BARRIERS TO THE IMPLEMENTATION 3D PRINTING CONCRETE TECHNOLOGY IN SRI LANKA

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Abstract: 3D Printing Concrete (3DPC) is a rapid and emerging innovation that has changed the landscape of the construction industry as we know it with its advantages that include reduced construction time, minimised material waste, improved design flexibility, and enhanced sustainability. Irrespective of the growth experienced worldwide, the adoption of 3DPC in Sri Lanka is negligible because of numerous constraints that prevent large-scale implementation. This study explores the barriers to the implementation of 3DPC in Sri Lanka through a qualitative methodology consisting of a literature review and semi-structured interviews with fourteen experts from academia and the industry. The results show a broad array of obstacles, identified in seven categories including both resource constraints and financial constraints, construction related challenges, stakeholder resistance, legal and regulatory gaps, environmental concerns, and socio-cultural barriers. These barriers were emphasising the technological, institutional, and cultural challenges Sri Lanka encounters while adopting advanced construction methods. The study concludes overcoming such barriers must follow a concerted approach of government, industry stakeholders, and academia in delivering standards, training, financial support, and awareness initiatives.

Keywords: *3D printing concrete, Construction innovation, Technology adoption*

1. Introduction

The construction industry has long been recognised as one of the most resource-intensive industries in the world and one that contributes far more to national economies and environmental impacts (Windapo and Cattell, 2013). In Sri Lanka, the sector is particularly important in sustainable development, infrastructure development and city development, but they are also affected by problems such as delay of projects, cost overruns, lack of labour and transfer low productivity (Durdyev & Ismail 2016). These recurring problems have formed a need to adopt new construction technologies that will help address inefficiencies and enhance sustainability (Waqar et al., 2024).

To mitigate these problems, construction technologies such as Building Information Modeling (BIM), robotics, augmented reality (AR), virtual reality (VR) and 3D printed concrete (3DPC) have been established in the industry (Oesterreich & Teuteberg, 2016; Zhang et al., 2013). Among them, 3DPC holds a unique position, as it revolutionises the construction process by directly manufacturing concrete components or entire structures from digital models, eliminating the need for formwork, and minimising human intervention (Bos et al., 2016). The layer-by-layer building process has the benefits of architectural freedom, shorter development cycles, and the use of more sustainable materials (Tay et al., 2017). The potential and viability of 3DPC have been proved by the projects such as 3D-printed office in Dubai, the pedestrian bridges in the Netherlands, the low-cost housing development in Mexico (Bhattacherjee et al., 2021; Gebhard et al., 2022; Salet et al., 2018).

When considering the benefits of 3DPC include reduction in construction time, improved material efficiency, reduced labour ability, increased sustainability and the ability to make complex geometries, which usually is difficult to make using the conventional techniques (Tay et al, 2017; Paul et al., 2018). Importantly, 3DPC also represents opportunities to utilise other types of binder, recycled aggregates, and waste materials as well; contributing to circular economy principle within the construction domain (Alhumayani et al., 2020).

Despite the ongoing positive development throughout the world, Sri Lanka has yet to convert rhetoric into broad practice regarding 3DPC. The domestic construction industry is still limited to traditional, labour-intensive methods that are becoming unsustainable due to rising construction material prices, the shortage of skilled labour, and deteriorating environmental factors (Cooray & Coomasaru, 2022). This lack of adoption leaves a critical research gap in that, although global literature exists reporting barriers to 3DPC across the board, there is little information about special challenges that exist in developing countries like Sri Lanka, where institutional frameworks, availability of resources and the cultural elements are also quite different from those in developed countries. This study fills the void and systematically identifies and analyse the barriers to implement 3DPC in Sri Lanka. Through it, it aims to educate policy makers, practitioners, and researchers on the contextual challenges that must be surmounted to facilitate successful uptake.

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2. Literature Review

2.1. EVOLUTION OF 3D PRINTING CONCRETE
3D printing, or additive manufacturing, was originally developed for polymer purposes in the 1980s, with the earliest patents targeting the development of rapid prototyping and product design (Gibson et al., 2015). By the 1990s, cementitious materials started to be experimented by researchers providing the basis for 3D Printing Concrete (3DPC) (Buswell et al., 2018). The principle of 3DPC consists of the extrusion of cement-based mix layer by layer without the assistance of any formwork and under the command of computer-aided design (Bos et al., 2016).

