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(REVIEW ARTICLE)

A literature review to determine the availability of materials for application in 3D printing processes within the Brazilian construction industry

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Abstract

In the present day, the civil construction industry grapples with various challenges, including low productivity, a shortage of skilled labour, resistance to technological innovations, and significant environmental impacts. Extensive literature underscores the urgency of modernizing the sector by embracing new technologies such as digital prototyping and advanced manufacturing processes. In light of these considerations, this article aims to assess the range of materials available for 3D printing to determine the feasibility of integrating this technology into the Brazilian civil construction industry (BCI). Through a comprehensive analysis of materials currently in use, drawn from scientific research, it becomes evident that mortar-based materials are emerging as a preferred choice for 3D printing components within civil construction. Considering that the Brazilian construction sector already heavily relies on cement as its primary material for constructing the built environment, a promising landscape unfolds for the gradual adoption and integration of three-dimensional printing technology into the industry. This alignment with existing practices and materials positions the BCI favourably for embracing the potential of 3D printing.

Keywords: Technology and construction; Digital prototyping; Additive process; 3D printing; Brazilian Construction Industry.

1. Introduction

The Construction Industry (CI) significantly contributes to the Gross Domestic Product (GDP) and is therefore essential for the economic development of the country [1]. Since it traditionally employs a substantial number of workers, the production of the built environment incorporates manufacturing processes and, consequently, is affected by issues arising from low productivity, the unavailability of skilled laborers, resistance to the adoption of technological innovations, and significant environmental impacts [2, 3, 4].

The transfer of technologies between industries presents an opportunity to mitigate the limitations and deficiencies found in the current model employed in the CI. It is observed that robotic production processes have been incrementally employed, and in the contemporary context, various authors highlight the use of digital prototyping and manufacturing technologies in various fields, including construction.

The argument is justified by the inherent characteristics of these processes, as they enable high efficiency, cost reduction, greater creative freedom, elimination of moulds, reduced exposure of workers to potential workplace hazards, component customization, and optimization of the environmental performance of buildings concerning atmospheric emissions and electricity usage [5, 6, 7, 8, 3].

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The primary objective of this research endeavour is to comprehensively explore the array of materials currently available in the market and cited in scientific literature databases, specifically those showcasing potential applicability within large-format 3D printing systems, as utilized for additive processes in the construction industry.

This investigation also seeks to assess and quantify the viability of incorporating this cutting-edge technology into the broader landscape of the Brazilian construction sector.

By undertaking this inquiry, we aim to shed light on the opportunities and challenges presented by the fusion of 3D printing technology with the construction industry in Brazil, ultimately contributing to a more informed and strategic decision-making process in the field.

2. Material and methods

2.1. Digital Prototyping and Manufacturing

In "Prototyping," Mitchell and McCullough [9] present the possibility of manufacturing customized solutions that could be produced directly from the designer's computer using CAD/CAM technology, with the benefit of providing greater independence from industry-standard solutions. The authors discuss prototyping on two distinct scales: prototyping of construction mock-ups or reduced models, and the manufacturing of components to be used on the construction site, with the latter being of greater interest to the research presented in this work.

According to Kolarevic [10], there are techniques that allow for the manufacturing of objects through prototyping methods, which can be classified as subtractive and additive.

Subtractive methods use equipment with multiple axes that guide the movement of milling tools, which are defined based on the material removal needs and move along computationally defined paths to machine the object from a substrate.

On the other hand, additive methods construct components by layering material, similar to lamination, until they result in a three-dimensional form of the digitally designed object.

In the work published by Singh, Kumar, and Sehgal [11], the techniques, materials, applications, advantages, and disadvantages of different additive processes are systematically organized in a flowchart.

It is observed that there is a considerable range of materials that can be employed to manufacture components for the construction industry, ranging from structural elements to hardware for doors and windows. However, since building envelopes and partition seals require a higher percentage of the services carried out on-site, this premise is used as the basis for the focus of this research. In this regard, additive processes using material extrusion are the ones that, initially, show the greatest potential for adoption by the industry.

