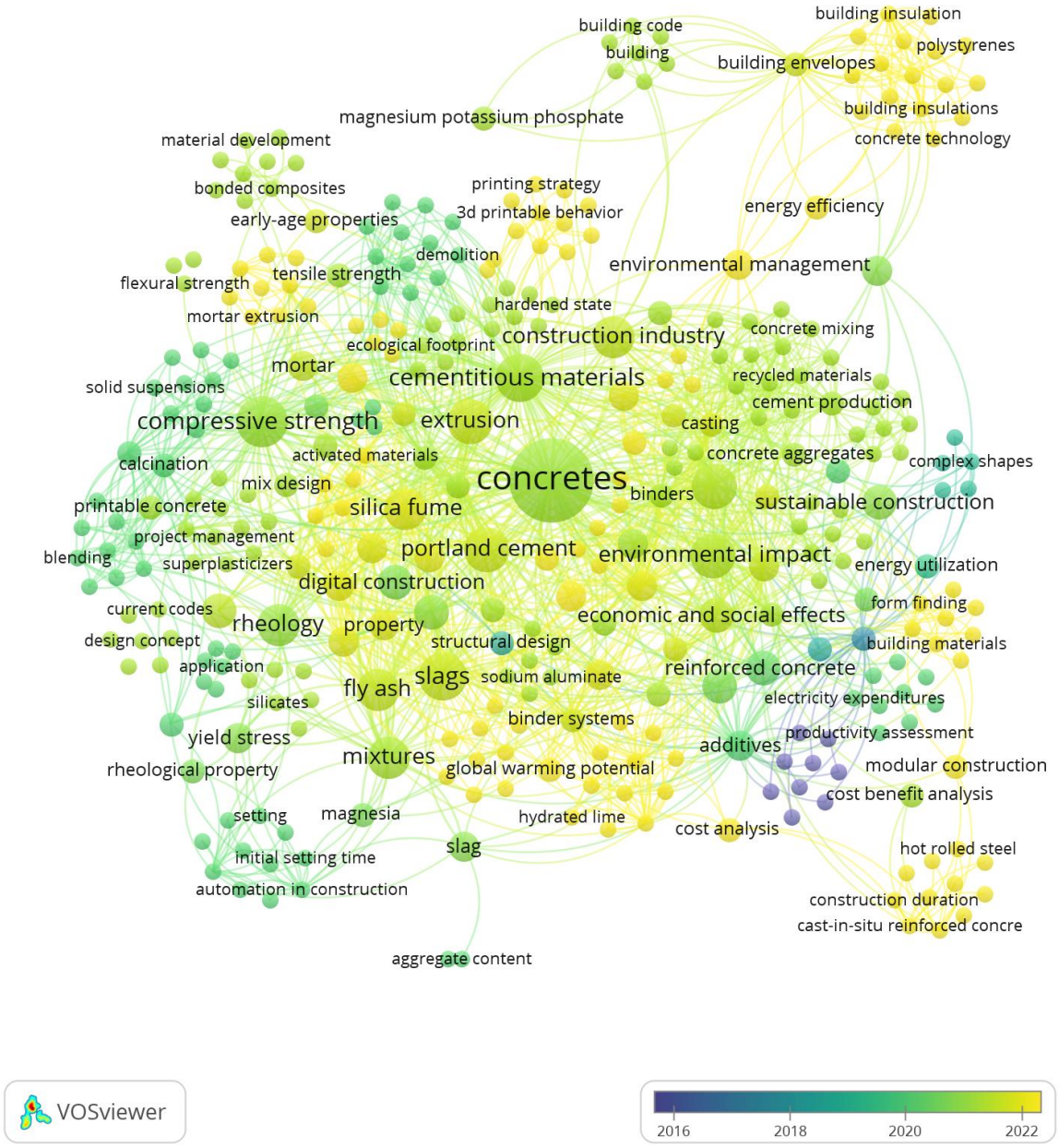


**Figure 2.** Overlay Visualization for 3DCP Keywords

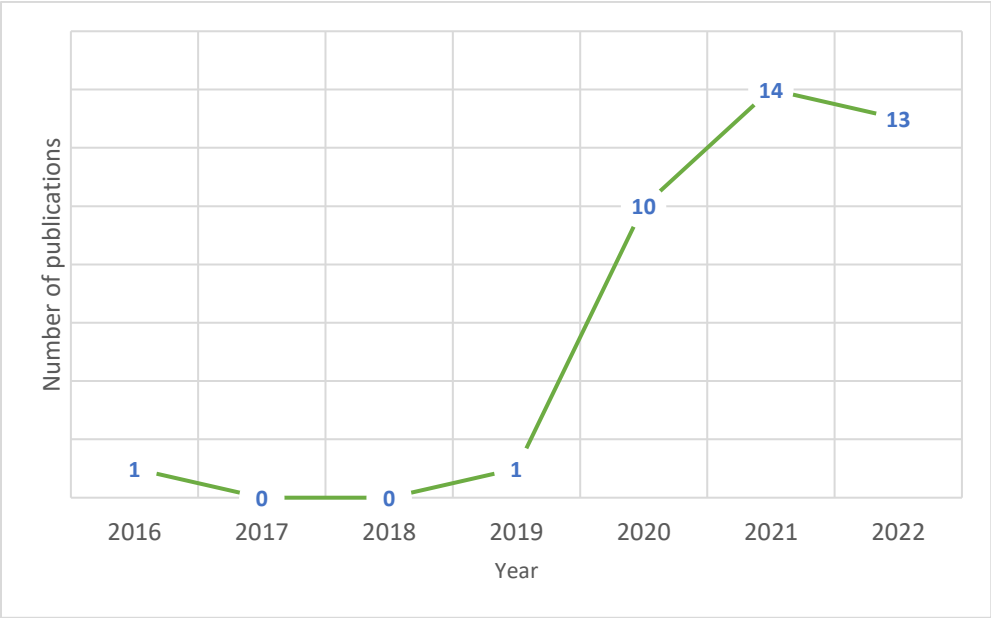


**Figure 3.** Articles mentioning 3DCP and Sustainability in Scopus (Q2, 2022)

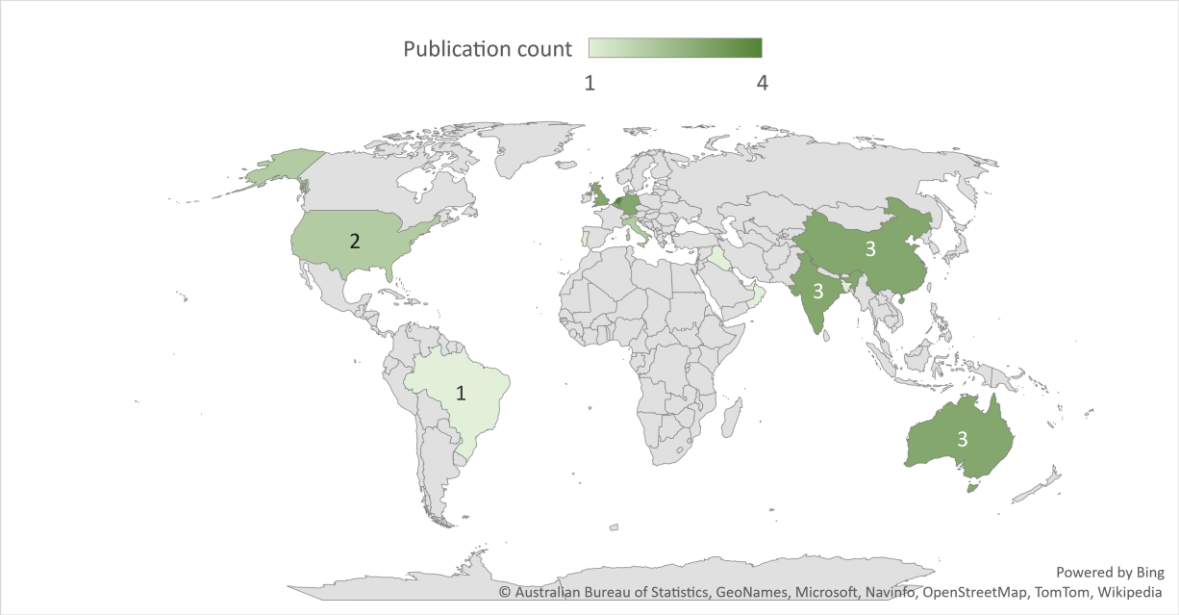


**Figure 4.** Geolocation of Articles mentioning 3DCP and Sustainability in Scopus (Q2, 2022)

| Country | Publication count |
|---|---|
| Netherlands | 4 |
| Australia | 3 |
| China | 3 |
| United Kingdom | 3 |
| India | 3 |
| Germany | 3 |
| Belgium | 3 |
| Singapore | 3 |
| United States | 2 |
| Italy | 2 |
| Qatar | 2 |
| United Arab Emirates | 1 |
| Australia | 1 |
| Brazil | 1 |
| Iraq | 1 |
| Bangladesh | 1 |
| Oman | 1 |
| Portugal | 1 |

**Table 2.** Number of articles mentioning 3DCP and Sustainability in Scopus by country (Q2, 2022)

## 3. Discussion

The keyword co-occurrence analysis provides a base for future publications and allows to visually understand which are the relevant subjects regarding the sustainability of 3DCP. Benefits as the usage of materials that would be otherwise considered unsuitable for the construction can have a major impact on future environmental strategies for organizations (Bai, Wang, Ma, Sanjayan, & Bai, 2021). 3D printing technology can also revolutionize the aspect of constructions while addressing size limitations, materials, and speed of production (Bañón & Raspall, 2021). This technology has the potential to use design techniques mostly used for the car and aerospace industries, biomimicry. Enhancing the structural integrity

while consuming less material, spending less time and effort (du Plessis et al., 2021). It can also have an impact on production and labour costs while decreasing waste (El Sakka & Hamzeh, 2017). Studies have shown that the implementation of supplementary cementitious materials (SCM) provides advantages in terms of durability and sustainability (Dey, et al., 2022). This can be a starting point for construction companies to visualize the benefits that are currently being analyzed to develop internal conversations on the viability of implementing 3DCP in their operations having a strong focus on sustainability.

## 4. Conclusions

This literature review identified a connection of a wide variety of keywords using VOSviewer co-occurrence methodology, three clusters were generated and main talking points for further research were found. It demonstrated that the discussion of sustainability in 3D Concrete Printing (3DCP) is becoming increasingly popular and has captured the attention of researchers with an increasing number of publications on a wide variety of subjects This paper purpose is to be used as a tool for further research, especially for the potential of identifying visually related fields of potential studies and decisions for companies to further explore this technology.

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