Economic Viability of 3D Concrete Printing: A Comparative Study with Traditional Construction Method

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Abstract –

The construction sector's considerable environmental impact has led to a growing demand for sustainable construction technologies. This study aims to compare the cost and environmental impact of traditional construction and 3D printing construction processes, starting from the supply of raw materials to the final construction and construction waste disposal. Based on the factors identified (raw material, printing equipment, transportation, warehousing, construction and waste disposal), traditional construction and 3D printing value streams are mapped to assess the potential factors or activities contributing to the cost and environmental burden. The results showed that 3D printing offers nearly 80% lower cost at the construction phase than traditional construction. However, 3D printing hardly reduces the total cost by only 0.96% and even produces significantly higher greenhouse gas (GHG) emissions than traditional construction due to the significant transportation cost of raw materials and 3D printing equipment. The higher transportation costs in 3D printing are mainly due to the lack of a well-established market for 3D printing equipment and raw material supply. Futuristic scenario analysis revealed that 3D printing could reduce the total construction cost (starting from raw material and equipment supply to construction waste disposal) by 61% when the infrastructure for 3D printing is established in the same way as traditional construction. The findings of this study explored the sustainability potential of 3D printing and offered insights for its application in construction projects.

Keywords – 3D printing; traditional construction; cost analysis; value stream mapping; GHG emissions

1 Introduction

As the global population continues to grow, the demand for new construction has surged, leading to significant expansion in the construction industry. This sector consumes 40% of natural resources, including minerals and fossil fuels, and is responsible for nearly 40% of greenhouse gas emissions among industrial sectors. With projections estimating a global population increase of 9.8 billion by 2050 and up to 11.2 billion by 2100 [1], the strain on mineral and fossil resources is expected to escalate dramatically. In light of this environmental impact, the adoption of smart construction technologies is essential to mitigate damage. One promising solution is 3D printing, also known as additive manufacturing, which creates components by layering materials. This technology has emerged as a sustainable alternative in construction, enabling the production of buildings and components through successive layers of concrete with minimal human intervention. 3D printing (3DP) offers a significant advantage by reducing the cost and environmental impact associated with traditional plywood and metal formwork [2], as it can produce self-supporting concrete layers. Unlike conventional methods, 3D printing minimizes economic and environmental burdens while allowing for the creation of complex geometries with less reliance on intricate formwork [3].

In the construction industry, 3D printing has offered significant benefits by reducing labor costs, material waste, and construction time. In addition, 3D printing streamlines the supply chain by enabling just-in-time delivery of equipment and raw materials directly to the construction site, eliminating the need for large inventories of raw materials and formwork. In 2020, the global 3D printing market experienced impressive growth, surging by 21% compared to 2019 and reaching an estimated value of $12.6 billion [4]. Owing to these benefits, several studies have conducted an extensive economic analysis for 3D printing with reference to