2.2. Materials for Prototyping in the Construction Industry

Hager, Golonka, and Putanowicz [6] state that materials intended for use in additive processes should have physical properties that include good workability, fluidity, rapid transition between the liquid and solid states so that the material can be deposited in overlapping layers, and finally, the ability to adhere between these layers.

Wu, Wang, and Wang [5] consider that materials intended for use in additive processes should have chemical properties that allow for the rapid curing of the layers deposited on the base.

Mechtcherine et al. [2] argue that the filament's size and section, as well as the material (cementitious) deposition speed, are decisive factors for the economic viability of similar solutions.

Hager, Golonka, and Putanowicz [6] provide a state-of-the-art overview of 3D printing of buildings and construction components, suggesting that this technology could offer better environmental performance to the built environment than traditional construction techniques, reduce timelines, and lower costs. The research evaluates various materials with the potential for use in Contour Crafting, such as eco-concrete, recycled construction waste with fiberglass, and concrete with sulphur additives.

Wu, Wang, and Wang [5] present a list of materials used in additive prototyping processes, including gypsum, polyester, metals, ceramics, and cement. The authors note that while the process is still in its infancy in the construction industry, its utilization depends on factors such as the precision of printing processes, material availability, process costs, and execution time.

Singh, Kumar, and Sehgal [11] focus on engineering materials in their state-of-the-art review. They compile information on materials used in various industries for additive processes, categorizing them into metals, ceramics, polymers, composites, and hybrid materials.

Mechtcherine et al. [2] developed CONPrint3D, a prototyping process using cement as the primary material. In their work, the authors provide a survey of various researchers who have conducted studies centred on this material, including data related to the ideal mix and mechanical properties of the tests conducted.

Hossain et al. [3] also present concrete mixes used in additive prototyping processes. According to the authors, researchers have tested various concrete mixes, including different types of aggregates and mixes with a predominance of cement additives such as geopolymers, fibres, nanoparticles, among others.

Xiao et al. [8] developed a deposition printing system for large-scale prototyping. Among the mechanisms designed, the authors highlight the extruder, which was developed to enable the use of cement with natural or recycled aggregates produced from construction waste. The authors conclude that, in addition to reducing the ecological footprint, mixes containing up to 25% recycled material did not demonstrate a significant reduction in physical or mechanical properties.

Craveiro et al. [12] research strategies to optimize the use of materials in additive processes involving cementitious materials, which use additives in the cement mix such as lightweight recycled aggregates, cork, etc., or materials whose chemical reactions produce bubbles, such as aluminium powder and limestone. They introduce the concept of multi-material functionally graded concrete structures, which involve manipulating the material composition according to the required structural strength.

Lin et al. [13] investigate the use of a composite material based on cement mortar with polymer flakes to increase the ductility of the material, similar to the behaviour of reinforced concrete structures. The authors developed a solution incorporated into the mortar deposition process, consisting of a horizontally printed ABS mesh with protrusions extending vertically into the cementitious material to reduce crack propagation.

Albar et al. [14] assert that materials for printing should possess properties that allow for good workability, fluidity, and continuous extrusion. The authors developed a 3D printing system for construction components, focusing on the use of polymer mortar-based materials. Their research aimed to adjust the material mix to allow good workability, fluidity, and continuous extrusion.

Jiang, Oguzlu, and Jiang [15] developed a lightweight cellulose-based biomaterial, assuming that the raw material is abundant and possesses low density and high-performance mechanical properties due to the material's cellular structure, making it suitable for structural elements in construction. In addition to this material, the authors mention epoxy-based composites, ceramics derived from polymers, carbonaceous materials, and metals.

