A systematic review of the variety of printing in the construction industry and its effect on the labor market

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Abstract The construction sector is one of the main employers worldwide and requires a lot of labor. For decades, the industry had little technological advancement and low output. In recent decades, there has been an increasing interest in various automation technologies, such as 3D printing, by the construction sector. It has been discovered that 3D printing holds great promise for automating building processes. It can reduce dangerous human operations, labor-intensive tasks, wasteful material use, construction time and more. A substantial amount of research has been done to comprehend the most recent developments, potential benefits and difficulties associated with the widespread use of 3D printing in construction projects. In this study, we review the labor-intensive industry of construction and any possible implications for the labor market from the increasing use of 3D printing. Empirical studies have indicated that 3D printing might mitigate the labor shortage by reducing the manpower needed, especially in countries where immigration is a major factor in the construction industry. However, in nations where labor is less expensive and construction is the primary industry, 3D printing cannot be advantageous. The findings indicate that the construction industry might benefit from 3D concrete/construction printing (3DCP) in terms of labor-intensive requirements, worker safety, as well as quicker construction and less wasteful material use.

Keywords: 3D construction printing, workforce, immigrant workers, construction labor

1. Introduction

The first 3D printer was created in 1983, and since then, the technology has advanced quickly. Over time, printers have become a necessary component of daily life and are used in a wide range of industries, including aerospace, automotive, medical and pharmaceutical industries. The use of this technology in structures is far more recent (Souza et al 2020). Recessions and downturns in the economy impact numerous countries. In addition to a few vital initiatives, commercial operations are required to maintain public safety. The public health system and the essential categories of medical goods and services have ended (Gamil and Alhagar, 2020). Approximately 6,711,000 workers, or 4.3% of the labor force, are employed in the U.S. construction business. The compound annual rate of change in employment in the construction industry from 2016 to 2026 is predicted to be 1.2%, closely lagging behind that in the top leading industries according to new statistics from the Bureau of Labor Statistics (BLS) (Kim et al 2020). One of the largest sectors in the world, construction, accounts for more than 13% of the global gross domestic product (GDP). Half of the resources in the world are consumed by the CON sector, which has an incredibly high level of resource usage. In addition, the construction sector has a poor track of innovation in buildings, strong resistance to change and low productivity (Valente et al 2019). Practically every type of social, commercial or economic activity is impacted by the COVID-19 pandemic. The engineering and construction sectors are affected by this crisis in a similar manner. Given the concerns of industry workers, construction activity has been temporarily suspended to stop the spread of the disease (Biswas et al 2021). Most countries spend between 9% and 15% of their GDP on construction, making the built environment close to half of the national investment. The building business is riddled with inefficiencies despite its immense economic significance (Ilhan and Yobas 2019). Construction contributes 9% of the world’s GDP, indicating that construction has a significant impact on a country’s economic development (Hossain and Nadeem 2019). At a rate of 1.85 parts per million per year, the atmospheric CO2 content is rising steadily and reached 414.3 parts per million in 2019. As a result, between 1880 and 2019, the global land and ocean surface temperatures increased by approximately 1.14°C (Weng et al 2020). The construction...
sector in the United Kingdom is criticized for its inefficiencies, overspending on projects, dangerous work environments and project delivery that surpass budgetary estimates. Digital technology is regarded as a feasible means of addressing these problems and revolutionizing the building industry (Shojaei and Burgess 2022). The sustainable development goals present a fresh opportunity for the building sector to prioritize sustainability for purposes other than environmental ones. Construction project management and delivery could be seen as sustainable if social, economic and environmental considerations are considered in project delivery methods, laws and practices (Srivastava et al. 2022).