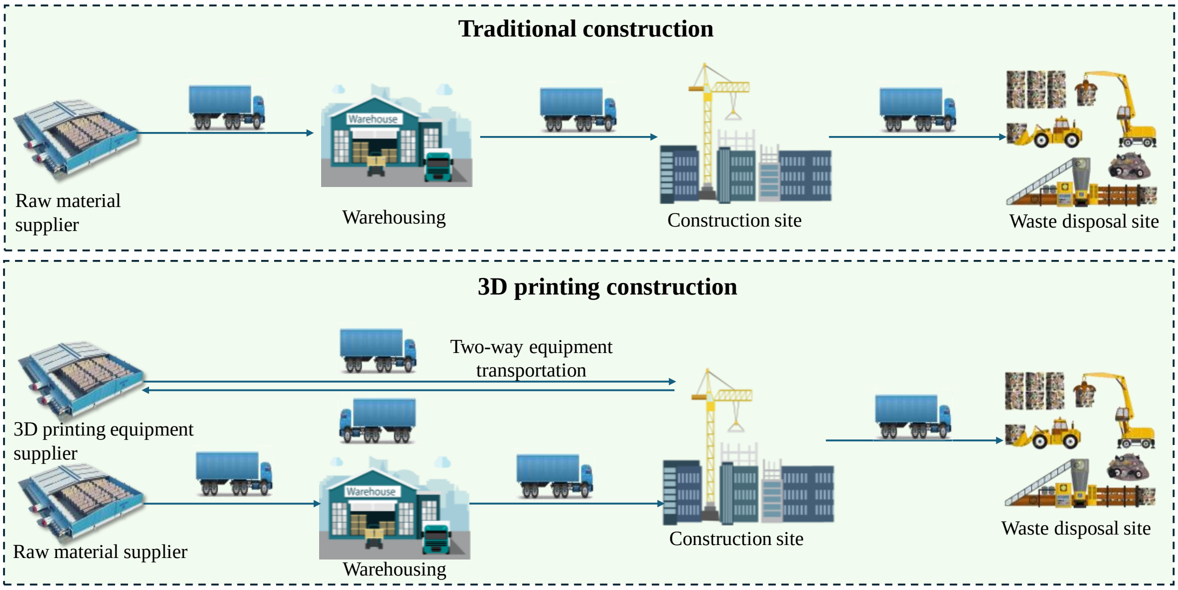

Figure 1. Supply chain configuration for traditional and onsite 3D printing construction.

traditional construction. In their study, Markin et al. [5] analyzed the cost components of 3D printing and found that labor costs contribute just 21%, while material costs account for 70% of the total construction expenses for 3D printing with foam concrete.

Weng et al. [6] conducted a comparative analysis of 3D printing and precast construction. Their findings revealed that 3D printing offered 34% less cost than precast construction. Batikha et al. [7] compared the cost of a two-story building using different construction methods. Their results showed that 3D printing yields 21% less construction cost than precast modular construction. Tobi et al. [8] conducted a cost analysis of a 3D printed house in the UK and revealed that the 3D printing method offers nearly 30% less construction cost than traditional methods. The findings of Allouzi et al. [9] revealed that the 3D printing method has the potential to reduce the material consumption cost by 65%. Abdalla et al. [10] conducted a comparison of formwork and raw material costs between construction 3D printing and traditional construction methods, revealing that 3D printing incurs a capital cost that is 78% lower, primarily due to the elimination of formwork and reduction in concrete consumption. Han et al. [11] considered a case study of a cylindrical silo for the comparative analysis of 3D printing and traditional construction methods. Their findings revealed that the construction cost (labor, electricity, formwork and fuel for operating equipment) of 3D printing is nearly 80% lower than conventional construction.

Apart from cost effectiveness, 3D printing also aids in reducing the environmental impact generated by the consumption of materials and energy due to their efficient utilization. Alhumayani et al. [12] examined the environmental effects of 3D printing compared to traditional casting methods in large-scale construction. Their findings indicated that the overall environmental impact of 3D concrete printing (3DCP) is 50% lower than that of conventional construction. In a study, Weng et al. [6] revealed that traditional construction produces nearly 86% higher carbon emissions than 3D printing construction. Batikha et al. [7] performed a comparative analysis of five construction methods—3D concrete printing (3DCP), prefabrication, cast in-situ, reinforced concrete, and both hot-rolled and cold-formed steel—for building a two-story structure. Their results showed that 3DCP generates 32% lower carbon emissions, whereas prefabricated modular construction has the highest carbon emissions among the methods studied. Han et al. [11] conducted a comprehensive sustainability analysis and revealed that 3D printing offers 2.9% less greenhouse gas emissions than conventional construction during the construction phase. Based on the extensive literature review, it can be believed that 3D printing can be a better alternative to conventional construction due to its cost-effectiveness and reduced environmental impact during the construction phase. However, Besklubova et al. [13] revealed that 3D printing construction is only cost-effective at the construction phase. In their study, it was observed that the logistics cost of 3D printing is significantly higher than that of traditional construction, which ultimately increases the overall construction cost of 3D printing. Based on the extensive literature review, it has been observed that most of the studies have compared the economic and environmental impact of 3D printing with traditional methods at the construction phase considering major factors such as labor hours, energy/fuel consumption, material consumption, and equipment usage. Therefore, there is a need for studies on the comprehensive economic and environmental impact analysis considering the entire supply chain starting from the supply of raw materials to the waste disposal phase.