Advancements in hardware have made 3DPC a much more feasible technology (Tu et al., 2023). Gantry systems and robotic arms ensure fine material placement and large-scale printers allow the fabrication of full-size structural parts (Paul et al., 2018). Parallel technologies have been developed in terms of software which have led to better digital modelling and integration with building information modelling (BIM) platforms, leading to better workflows from design to production (Tay et al., 2017). In addition, research into rheology and material science yielded printable mixes with improved characteristics such as buildability and flowability as well as initial strength development to allow for the construction of multi-storey structures (Xiao et al., 2021).

2.2. BENEFITS OF 3D PRINTING CONCRETE
One of the major benefits of 3DPC technique is that the process can decrease construction time by avoiding time-consuming activities such as formwork installation and manual labour (Tay et al., 2017). Studies report a reduction in construction time of up to 70% with the use of 3DPC in comparison with traditional methods (Buswell et al. 2020). Another significant advantage is cost savings especially in terms of labour and formwork and the cost of these items traditionally represent a major part of work funding (Allouzi et al., 2020).

3DPC further leads to sustainability in terms of material waste and efficiency of structural forms (Alhumayani et al., 2020). The use of supplementary cementitious materials, recycled aggregates, and alternative binders such as the use of geopolymers contributes to an improved environmental profile of 3DPC (Paul et al., 2018). Furthermore, the technology enables a level of design freedom that has no real comparison with conventional constructs, especially in ways that enable organic and customised designs since it enables architects to manufacture architectural forms which are otherwise difficult or impossible with conventional methods (Seifan, 2024).

2.3. GLOBAL APPLICATIONS OF 3D PRINTING CONCRETE
Several international projects demonstrate the growing feasibility and real-world applicability of 3DPC. In February 2024, Germany completed The Wave House in Heidelberg, recognised as the largest 3D-printed building in Europe and a milestone in automated construction (Pall, 2024). The Kingdom of Saudi Arabia has also advanced significantly with the Abdulaziz Abdullah Sharbatly Mosque, the world's first 3D-printed mosque (Fakharany, 2024). Switzerland further pushed global boundaries with Tor Alva, completed in 2025, which stands as the world's tallest 3D-printed building (Crook, 2025). Earlier pioneering examples include the Office of the Future in Dubai, completed in 2016, which is widely recognised as the world's first functional building constructed using 3DPC technology and showcases the design flexibility and efficiency of 3D-printed construction (Bhattacherjee et al., 2021). Similarly, the 3D-printed pedestrian bridge built by Eindhoven University of Technology in the Netherlands demonstrated structural performance and durability (Salet et al., 2018). In China, Winsun showcased rapid mass production of housing units using large-scale printers without formwork (Xu et al., 2019). Dubai continues to lead with policies requiring 25% of new buildings to incorporate 3D printing by 2030, while companies such as ICON in the United States are advancing affordable 3D-printed housing initiatives (Cohen, 2021). Collectively, these global initiatives illustrate that 3DPC has progressed from experimental trials to increasingly practical and scalable construction applications.

2.4. GLOBAL BARRIERS TO 3DPC IMPLEMENTATION
Despite the promise of it, 3DPC adoption is limited due to several challenges (Ambily et al., 2023). High capital investment cost is also a major obstacle because the network of buying and maintaining large-scale printers are a major investment in terms of resources (Buswell et al., 2018). There is material limitations associated with adoption as well, as conventional concrete mixtures do not lend themselves to extrusion without adjustment (Paul et al., 2018). Another important barrier is the lack of well-trained workforce as 3DPC requires knowledge not only of digital modelling, but also of construction materials - a shortage of skilled labour means that the conversion of data into a 3D printed structure demand cross-disciplinary knowledge (Cohen, 2021). Regulatory and institutional issues are prominent. Most of the countries do not have building codes and safety standards for 3DPC which leads to legal uncertainties in the minds of engineers and contractors (Mogale, 2023). In addition, there are ongoing concerns of challenges in structural durability of printed elements, especially under varied climatic conditions and long term loading conditions (Xiao et al., 2021). Finally, cultural resistance in the building industry also causes adoption to move slower, as several stakeholders may favour the traditional labour-intensive methods that are perceived to be more dependable (Seifan, 2024).

In developing countries such challenges are augmented by the poor institutional frameworks, financial constraints, and low technological infrastructure of these populations. For instance, research from Africa in particular stresses racism and the lack of local suppliers and reliance on imported equipment as major barriers to construction innovation (Mogale, 2023). Based on the research in South Asia, it has been suggested that limited awareness, poor training, and low capacity for investment pose barriers to the adoption of technologies of advanced controversy (Xiao et al., 2024). Such factors imply that unless there is intervention by governments or more specific policy support, the spread of 3DPC across developing contexts will be slow. Although Sri Lanka has emphasised the significance of innovation and construction, research on the 3DPC is yet scarce (Cooray & Coomasaru, 2022). The country experiences some special difficulties, where there are limitations on foreign exchange and the cost of construction is high and rely on labour-intensive practises, which could also be a reason for further limiting the use of 3DPC (Ambily et al., 2023). Moreover, there is no systemic study in categorisation of barriers to 3DPC in Sri Lankan context. There is a need to address this gap because Sri Lanka is in the dire need of affordable, sustainable, and efficient construction solutions to meet the rising housing and infrastructure demands (Durdyev and Ismail, 2016).