3. Discussion

Extensive research is currently underway with the aim of expanding the spectrum of available materials. This enables architects and engineers to enhance the application of 3D printing as a tool for the industrialized manufacturing of components in the construction industry. In this literature review and bibliographic research, we have identified ten distinct materials whose applicability on a large scale, that is, in large dimensions, is strictly conditioned by the development of technologies that allow for the expansion of deposition printing capacity. However, this must be done without compromising the quality of the printed products, ensuring that their physical and aesthetic properties are fully explored.

Table 1 Systematization of the research of scientific literature

AUTHOR	YEAR	CITED MATERIAIS									
		Concrete/ Mortar with additive fibres	Concrete/ mortar	Recycled concrete	Multimaterial	Biomaterial	Composite materials	Metals	Gypsum	Ceramic	Polymers
Hager, Golonka e Putanowicz	2016	●		●							
Lin et al	2020		●				●				●
Craveiro et al	2020			●	●						
Xiao et al	2020		●	●							
Hossain et al	2020	●									
Mechtcherine et al	2019		●								
Jiang, Oguzlu e Jiang	2021					●	●	●		●	
Wu, Wang e Wang	2016		●					●	●	●	●
Singh, Kumar e Sehgal	2020						●	●		●	●
Albar et al	2020		●								
Total citations		2	5	3	1	1	3	3	1	3	3

The data collected from this research are organized in a table that lists the materials and the number of identified citations. Through the analysis of the results, it becomes possible to deduce that the materials receiving the most attention in research are those with the greatest potential for assimilation, dissemination, and use in the construction industry, whether in a national or international context.

This working process also allows for the identification of the required properties for a given material to have the potential to be incorporated into the global production process. Additionally, this characterization helps identify local barriers and opportunities that may provide better conditions for its adoption as a construction method.

Therefore, considering the fact that the Brazilian construction system is organized around the use of cement – necessary for the production of mortars and concretes – a positively configured scenario for exploration and gradual incorporation into the productive chain of the construction industry is observed. This argument is based on the fact that there will be no need for a massive shift to the production of innovative materials in their essence, unlike in other countries where wood and steel are predominantly used.

4. Conclusion

Throughout the development of this work, it was not possible to identify original scientific research conducted by Brazilian researchers, as the articles reviewed were focused on the state of the art of technology on the international scene.

Therefore, based on this observation, two hypotheses can be formulated: (i) given the cement-based culture of the built environment industry, it is unlikely that the incorporation of new 3D printable materials into the Brazilian Construction Industry Park will be successful in the short term. In this sense, scientific production regarding this topic would have little effectiveness; (ii) technological limitations imposed by the need to develop large-scale equipment allow for research and subsequently the transition of technology to the productive market.

Regarding equipment requirements, the research suggests that additive processes using material extrusion are those with the greatest potential for incorporation by the national industry, as the investment in technological solutions is lower. It is even estimated that it is possible to adapt existing equipment on the market, such as overhead cranes used in the manufacture of precast parts.

Reading of scientific papers suggests that there is still a need to expand the volume of research on equipment configuration parameters, as several authors point to the sensitivity of printing parameter settings related to extrusion nozzle speed and distance and their impact on the quality of the final product.

It is evident that there is a trend towards the use of mortars as the main raw material for the manufacture of printed structures. However, it is also possible to note that the material composition still requires adjustments to enable the expansion of applications beyond enclosures, with the potential for use in structural solutions with different densities of printed material, defined based on the analysis of shear and bending behaviour.

Therefore, it can be inferred from the scientific production that the greatest challenge for the incorporation of additive processes in the construction industry is technological in nature, but it is not necessarily related to equipment production, but rather to the technology – or science – of materials.

In this aspect, it is understood that research in Brazil should be directed towards incorporating recycled materials into the composition of materials to be developed, as well as exploring natural fibres, abundant in the country, for the structural development of cement-based composite materials, similar to rammed earth or reinforced mortar, which have been widely used in traditional Brazilian construction.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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