Even though 3D printing has sustainability potential due to a higher level of automation, it has been reported that the higher logistics cost can hinder its real-time application [13]. Therefore, there is a need to investigate the potential reasons for its higher logistics cost and to enhance its economic benefits. This study aims to conduct a comprehensive economic analysis to determine the potential factors contributing to the higher cost and throughout the value stream of 3D printing construction and highlight its possible economic benefits by considering a hypothetical scenario representing the future state of the 3D printing market in the construction industry. Moreover, this study also focused on the analysis of the environmental impact of both 3D printing and traditional construction and features potential environmental perks in the future state.

2 Methodology

This section covers the selection of major factors or activities for traditional construction and 3D printing that incur costs and cause environmental burdens. In the next step, the methodology for mapping these activities on the value stream is presented. After mapping the value streams, real-time case studies have been considered to assess the activities that experience significant costs and contribute to the environmental burden.

2.1 Parameters identification

First of all, the activity-based costing (ABC) approach has been used to highlight the activities that incur the resources and costs at the different phases of the construction process. The ABC method offers more precise cost information, facilitating effective monitoring of supply chain and construction strategies. In both construction methods, activities are highlighted, from the supply of the raw materials to the construction waste disposal to estimate the cost. All activities are further disintegrated into several other small factors. For transportation, the amount of material to be transported, distances, labor cost, handling cost, fuel cost and environmental cost are considered. For the construction phase, factors including labor cost, construction time, equipment depreciation, energy cost, material cost, and environmental cost are encountered. Apart from the cost, the factors contributing to the greenhouse gas emissions, including fuel (for transportation), energy and construction materials in different construction phases, are also highlighted.

2.2 Mapping the value streams

Value stream mapping was used to highlight the cost- and emissions-intensive phases of the construction processes. Value stream mapping is a valuable tool for visualizing and quantifying activities across the construction supply chain. Figure 1 illustrates the supply chains for both traditional and 3D printing construction, which aid in the development of value streams. Within the value stream, activities related to 3D printing and traditional construction processes are clearly delineated into facility-based and non-facility-based activities. Facility-based activities include warehousing and onsite construction, while material and equipment handling and their transportation between these facilities are classified as non-facility-based [14]. For traditional construction, the value stream starts with the supply of raw materials from the suppliers to the warehouse and then to the construction site, which finally ends with the transportation of construction waste material from the construction site to the disposal site. The value stream of onsite 3D printing is nearly the same as traditional onsite construction; however, it also involves the two-way transportation of 3D printing equipment from the supplier to the construction site and back to the supplier (upon project completion). After highlighting the processes, the cost and carbon emissions are highlighted for each stage of the value stream for both traditional construction and 3D printing processes. Upon mapping the cost and environmental value streams, critical stages are highlighted in order to reduce their economic and environmental impacts.

2.3 Case study and data collection

This section outlines the application of the proposed model to evaluate the feasibility of 3D printed projects in comparison to traditional construction methods. For this analysis, case studies of residential buildings in Berlin and Beckum, Germany, were selected. The onsite 3D printed project, a joint venture involving PERI, COBOD, and others, was chosen for its unconventional design and onsite construction, which aligns with industry interests. This project has received a building permit from the local authorities in Beckum, providing valuable insights. The study gathered data from open-access articles, reports, and official websites to design a technical questionnaire for operational employees, focusing on project specifics, resource logistics, and costs. Follow-up interviews with senior management addressed gaps and enriched insights. Collected data was then applied to a model to validate the feasibility and practical implementation in the case studies, demonstrating the utility of the results.

In contrast, a traditionally built house in Berlin, constructed with sand-lime blocks and having a similar floor area, was selected for comparison. Bricks or sand-