Klinc and Turk (2019) explained the underlying concepts in Industry 4.0. They discuss many facets of Industry 4.0, including what it entails for businesses, consumers and the sector at large. Using that framework, they examined what Industry 4.0 can mean for the construction industry and discovered that, due to a few industry-specific variables, the sector is extremely ahead of the curve in regard to adopting the concepts of Industry 4.0. Cai et al. (2019) investigated the advancement of robotics and automation in academic research and real-world applications. Using scientometric analysis and critical literature evaluations based on academic publications from the 1980s to the present, important research areas were identified, and their development was investigated. Delgado et al. (2019) provided an analysis of the elements unique to the CON sector that restrict adoption. A combination of qualitative and quantitative data gathering as well as analysis, together with a study of the literature, was used in this mixed research method. There were three focus groups with twenty-eight specialists each, along with an online survey. Zhang et al. (2019) examined the development of 3D-printed concrete with regard to its mechanical qualities, workability and construction plan design. 3D printing technology has been used to evaluate a few isolated products and projects in the early stage. Notably, there was considerable fragmentation in these tests, and breakthroughs surrounding the use of 3D printing in the building industry occurred at the time of the study (El-Sayegh et al 2020). Jung et al. (2022) investigated the current state of 3D printer technology and the future path for creating 3D printing. The key methods required to construct a 3D printer for the building were examined. The main technologies of the research organizations working on developing printing-related projects around the world were examined and discussed. Grigoryan and Semenova (2020) provided instructions on how to automate the building process in construction using a hinged robot. Issues such as 3D printer mobility have been resolved. Using nozzles with specific construction-related skills is the basic idea. Mechtherine et al. (2019) proposed the CONPrint3D concept, which was created at TU Dresden for on-site monolithic 3D printing and assessed the state of the art in relation to these needs. The constraints and requirements of construction practices are the driving forces behind this phenomenon. It conforms to accepted architectural standards, legitimate design codes, current concrete classes and common financial limitations. Allouzi et al. (2020) provided an up-to-date assessment of the developments in 3D printing construction technologies. Next, the structural, financial, environmental and architectural aspects of 3D printing are discussed. This study was motivated by Jordan’s construction issues, which are mentioned together with examples of 3D-printed structures. Kruger et al. (2020) created a theoretical framework for an analytical form retention model that depends on the rheology of a material and established the most stable filament layer height at which plastic production is prohibited.

The rest of the paper proceeds as follows: Part 2 describes the experimental methods in great detail. The results and discussion are covered in parts 3 and 4. The conclusion is covered in part 5.

2. Materials and Methods

This section provides a methodical analysis of print diversity in the construction sector and how it affects the labor market.

2.1. Organizational structure of 3D concrete/construction printing (3DCP)

A building project’s design and planning will require more architects, engineers and builders as a result of 3DCP, which will completely eliminate the need for craft workers at the construction site (Murphy 2020). Although not investigated, it is evident from the literature that acquiring certain abilities is necessary for an organization to implement 3DCP, even if fewer personnel are required for the design and planning phase (Pan et al 2021). Therefore, rather than using traditional building methods, the process and organizational structure can be modified to incorporate 3DCP or digital fabrication (dfab), as shown in Figure 1.

2.2. 3D-Printable Substances and Difficulties

The compositions of cement-based 3D-printed materials and conventional materials differ in terms of binders and aggregate quantities. High-performance materials are required because layer-by-layer deposition, pumping, mixing and other processes must be performed on a wet mix of 3D-printed materials. Researchers have used a variety of cement-based materials in 3DCP, including standard fiber mixed mortar, geopolymer mortar, mortar mix and nanoparticle mixed mortar (Nerella and Mechtherine 2019).

2.3. Problems with 3D Printing Materials for Large-Scale Buildings

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The properties of the material are its special qualities for 3D printing, such as viscosity, workability and green strength, and determine how well 3DCP performs. In general, 3DCP prevents bead layer deformation and settlement by requiring no slump but pumpable material. The soft material is an additional option; material that allows for some slump value but regains hardness after that is put through the nozzle head (Jayathilakage et al. 2019). The bead layer distortion can be managed in this fashion. This approach is difficult since it requires precise material composition selection, which might not be important for regular concrete.

![Figure 1 Organizational Framework.](https://media.springernature.com/lw685/springer-static/image/art%3A10.1007%2Fs40964-023-00409-8/MediaObjects/40964_2023_409_Fig17_HTML.png)

2.4. Additional DCP Challenges

The majority of the time, 3DCP uses physical labor to reinforce structural members via embedded or posttensioning rebar. This approach limits the use of these forms in architectural design to maintain linear hollow areas for posttensioning rebar (Ahmed et al. 2022). The layering effect of the 3DP process is another issue; in addition, it causes uneven surfaces and raises the possibility of cavities between the layers. This represents a significant constraint on the 3DCP. Although thin layers can mitigate this effect, constructing a full structure requires additional time and work. The ambiguity surrounding the technology is increased by the inability of 3DCP to be broadly adopted, which has shown success (Kruger et al. 2021).