3. Methodology

This study used a qualitative research design to gain insights into the existing complex and context specific challenges of the implementation of 3D Printing Concrete (3DPC) technology in Sri Lanka. A qualitative approach was appropriate because the topic is under-researched locally, and no official statistical data specifically track 3DPC adoption in Sri Lanka. However, related industry indicators such as CIDA reports on rising construction material costs and persistent labour shortages were used to contextualise and support the interpretation of interview findings. Data collection was conducted using semi-structured interviews with fourteen participants (Table 1) who were recruited by using purposive and snowball sampling. The participants comprised the amalgamation of Sri Lankan academics, engineers, construction managers, and international experts with awareness of 3DPC, providing for a wide perspective on the subject. Semi-structured interviews offered the flexibility to pursue burgeoning themes while at the same time ensuring consistency across interviews, which lasted between 30 to 45 minutes. The themes related to the materials availability, cost implications, construction feasibility, stakeholder perceptions, and legal frameworks were developed as a guide for the interviews. The data were transcribed and analysed with manual content analysis, where recurring statements were coded and grouped into the categories. This process eventually led to the identification of seven broad categories of barriers including those related to resources, financial issues, construction-related barriers, stakeholder-related barriers, legal and regulatory barriers, environmental barriers, and socio-cultural barriers. The use of expert views helped to ensure that findings reflected both practical realities and academic perspectives, whilst international participants allowed for comparisons between Sri Lanka and where 3DPC has already been evaluated. To ensure credibility the coding process was iterative and cross-checked to minimise bias. While the research has limitations because it relied on perceptions versus field trials in the empirical study, such an approach is not out of place in exploratory research in adoption of innovativeness where expert interpretation is often the source of best evidence of established industry data. Overall, the methodological design was a systematic way of identifying the barriers of 3DPC in Sri Lanka, as well as ensuring that the findings arise both from the global and local realities.

Following table present the summary of the experts.

Table 1: Caption (*Source: If applicable*)

Expert Code	**Designation**	**Experience (Years)**		**Key expert area related to the study**
		Industry	**Academic**	
E1	Senior Lecturer - Quantity surveying	-	13	Construction technologies
E2	Architect	5	3	3DPC
E3	Cost Manager	7	-	Construction Management
E4	Civil Engineer	4	4	3DPC, Construction Materials
E5	Architect	13	-	3DPC
E6	Senior Lecturer - Civil Engineer	-	12	3DPC, Construction technologies
E7	Construction Project Manager	16	-	3DPC, Construction technologies
E8	Civil Engineer	4	-	3DPC
E9	PhD. Scholar-Civil Engineering	5	2	3DPC, BIM
E10	Lecturer - Quantity Surveying	-	4	Construction technologies
E11	Production Engineer	20	-	3DPC, Additive manufacturing
E12	Civil Engineer	4	5	3DPC, Construction technologies

E13	Civil Engineer	4	8	3DPC, Construction technologies
E14	Research Assistant	2	2	Construction Manage-ment

4. Findings

The findings of the fourteen interviews held with experts identified seven categories of barriers which collectively impact the implementation of 3D Printing Concrete (3DPC) in Sri Lanka. These barriers include resource-related, financial, construction-related, stakeholder-related, legal, and regulatory, environmental, and socio-cultural challenges. Each of these categories is discussed in detail below with support of expert responses.

4.1. RESOURCE-RELATED BARRIERS

A key finding was the severe limitation in terms of resources that are required to initiate 3DPC in Sri Lanka. One of the indicators which experts emphasised was that the country lacks the access to advanced 3D printing equipment, with no locally available 3D printing equipment capable of producing outputs that would be relevant for structural scales. According to E01, *"Currently, Sri Lanka lacks 3D printers with construction-specific applications and the importing of such equipment has been expensive and rather complicated because of technical requirement".* This lack of infrastructure makes it even hard to start out with pilot projects. Material availability was another timely issue since Sri Lankan cementitious materials are not optimised for extrusion. E04 explained, *"We might not suit our cement and aggregates to the needs of the rheological properties for 3D printing".* Without specialised additives or imported binders, it is tough to get the flowability and buildability required. Furthermore, experts said that it is not supported by adequate facilities for e.g. testing laboratories, calibration centres, and maintenance hubs, thus deterring investment in the technology. These constraints related to the availability of resources constitute the root of any impediment made towards a serious attempt at 3DPC in the country.