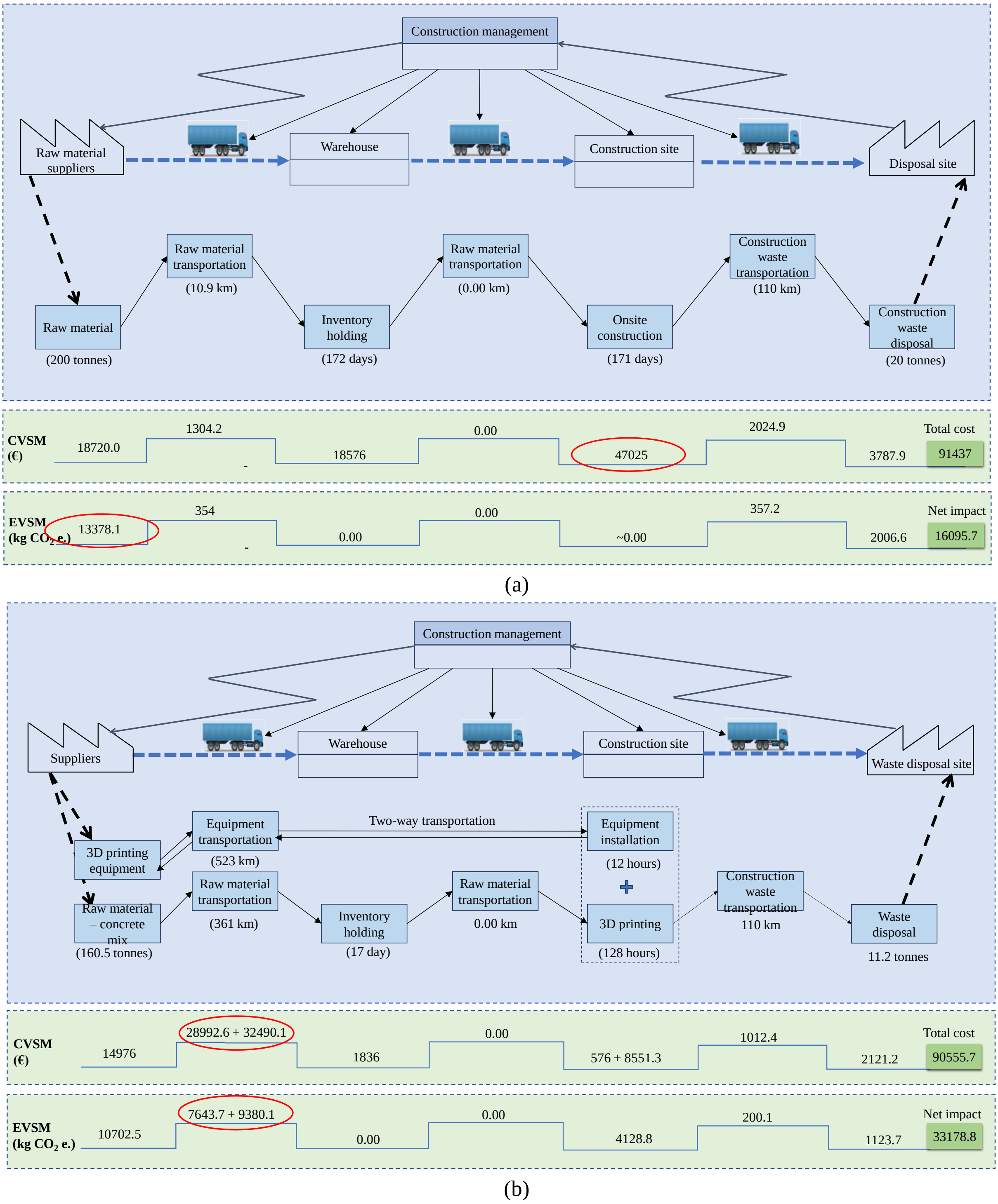

Figure 2. CVSM and EVSM for (a) traditional construction (b) 3D printing construction.

lime blocks are chosen over cast-in-place concrete in small-scale construction because they have lower structural needs (sufficient strength for low-rise buildings), are less expensive (no formwork, easier labor and logistics), and can be built more quickly (no curing delays). They are easier to manage in tight places and provide greater thermal/acoustic performance, reduced dead loads, and shrinkage-free stability. These projects meet the criteria for the case study as they are real-world examples from the same country, use the same currency, and involve a similar scope of work, offering comprehensive data on various aspects. Although the projects were implemented in cities of different sizes (Berlin and Beckum), the cost calculations were based on average values for Germany, considering factors such as materials, equipment, and waste transportation, which often require intercity logistics. Based on the parameters identified and mathematical models developed by Besklubova et al. [13], the cost-based value streams have been determined for the comparative analysis of traditional construction and 3D printing. To assess the environmental impact of both construction techniques, a detailed methodology of Life cycle analysis presented by Raza et al. has been adopted [15].