2.5. Global 3D Printing Industry

After three decades of study in a number of domains, 3D printing has become popular in the building industry in recent years. In 2014, the Chinese company WinSun printed numerous homes in less than a day. Despite the challenges associated with 3D printing that were previously discussed, the development of large-scale 3D printers and technological breakthroughs has allowed for the creation of numerous structures, such as homes, offices, bridges, pavilions and shelters, worldwide (Wolfs et al. 2023).
2.6. Largest 3D-Printed Structure in the World

The structure was built more quickly than in a traditional construction project, even though the on-site assembly of the 3D-printed components required two weeks. Because of the general contractor’s integrated ceiling, fixtures and electronics, the printing process took more than two months (Schuldt et al. 2021). Evidently, every wall that makes up the majority of the structure’s concrete was created using a 3D printer. Furthermore, the need for formwork supplies and labor were reduced by printing column formwork. Conventional procedures were employed for the remaining construction tasks. These savings could include labor cost savings of 50–80%, construction expense savings of 50–70% and material waste savings of 60% (Jewell 2021). Table 1 lists the various architectural elements and their construction techniques in general.

Table 1 Construction techniques for different parts.

<table>
<thead>
<tr>
<th>Building Components</th>
<th>Construction Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>3D printed</td>
</tr>
<tr>
<td>Foundation</td>
<td>Traditional building techniques used by the general contractor</td>
</tr>
<tr>
<td>Slab</td>
<td>Precast</td>
</tr>
<tr>
<td>Ceiling, Roof, Windows, Insulation</td>
<td>The traditional approach used by the general contractor</td>
</tr>
<tr>
<td>Installation of electrical and plumbing systems</td>
<td>Conventional method</td>
</tr>
</tbody>
</table>
| Columns              | Ø The reinforcements were applied by hand.  
|                      | Ø Formworks were printed using 3D technology. 
|                      | Ø Concrete was put up by hand. |

2.7 World’s Tallest 3D-Printed Structure

The five-story residential structure created by 3D printing is thought to be the world's tallest 3D-printed structure. All of the building components were printed as prefabricated sections that were moved and installed both on and off site. Traditional methods, such as windows and doors, were used to complete the finishing touches. Moreover, construction technologies reduce building time by 50–70%, labor costs by 50–80% and construction waste by 30–60% (Waqar et al. 2023).

2.8 The Future of 3DCP

As of 2030, 25% of Dubai buildings will be built using 3DCP. Residential villas, galleries, shops, parks and amenities are among the structures that are built. In addition, there are foundations along with joints for construction, lighting fittings, mobile houses and buildings for philanthropic reasons (Holt et al. 2019). The possibility of using 3D printing to create inexpensive homes for those in need was proposed by the writers. After two 3D-printed homes were completed in less than 24 hours each, 3D printing was used to construct 50 dwellings in Tabasco, Mexico. A kitchen, living area, two bedrooms and a bathroom are included in a 500-square-foot home (Bos et al. 2022).

3. Results

3.1. Chemical components of the raw materials

The selection of chemical components for 3D buildings requires careful consideration of the project’s unique needs, including durability, cost effectiveness, mechanical qualities and environmental sustainability. Furthermore, obtaining effective and superior construction results depends on the compatibility of the material with the 3D printing procedure and machinery. Table 2 lists the main chemical components of the binder. The main chemical components of the binder are shown in Figure 2.

Table 2 The primary constituents of the binder’s chemical makeup.

<table>
<thead>
<tr>
<th>Particles</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO₂</td>
</tr>
<tr>
<td>Portland Cement (PC)</td>
<td>18</td>
</tr>
<tr>
<td>Limestone Filler (LF)</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3 Chemical Composition of the Dry Components.

<table>
<thead>
<tr>
<th>Particles</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO₂</td>
</tr>
<tr>
<td>LCC</td>
<td>56</td>
</tr>
<tr>
<td>HPCC</td>
<td>48</td>
</tr>
</tbody>
</table>
Table 4 displays the chemical compositions of ground granulated blast-furnace slag (GGBS), silica fume (SF) and fly ash (FA). Figure 4 shows the chemical compositions of the GGBS, SF and FA samples.

<table>
<thead>
<tr>
<th>Particles</th>
<th>SiO$_2$</th>
<th>Al$_2$O$_3$</th>
<th>CaO</th>
<th>Fe$_2$O$_3$</th>
<th>MgO</th>
<th>SO$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>50</td>
<td>40</td>
<td>5</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>GGBS</td>
<td>30</td>
<td>16</td>
<td>40</td>
<td>4</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>SF</td>
<td>98</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 2 The principle chemical components of the binder.

Figure 3 Comparisons of the HPCC and LCC.