4.2. FINANCIAL BARRIERS

Financial problems became one of the most important barriers to the adoption of 3DPC. The initial capital investment needed to acquire 3D printers at the large scale is very heavy. E07 noted, *"Even if the technology is available the price of one printer can match a couple of million rupees, which no local contractor would risk obtaining without a demonstrated demand".* Integration costs are also a challenge, as firms would need to adjust pre-existing workflows and re-train staff on how to use the new system. E10 stated that *"The issue is not only about to purchase the machine, but it is a matter of changing the entire process of the construction".* That transition has a hidden cost. Maintenance costs were also mentioned as a problem and the lack of local availability of spare parts and technical knowledge. E02 commented, *"If the printer breaks down international parts would have to be imported or foreign specialists would have to be brought in, which adds ongoing costs that most companies cannot afford".* Collectively these, financial constraints make 3DPC adoption, highly unattractive to the private on firm, unless Government support or incentives are introduced.

4.3. CONSTRUCTION-RELATED BARRIERS

Several practical challenges in relation to answers and construction processes were identified. Experts pointed out that buildability is also a consideration because current 3D printing technology has a challenging time with large-scale or high-rise projects. E03 commented that, "It is not yet clear how much 3D printing can be scaled up to multi-storey construction, which is the main demand in urban Sri Lanka." Site preparation was another problem, because many Sri Lankan construction sites do not possess the stable and controlled conditions required for automated printing. E05 found, "Our sites are simply not facilitated for robotic devices-space or power supply, and surface often leave much to be desired." Uncertainty in cost estimation was also highlighted as one of the parties residing challenges as benchmarks for printed structures do not exist from in Sri Lanka to complicate the tendering and planning processes. Durability was another concern: Emphasising these, E09 write, "We do not yet know how these structures would behave in a tropical climate with high humidity, heavy rains, and saline conditions." This construction related issues can be said to highlight technical and environmental mismatch between 3DPC and Sri Lankan conditions.

4.4. STAKEHOLDER-RELATED BARRIERS

Stakeholder perceptions turned out to be another critical obstacle. Experts said many construction professionals in Sri Lanka are still sceptical about how 3DPC could in practise work. E06 said, "There is a mindset remaining that conventional methods are more safe and more dependable; people are reluctant to invest in something they don't fully trust." This scepticism is associated with lack of awareness and training from an engineer and contractor point of view, in that, the technology is not widely taught in universities, or engineer or contractor programmes. E08 commented, "We don't know people yet who are specialists in things like 3D Printing construction." Even if the machines come to stuff, who is going to drive them?" Labour-related issues also came out vociferously. As E11 explained, "There is a perception among workers, particularly masons and formwork carpenters see this as a threat to their livelihoods and that creates resistance." To overcome the difficulty of adopting the system, this combination of professional scepticism, skills shortages and labour pushback moves stakeholder acceptance to one of the most difficult barriers to overcome in the near term.

4.5. LEGAL AND REGULATORY BARRIERS

Experts unanimously agreed that lack of legal frameworks and lack of national standards is a major obstacle to 3DPC implementation in Sri Lanka. E01 commented, "There is no clause in our building codes that recognises 3D printed structures, hence any project will have legal complications in approval." Liability in the case of structural failure was another grey area. E07 called attention to, "If a printed wall collapses, who is responsible -- the printer manufacturer, the contractor, or who designs it?" This is not yet defined." Furthermore, lack of government policies and incentives currently favours the introduction of 3DPC. E13 highlighted, "Other countries have national policies pushing 3D printing [but] here, the government has not even started a conversation on it." Without legal recognition and institutional support, how dangerous is 3DPC compared to potential benefits from 3DPC to most stakeholders.

4.6 ENVIRONMENTAL BARRIERS

Environmental issues have also been listed as inhibitions, especially regarding energy consumption and material finding. E04 commented, "These printers use a lot of electricity, and given our unstable energy supply this becomes a practical problem." The dependency on imported binders and admixtures also increases the sustainability concerns because it increases the carbon footprint of projects. E12 explained, "If the raw materials have to come from abroad, we can't claim this is sustainable construction." In addition, there appears to be little work done locally on the environment lifecycle impacts of 3DPC structures in Sri Lankan conditions. As E02 stated, "We don't know how these buildings are going to perform environmentally through the decades; and that's a knowledge gap that's a barrier in itself." These concerns underpin the message that the ambitions of sustainability, which form a fundamental selling point for 3DPC at strategic levels globally, may not be able to be fully realised in Sri Lanka without localised adaptation.