3 Results and discussion

This section provides a comparative analysis of the traditional and 3D printing construction techniques in terms of cost and environmental impact. To illustrate the cost incurred and environmental impact produced at different stages of construction, cost-based value stream mapping (CVSM) and environmental value stream mapping (EVSM) for both traditional and 3D printing construction are considered.

3.1 Cost-based value stream mapping

Cost-based value streams of traditional and 3D printing construction are mapped to investigate the costs at the different phases. In the case of value streams, costs associated with raw materials, transportation, warehousing, labor, and construction waste disposal are considered for a low-rise building. Value streams start with the supply of raw materials, and raw material cost is incurred in the first stage. From Figure 2, it can be seen that the raw material cost of 3D printing (14976 €) is lower than that of the traditional construction process. This is primarily due to the fact that traditional construction consumes more material due to cutting, shaping, and fitting materials in intricate shapes, leading to the consumption of more material. On the other hand, 3D printing does not require any excessive material in the case of complex designs. The next step involves transporting raw materials from the supplier to the warehouse or construction site. It has been observed that traditional construction suppliers are available quite close (10.9 km) to the construction site. However, 3D printing requires specialized composition or formulation of concrete material, which is not commonly available in the market; therefore, the raw material is procured from a specific supplier from a distant place. Increased distance (361 km) between the supplier and warehouse or construction site significantly increases the transportation cost to 32490.1 €. 3D printing also involves the transportation of large sized 3D printing equipment. Similarly, in the case of 3D printing material supply, printing equipment is also delivered by particular suppliers which are not commonly available. Transportation of printing equipment involves the delivery of a large-sized gantry system, piston pump, batching plant and a silo, and equipment is returned to the supplier upon the completion of the project.

Two-way transportation from a distant place (523 km) incurs a significant transportation cost of 28992.6 €. Warehousing cost is also a distinguishing factor between traditional and 3D printing construction. The warehousing cost of traditional construction is significantly higher (18576 €) as construction materials are held for a longer time as the construction time of traditional construction is almost 171 days; therefore, material holding is considered for almost the same duration with an additional one day. On the other hand, 3D printing time is significantly shorter; therefore, raw materials are held for a short period of time (17 days). In this case study, the warehouse is considered close to the construction site; therefore, the transportation of materials from the warehouse to the construction site is negligible. On the construction phase, typical construction cost involves labor, energy and equipment cost. In traditional construction, low-rise buildings typically involve manual operations for small-scale projects, leading to substantial labor costs. As a result, the construction phase incurs significantly higher expenses, amounting to approximately €47025. Equipment and energy costs are negligible compared to labor costs. However, 3D printing involves the printing of material, which requires few operators for its installation and printing process and consumes energy. Due to the significant level of automation, the cost of the

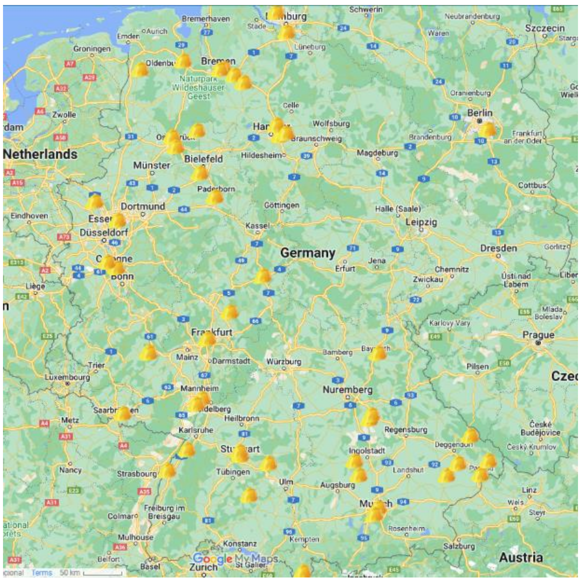

Figure 3. Locations of construction companies in Germany are highlighted with yellow icons on the map [16].