Figure 4 Chemical compositions of the GGBS, SF and FA samples.
Table 5 shows the degree of reactivity between the HPCC and LCC. The degree of responsiveness of the LCC and HPCC is displayed in Figure 5.

3.2. A Two-Story House Printed 3D on Location

The two-story home was printed on location, but the entire construction process, including the plumbing and other mixtures, was completed in just 1.5 months. A similar structure built in a traditional fashion would take roughly six to seven months. This 3D-printed building was constructed utilizing a unique printing technique, in contrast to earlier ones. Initially, the rebar support system and plumbing were installed in the home frame. Then, a massive 3D printer was used for printing (Adeeb Fahmy Hanna 2019).

Table 5 The degree of reactivity between HPCC and LCC.

<table>
<thead>
<tr>
<th>Particles</th>
<th>I.R</th>
<th>Reactive component</th>
<th>Reactive SiO₂</th>
<th>Reactive Al₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCC</td>
<td>52</td>
<td>49</td>
<td>13</td>
<td>32</td>
</tr>
<tr>
<td>HPCC</td>
<td>25</td>
<td>75</td>
<td>35</td>
<td>40</td>
</tr>
</tbody>
</table>

Figure 5 The level of responsiveness of LCC and HPCC.

3.3. The Effect of the Construction Labor Market and 3DCP

Construction has employed a large portion of the global workforce and requires considerable labor. Another significant expense in construction projects is labor. Moreover, low labor productivity and a lack of semiskilled, skilled and unskilled labor are two of the biggest factors contributing to construction project delays (Mindell and Reynolds, 2022). Labor is crucial to the building sector. Young people are less likely to choose physically demanding careers these days. There are increasingly fewer persons in Central Europe accessible for skilled manual labor. However, because of their low labor productivity, nations with large populations of construction workers are struggling with issues such as timely completion and high-quality construction (Hidayat et al 2019).

3.4. Problems with the Labor Shortage in Construction

Many businesses think that workers who are immigrants are dependable, industrious and prepared to accept positions that are risky, challenging and low-paying, which other workers would turn down. Immigrant laborers receive cheap wages, which lower production costs and product prices (Edo 2019). Approximately 70% of Malaysian workers are employed in the construction business, making foreign workers the largest segment of the labor market (Najib et al 2019). This applies to Brunei, Singapore and the majority of Middle Eastern nations.

3.5. Difficulties with Skilled Labor in Construction

Large companies can have better job contracts, which make it easier for them to find talented workers. However, hiring competent personnel is a problem that small and medium-sized businesses face. Some companies find that the construction courses or specialized staff that they pay for training do not yield a full return on investment. This is because many construction
workers are employed on an as-needed or project-by-project basis, and they regularly switch between companies. When immigrant workers return home, they lose the abilities that they acquired at work (Aghimien et al. 2023).

4. Discussion

In addition to the anticipated reduction in the amount of human resources needed for 3DCP, masonry experts and digital technologists will need to identify any anomalies in the digital model while the masonry is constructed (Brehm 2019). They ought to be able to combine robotics and civil works with 3D printing. As 3DCP is used, current employees will need to either receive the training they need to adapt to the new working procedures of 3DCP or look for other employment opportunities. The widespread usage of 3DCP will result in many construction workers losing their employment in entry-level, low-skilled jobs. For businesses where a labor shortage is a major concern and they rely on migrant labor, this approach will be advantageous.

For experts in the building industry, losing their jobs could be harmful, but there are other benefits to technological progress as well. For example, the automation of low-skilled tasks can improve and advance the list of professions with higher-level responsibilities, such as research as well as development, legal advice, material quality control, 3D design, modeling and 3D printer supervision. Finally, the CON sector will continue to be impacted by new technologies in a number of ways. Building projects can be completed more quickly and efficiently with the use of cutting-edge technologies such as robotics, 3D printing and drones. It will continue to collaborate with human workers as a team rather than necessarily replacing them (Aitbayeva and Hossain 2019).

5. Final considerations

The construction sector is a labor-intensive business that exhibits low productivity and minimal use of technology. This study examined the potential effects on the construction labor market, given the potential for broad implementation of 3DCP. According to the findings, 3DCP offers a great deal of potential to advance the construction sector in areas such as increased labor-intensive specifications, worker safety, quicker construction and reduced material waste. A growing number of construction projects using 3DCP are anticipated in the near future according to the literature, although the research and development stage of 3DP in construction has produced a modest number of buildings and small bridges that are usable in daily life worldwide.

Ethical Considerations

Not Applicable.

Conflict of Interest

The authors declare no conflict of interest.

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