4.7. SOCIO-CULTURAL BARRIERS

Finally, socio-cultural resistance was revealed as the important barrier unique to the Sri Lankan context as a barrier. The construction industry has a culture of working by manual labour and this Ed pixelates position client and contractor. E09 noted, "Clients here like to have the workers there, and they equate numbers with quality and progress." A machine constructing a house could invoke no such confidence. Similarly, conservative attitudes in the industry do not encourage experimentation. E05 commented, "our industry is cautious, often too cautious; similarly, people like to use the methods they know." There has also been a cultural preference to maintain traditional artisanry resulting in a clash of the automated and digital nature of 3DPC. E14 summed this up: "In Sri Lanka, construction is not only about buildings, but also about people and employment; replacing that with machines is socially difficult." This socio-cultural barrier means that even when financial, technical, and regulatory issues are solved, it may be slow in accepting such vehicles among the society and industry until then.

Table 2 below summarises the identified barriers and expert responses regarding whether they agree or disagree with the barriers identified from the literature review and expert suggestions to implementing 3DPC technology in Sri Lanka.

Table 2: Identified Barriers

Barriers	**Identified by Lit.**	**Suggested by experts**	**Experts who agreed**
Resource related			
Selection of Suitable Materials	[1], [2]		E04, E05, E06, E08, E09, E10, E11, E13
Selections of Suitable 3D Printers	[3], [4]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Selection of Suitable software for 3D Printers	[1], [2]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Geometrical limitations of 3D Printers	[5], [6]		E01, E02, E03, E04, E06, E07, E08, E09, E10, E11, E13
Cyber Security	[7]		E10, E12, E13
Financial related			
High initial investment cost	[4], [8]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
High integration cost with traditional industry	[9], [10]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
High operational and maintenance cost	[10], [11]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Construction related			
Material Delivery and Placement	[11], [12]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Site Setup	[13], [14]		E01, E02, E03, E04, E06, E07, E08, E09, E10, E11, E13, E14
Preparation of Cost Estimation	[15], [16]		E04, E06, E13

Buildability - Difficult to Print a Bulk Quantity in One Time	[12]		E01, E02, E03, E04, E06, E07, E08, E09, E10, E11, E13, E14
Construction Scheduling	[17]		E06, E10, E13
Resistance to Change in Traditional Industry		√	E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Stakeholders related			
Scepticism about the potential of 3D printing	[8]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Lack of Specialists or trained professionals	[15], [17]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
New skills for the workers	[17]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Environmental related			
High Energy Consumption	[13]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Climatic conditions		√	E05, E07, E09, E10, E11, E12, E13
Legal and Regulations related			
Lack of Regulation Codes	[13], [18]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Liability issues	[18]		E01, E02, E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Socio-Cultural Barriers			
Limited Public Awareness of 3DPC		√	E03, E04, E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Absence of R&D in 3DPC		√	E05, E06, E07, E08, E09, E10, E11, E12, E13, E14
Cultural resistance to new housing aesthetics		√	E03, E06, E08, E10, E11, E12, E13, E14
Reference: [1]. (Li et al., 2020), [2]. (Paul et al., 2018), [3]. (Hack et al., 2020), [4]. (Shahzad et al., 2022), [5]. (Bos et al., 2016), [6]. (Costanzi et al., 2018), [7]. (Labonnote et al., 2016), [8]. (El-Sayegh et al., 2020), [9]. (Hosseini et al., 2015), [10]. (Alzarrad & Elhouar, 2019), [11]. (Mechtcherine et al., 2020), [12]. (Xiao et al., 2021), [13]. (Friis, 2020), [14]. (Shaker et al., 2021), [15]. (Wang, 2024), [16]. (Ma et al., 2022), [17]. (Tay et al., 2017), [18]. (Panda & Tan, 2018)			

5. Discussion

The findings of this study reveal that the implementation of 3D Printing Concrete (3DPC) in Sri Lanka is constrained by a complex set of interrelated challenges spanning technical, financial, institutional, environmental, and socio-cultural dimensions. These factors collectively create an environment in which the adoption of advanced construction technologies remains extremely difficult. Resource-related barriers, including the absence of large-scale printing equipment and locally compatible printable materials, highlight that the country does not yet possess the foundational infrastructure required to support 3DPC. Without such prerequisites, even pilot-level applications are unlikely to be feasible.