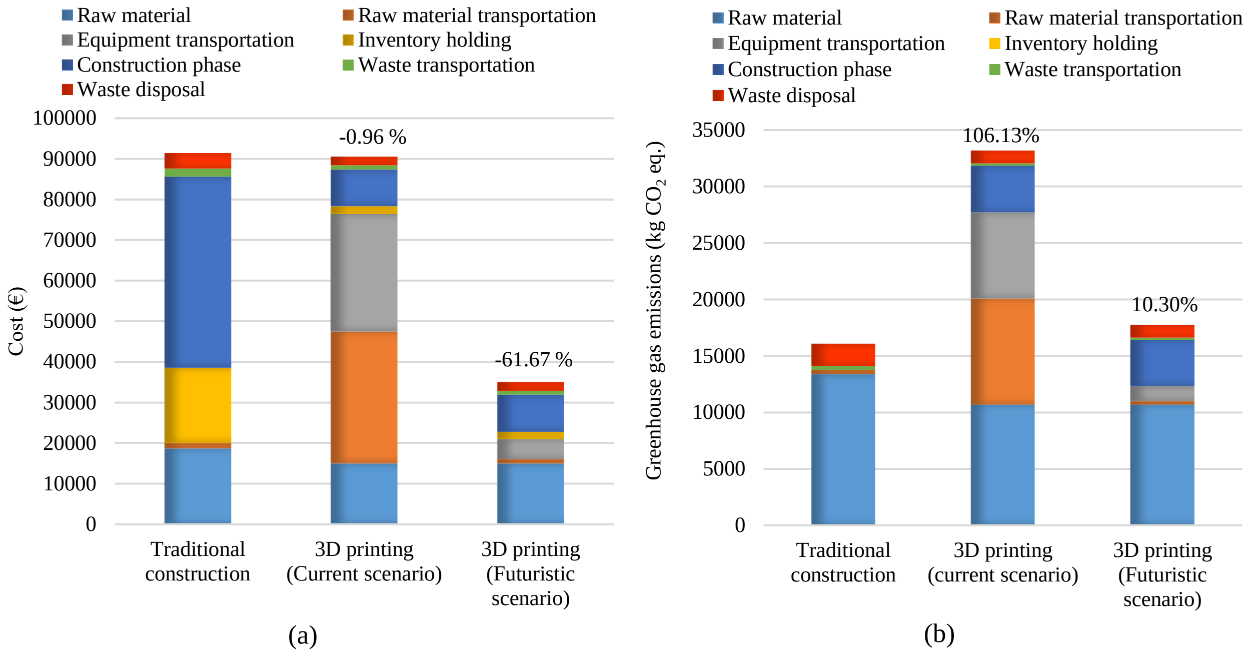

Figure 4. Comparative analysis of traditional construction with a futuristic scenario of 3D printing for (a) total construction cost (b) total greenhouse gas emissions.

construction phase is observed to be 9127.3 €, which is nearly 80% lower than that of traditional construction. In the case of waste disposal, nearly the same distance is considered for both construction methods. Analysis shows that the waste disposal cost of 3D printing (2121.2 €) is lower than that of traditional construction (3778.9 €), which is due to the lower amount of waste produced. Comparative analysis shows that even though 3D printing offers significantly lower construction costs due to a higher level of automation, its total cost (90555 €) is still quite close to the traditional construction cost (91437 €). The prime reason for the higher total cost of 3D printing is the transportation of raw materials and 3D printing equipment from distant places or facilities due to the lack of a well-established market for 3D printing.

3.2 Environmental value stream mapping

EVSM is a valuable tool used to assess the potential sources of greenhouse gas emissions throughout the value stream of the construction process [15]. The analysis shows that GHG emissions from the raw material (13378 kg CO_2 eq.) are significantly higher than any other activity in the value stream. However, the GHG emissions from the raw material for 3D printing (10702.5 kg CO_2 eq.) are lower than those from traditional construction due to the relatively lesser amount of material used. The transportation of raw materials and 3D printing equipment contributed to the GHG emissions to a significant extent of 17023 kg CO_2 eq. which are mainly due to the large distances between the suppliers and construction site. On the other hand, traditional construction hardly commits 353.98 kg CO_2 eq., which shows that transportation is the decisive factor for the selection of environmentally friendly alternatives. In the next phase of construction, 3D printing also contributes 47025 kg CO_2 eq. to the GHG emissions, which are associated with the energy consumed during the concrete mixing, pumping and printing process. As (in this study), a low-rise building is considered where most of the operations are performed manually in traditional construction; therefore, negligible GHG emissions are observed during the construction phase.

However, in the case of high-rise buildings or large construction projects, a significant amount of energy is also consumed in the concrete mixing and pumping process, which generates a competitive amount of GHG emissions. In the case of construction waste transportation and disposal, 3D printing outperformed by producing 200.05 kg CO_2 eq. and 1123.70 kg CO_2 eq. respectively, due to the generation of less construction waste than traditional construction. Net GHG emissions analysis depicts that traditional construction produces almost 51% less GHG emissions than 3D printing construction.

3.3 Futuristic scenario for 3D printing construction

From the previous discussion on value stream assessment, it has been observed that traditional construction outperformed 3D printing in terms of cost and environmental impact for low-rise buildings. The prime reason for the higher cost and environmental impact was observed to be the larger distances between the suppliers and construction sites for 3D printing. The market and infrastructure for traditional construction are well established, and raw material suppliers (for traditional construction) are frequently available. Moreover, most of the traditional construction companies are located within a 100-kilometer radius, as shown in Figure 3. Conversely, 3D printing technology is not yet fully developed, and suppliers of its equipment and raw materials are not consistently accessible. Thus, it would be premature to conduct a comparative analysis of both techniques at this stage. Therefore, this study presents a futuristic scenario for 3D printing by considering the equipment supplier at 90 km and the raw material supplier at the same as traditional construction (10.9 km). In the current scenario, it has been observed that 3D printing hardly reduces the total cost by 1%, as shown in Figure 4a (the negative sign depicts the percentage reduction). A futuristic scenario for 3D printing shows that 3D printing could reduce the overall cost by 61.67% as compared to traditional construction. In the case of environmental impact, it has been observed that the current scenario produces almost 106% higher GHG emissions, which could be reduced to 10% higher than that of traditional construction (Figure 4b). The higher GHG emissions are associated with energy consumption due to higher levels of automation. However, in the case of large construction (where traditional construction processes also use machines for mixing and pouring), 3D printing has the potential to offer even lower GHG emissions than traditional construction.

4 Conclusion

This study outlines the key factors and activities in traditional construction and 3D printing that incur costs and impact the environment. It then presents the methodology for mapping these activities on the value stream. Finally, real-time case studies are analyzed to evaluate the activities that significantly contribute to costs and environmental burdens. The following conclusions are drawn from the findings of this study.

- In traditional construction, the primary factors driving total costs are raw materials, warehousing, and labor. In contrast, for 3D printing, transportation of raw materials and printing equipment significantly influences overall costs, primarily due to the absence of a well-established infrastructure compared to traditional construction.
- In the case of environmental burden, raw material is the major source of GHG emissions for traditional construction due to the significant amount of material used. On the other hand, transportation of raw materials and equipment remains a significant factor for 3D printing due to the large distances from the suppliers.
- In the construction phase, 3D printing offers nearly 80% less cost than traditional construction, which is mainly due to the significant automation involved. In contrast, labor remained the major factor in the higher cost of traditional construction.
- To assess the potential of 3D printing, a futuristic scenario has been presented, revealing that 3D printing can reduce overall construction costs (including transportation, warehousing, construction, and waste disposal) by nearly 61.67% if raw materials and equipment are available close to the construction site, similar to traditional construction.
- The environmental impact of 3D printing is 106% higher than that of traditional construction, which can be reduced to only 10% higher (for low-rise buildings or small-scale construction) if the raw materials and equipment are readily available. However, the environmental burden of traditional construction could be even higher than 3D printing in large-scale construction projects due to the energy consumption by batching plants and piston pumps.

This study revealed that 3D printing offers an even higher cost and environmental burden at this stage due to the lack of well-established infrastructure same as traditional construction. However, 3D printing could be the potential alternative to traditional construction due to its potential to limit the overall construction cost and environmental burden.

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References

[1] UnitedNations. "Department of Economic and Social Affairs, Population Division, World population." https://www.un.org/en/desa/world-population-projected-reach-98-billion-2050-and-112-billion-2100 (accessed 2025).

[2] H. Hassan, E. Rodriguez-Ubinas, A. Al Tamimi, E. Trepci, A. Mansouri, and K. Almehairbi, "Towards

innovative and sustainable buildings: A comprehensive review of 3D printing in construction," *Automation in Construction*, vol. 163, p. 105417, 2024/07/01/ 2024, doi: https://doi.org/10.1016/j.autcon.2024.105417.