Financial barriers further intensify these limitations. The high cost of acquiring and maintaining 3DPC equipment, coupled with reliance on imported additives, creates significant financial risk for private-sector organisations. When combined with existing industry challenges such as fluctuating material prices and ongoing financial instability the introduction of an expensive new technology becomes particularly prohibitive. This situation reinforces expert concerns that 3DPC adoption will remain unattractive without substantial external incentives.

Construction-related constraints also emerged as critical. Experts emphasised uncertainties regarding buildability, site preparation, and long-term durability, particularly under Sri Lanka's tropical climatic conditions. As E09 noted, "We do not yet know how printed elements will behave under long-term exposure to humidity, rainfall, or saline environments", underscoring the need for empirical performance data. These concerns heighten industry hesitation, especially in the absence of local standards or successful reference projects.

Stakeholder-related barriers further slowdown potential adoption. Construction professionals expressed hesitation towards unfamiliar automated processes, while labour groups feared displacement. Such perceptions reinforce the deep-rooted preference for conventional methods. Legal and regulatory barriers amplify these uncertainties, as the absence of standards, approval mechanisms, and liability frameworks discourages experimentation. Environmental considerations, including high energy consumption and dependency on imported raw materials, weaken the perceived sustainability gains of 3DPC when applied within the Sri Lankan context.

Socio-cultural resistance adds an additional layer of complexity. The industry's strong preference for labour-intensive construction, coupled with client expectations of visible manual work, limits the acceptance of automated systems. These entrenched cultural norms pose long-term challenges, even if technical and financial hurdles are resolved.

Overall, the results demonstrate that the transition toward 3DPC is constrained not by a single dominant barrier but by the cumulative effect of multiple interconnected challenges. Addressing these barriers will require a coordinated effort among policymakers, industry practitioners, academic institutions, and technology suppliers to strategically guide Sri Lanka toward a more sustainable and technologically advanced construction landscape.

6. Conclusion and Recommendations

This study discussed the barriers for implementation of 3DPC technology in Sri Lanka. Through a qualitative research design consisting of semi-structured interviews with fourteen peers of experts, seven categories of barriers were identified: resource related, financial, construction, stakeholder, legal and regulatory, environmental, and socio-cultural. The results confirm that while 3DPC has the potential to provide immense benefits such as less construction time, smaller waste and better design flexibility, there are complex and linked challenges in their adoption in Sri Lanka. Resource-related barriers such as lack of equipment, and appropriate raw materials, comprise the most immediate barriers. Financial barriers, including high upfront investment costs and maintenance services, unmake private sector adoption without the support of the government. Construction-related problems, such as buildability, site preparation and durability in tropical climates cast doubt over the technical feasibility. Stakeholder resistances, related both to professionals and labour groups, sketch a profound degree of scepticism and fears on issues of job displacement. Legal and regulatory gaps, such as the lack of standards and liability frameworks, are the most significant barrier, because they generate institutional uncertainty. Environmental issues of energy consumption and the importation of materials bring down the sustainability case for 3DPC, whereas socio-cultural difficulties relate to conservative attitudes that promote traditional methods of work and continued employment.

Based on these findings, number of recommendations are presented. First, policy intervention is required. The government really should create national standards and codes for 3DPC and generate regulatory clarity. Incentives like subsidies, tax concession or public-private partnership can help overcome high capital costs and die to incentivize pilot projects. Second, capacity building is particularly important. Universities and professional institutes should include 3DPC in the curriculum and training programme to ensure engineers and contractor have enough skills. Third, awareness and acceptance can be strengthened through pilot construction trials, technology exhibitions, and structured knowledge-sharing platforms that demonstrate tangible benefits. Fourth, there should be a focus in research and innovation, at the local level, devoted to localising the materials to Sri Lankan needs, including tropical spatial durability, and energy-efficient printing approaches. Finally, issues of cultural acceptance will have to be overcome by adopting a view of 3DPC not as a replacement of labour, but as a complement, one that engenders novel roles in design, in machine operation and quality assurance. Finally, Sri Lanka is at a significant crossroads where it can achieve change within its construction industry through the adoption of technological innovation.

This study provides an important contribution to sustainable construction research by offering the first context-specific analysis of barriers to adopting 3D Printing Concrete (3DPC) technology in Sri Lanka. By integrating insights from local and international experts, the study highlights how technological, financial, institutional, and socio-cultural constraints collectively hinder the uptake of a construction method that could significantly reduce material waste, labour dependency, and environmental impact. However, the research is limited by its reliance on qualitative interviews without empirical pilot testing, which restricts the validation of sustainability-related performance claims. The small sample size, although appropriate for exploratory research, may not fully capture the diversity of industry views. Additionally, the absence of national 3DPC data required the use of broader sustainability indicators. As 3DPC technology evolves rapidly, continuous research is needed to assess long-term environmental performance and local material suitability.