[3] M. H. Raza and R. Y. Zhong, "A sustainable roadmap for additive manufacturing using geopolymers in construction industry," *Resources, Conservation and Recycling*, vol. 186, p. 106592, 2022/11/01/ 2022, doi: https://doi.org/10.1016/j.resconrec.2022.106592.

[4] H. Everett. "3D Hubs AM Trends Report reveals 3D printing grew 21% despite Covid-19. 3D Printing Industry." https://3dprintingindustry.com/news/3d-hubs-am-trends-report-reveals-3d-printing-grew-21-despite-covid-19-189087/ (accessed 04 March 2025.

[5] V. Markin, M. Krause, J. Otto, C. Schröfl, and V. Mechtcherine, "3D-printing with foam concrete: From material design and testing to application and sustainability," *Journal of Building Engineering*, vol. 43, p. 102870, 2021/11/01/ 2021, doi: https://doi.org/10.1016/j.jobe.2021.102870.

[6] Y. Weng *et al.*, "Comparative economic, environmental and productivity assessment of a concrete bathroom unit fabricated through 3D printing and a precast approach," *Journal of Cleaner Production*, vol. 261, p. 121245, 2020/07/10/ 2020, doi: https://doi.org/10.1016/j.jclepro.2020.121245.

[7] M. Batikha, R. Jotangia, M. Y. Baaj, and I. Mousleh, "3D concrete printing for sustainable and economical construction: A comparative study," *Automation in Construction*, vol. 134, p. 104087, 2022/02/01/ 2022, doi: https://doi.org/10.1016/j.autcon.2021.104087.

[8] A. L. M. Tobi, S. A. Omar, Z. Yehia, S. Al-Ojaili, A. Hashim, and O. Orhan, "Cost viability of 3D printed house in UK," *IOP Conference Series: Materials Science and Engineering*, vol. 319, no. 1, p. 012061, 2018/03/01 2018, doi: 10.1088/1757-899X/319/1/012061.

[9] R. Allouzi, W. Al-Azhari, and R. Allouzi, "Conventional Construction and 3D Printing: A Comparison Study on Material Cost in Jordan," *Journal of Engineering*, vol. 2020, no. 1, p. 1424682, 2020/01/01 2020, doi: https://doi.org/10.1155/2020/1424682.

[10] H. Abdalla, K. P. Fattah, M. Abdallah, and A. K. Tamimi, "Environmental Footprint and Economics of a Full-Scale 3D-Printed House," *Sustainability*, vol. 13, no. 21, doi: 10.3390/su132111978.

[11] Y. Han, Z. Yang, T. Ding, and J. Xiao, "Environmental and economic assessment on 3D printed buildings with recycled concrete," *Journal of Cleaner Production*, vol. 278, p. 123884, 2021/01/01/ 2021, doi: https://doi.org/10.1016/j.jclepro.2020.123884.

[12] H. Alhumayani, M. Gomaa, V. Soebarto, and W. Jabi, "Environmental assessment of large-scale 3D printing in construction: A comparative study between cob and concrete," *Journal of Cleaner Production*, vol. 270, p. 122463, 2020/10/10/ 2020, doi: https://doi.org/10.1016/j.jclepro.2020.122463.

[13] S. Besklubova, M. H. Raza, R. Y. Zhong, and M. J. Skibniewski, "3D Printing vs. Traditional Construction: Cost Comparisons from Design to Waste Disposal Stages," in *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*, 2024, vol. 41: IAARC Publications, pp. 1247-1254.

[14] M. H. Raza, S. Besklubova, and R. Y. Zhong, "Economic analysis of offsite and onsite 3D construction printing techniques for low-rise buildings: A comparative value stream assessment," *Additive Manufacturing*, vol. 89, p. 104292, 2024/06/05/ 2024, doi: https://doi.org/10.1016/j.addma.2024.104292.

[15] M. H. Raza, S. Besklubova, and R. Y. Zhong, "Comparative environmental value stream assessment of offsite and onsite 3D construction printing processes," *Procedia CIRP*, vol. 130, pp. 1012-1019, 2024/01/01/ 2024, doi: https://doi.org/10.1016/j.procir.2024.10.200.

[16] LetsBuild. "The biggest construction companies in Germany." https://www.letsbuild.com/blog/biggest-construction-companies-in-germany (accessed 06-March-2025).