Future research should focus on (i) conducting real-world pilot projects to validate technical performance under Sri Lankan conditions, (ii) developing cost–benefit models comparing 3DPC with conventional methods, (iii) exploring policy mechanisms that incentivise safe adoption, and (iv) evaluating long-term environmental and structural performance through local life-cycle studies.

Whilst barriers to 3DPC adoption are significant, they are not insurmountable. With concerted efforts across policies, industries and academia, Sri Lanka can overcome these barriers in a phased and move forward to reap the benefits of 3DPC for sustainable, efficient, and affordable infrastructure development.

7. References

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

Allouzi, R., Al-Azhari, W., & Allouzi, R. (2020). Conventional Construction and 3D Printing: A Comparison Study on Material Cost in Jordan. *Journal of Engineering*, *2020*, 1–14. https://doi.org/10.1155/2020/1424682

Alzarrad, M. A., & Elhouar, S. (2019). 3D Printing Applications in Construction from the Past and into the Future. *Proceedings of the Creative Construction Conference 2019*, 754–760. https://doi.org/10.3311/CCC2019-103

Ambily, P., Kaliyavaradhan, S. K., & Rajendran, N. (2023). Top challenges to widespread 3D concrete printing (3DCP) adoption – A review. *European Journal of Environmental and Civil Engineering*, *28*(2), 300–328. https://doi.org/10.1080/19648189.2023.2213294

Bhattacherjee, S., Basavaraj, A. S., Rahul, A. V., Santhanam, M., Gettu, R., Panda, B., Schlangen, E., Chen, Y., Copuroglu, O., Ma, G., Wang, L., Basit Beigh, M. A., & Mechtcherine, V. (2021). Sustainable materials for 3D concrete printing. *Cement and Concrete Composites*, *122*, 104156. https://doi.org/10.1016/j.cemconcomp.2021.104156

Bos, F., Wolfs, R., Ahmed, Z., & Salet, T. (2016). Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing. *Virtual and Physical Prototyping*, *11*(3), 209–225. https://doi.org/10.1080/17452759.2016.1209867

Buswell, R. A., De Silva, W. R. L., Jones, S. Z., & Dirrenberger, J. (2018). 3D printing using concrete extrusion: A roadmap for research. *Cement and Concrete Research*, *112*, 37–49. https://doi.org/10.1016/j.cemconres.2018.05.006

Buswell, R. A., De Silva, W. R. L., Bos, F. P., Schipper, H. R., Lowke, D., Hack, N., Kloft, H., Mechtcherine, V., Wangler, T., & Roussel, N. (2020). A process classification framework for defining and describing Digital Fabrication with Concrete. *Cement and Concrete Research*, *134*, 106068. https://doi.org/10.1016/j.cemconres.2020.106068

Cohen, Z. (2021). Recasting Concrete: A Case Study in Concrete 3D Printing as an Architectural Pedagogy. *Expanding The View*, 192–199. https://doi.org/10.35483/ACSA.AM.109.28

Cooray, N. K. V., & Coomasaru, P. (2022). Adoption of 3D printing technology in Sri Lanka's construction industry. *15th International Research Conference - FARU 2022*, 102–109. https://doi.org/10.31705/FARU.2022.12

Costanzi, C. B., Ahmed, Z. Y., Schipper, H. R., Bos, F. P., Knaack, U., & Wolfs, R. J. M. (2018). 3D Printing Concrete on temporary surfaces: The design and fabrication of a concrete shell structure. *Automation in Construction*, *94*, 395–404. https://doi.org/10.1016/j.autcon.2018.06.013

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications, Incorporated.

Crook, L. (2025). World's tallest 3D-printed tower unveiled in Switzerland. *Dezeen.* https://www.dezeen.com/2025/05/21/worlds-tallest-3d-printed-tower-tor-alva/

Durdyev, S., & Ismail, S. (2016). On-site construction productivity in Malaysian infrastructure projects. *Structural Survey*, *34*(4–5), 446–462. https://doi.org/10.1108/SS-12-2015-0058

El-Sayegh, S., Romdhane, L., & Manjikian, S. (2020). A critical review of 3D printing in construction: benefits, challenges, and risks. In *Archives of Civil and Mechanical Engineering* (Vol. 20, Issue 2). Springer. https://doi.org/10.1007/s43452-020-00038-w

Fakharany, N. (2024, July 23). *World's First-Ever 3D printed mosque opens in Jeddah, Saudi Arabia.* ArchDaily. https://www.archdaily.com/1014542/worlds-first-ever-3d-printed-mosque-opens-in-jeddah-saudi-arabia

Friis, K. (2020). *3D printed concrete bridges: Opportunities, Challenges, and Conditions*.

Gibson, I., Rosen, D. W., & Stucker, B. (2015). *Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing* (2nd ed.). Springer.

Gill, S. L. (2020). Qualitative Sampling Methods. *Journal of Human Lactation*, *36*(4), 579–581. https://doi.org/10.1177/0890334420949218

Hack, N., Dressler, I., Brohmann, L., Gantner, S., Lowke, D., & Kloft, H. (2020). Injection 3D Concrete Printing (I3DCP): Basic Principles and Case Studies. *Materials*, *13*(5), 1093. https://doi.org/10.3390/ma13051093

Hosseini, M. R., Chileshe, N., Zuo, J., & Baroudi, B. (2015). Adopting global virtual engineering teams in AEC Projects: A qualitative meta-analysis of innovation diffusion studies. *Construction Innovation*, *15*(2), 151–179. https://doi.org/10.1108/CI-12-2013-0058

Kim, K., Park, S., Kim, W., Jeong, Y., & Lee, J. (2017). Evaluation of Shear Strength of RC Beams with Multiple Interfaces Formed before Initial Setting Using 3D Printing Technology. *Materials*, *10*(12), 1349. https://doi.org/10.3390/ma10121349

Labonnote, N., Ronnquist, A., Manum, B., & Ruther, P. (2016). Additive construction: State-of-the-art, challenges and opportunities. *Automation in Construction*, *72*, 347–366. https://doi.org/10.1016/j.autcon.2016.08.026

Li, Z., Hojati, M., Wu, Z., Piasente, J., Ashrafi, N., Duarte, J. P., Nazarian, S., Bilen, S. G., Memari, A. M., & Radlińska, A. (2020). Fresh and Hardened Properties of Extrusion-Based 3D-Printed Cementitious Materials: A Review. *Sustainability*, *12*(14), 5628. https://doi.org/10.3390/su12145628

Loosemore, M. (2013). Innovation, strategy and risk in construction. In *Routledge eBooks*. https://doi.org/10.4324/9780203809150

Ma, G., Buswell, R., De Silva, W. R. L., Wang, L., Xu, J., & Jones, S. Z. (2022). Technology readiness: A global snapshot of 3D concrete printing and the frontiers for development. *Cement and Concrete Research*, *156*, 106774. https://doi.org/10.1016/j.cemconres.2022.106774

Mechtcherine, V., Bos, F. P., Perrot, A., De Silva, W. R. L., Nerella, V. N., Fataei, S., Wolfs, R. J. M., Sonebi, M., & Roussel, N. (2020). Extrusion-based additive manufacturing with cement-based materials – Production steps, processes, and their underlying physics: A review. *Cement and Concrete Research*, *132*, 106037. https://doi.org/10.1016/j.cemconres.2020.106037

Mogale, S. P. (2023). *3D Concrete Printing Technology: Enhancing Productivity in the South African Construction Industry-Exploring the Benefits, Barriers, and Improvement Strategies*. https://scholar.sun.ac.za

Noy, C. (2008). Sampling Knowledge: The Hermeneutics of snowball sampling in Qualitative research. *International Journal of Social Research Methodology*, *11*(4), 327–344. https://doi.org/10.1080/13645570701401305

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2013). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research*, *42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Pall, L. (2024,). *Heidelberg inaugurates Europe's largest 3D printed building: the Wave House Data Center.* COBOD. https://cobod.com/heidelberg-inaugurates-europes-largest-3d-printed-building-the-wave-house-data-center/

Panda, B., & Tan, M. J. (2018). Experimental study on mix proportion and fresh properties of fly ash based geopolymer for 3D concrete printing. *Ceramics International*, *44*(9), 10258–10265. https://doi.org/10.1016/j.ceramint.2018.03.031

Paul, S. C., Zijl, G. P. A. G. V., Tan, M. J., & Gibson, I. (2018). A review of 3D concrete printing systems and materials properties: current status and future research prospects. *Rapid Prototyping Journal*, *24*(4), 784–798. https://doi.org/10.1108/RPJ-09-2016-0154

Salet, T. A. M., Ahmed, Z. Y., Bos, F. P., & Laagland, H. L. M. (2018). Design of a 3D printed concrete bridge by testing. *Virtual and Physical Prototyping*, *13*(3), 222–236. https://doi.org/10.1080/17452759.2018.1476064

Seifan, M. (2024). Sustainable three-dimensional printing concrete: advances, challenges, and future direction. In *Sustainable Concrete Materials and Structures* (pp. 343–370). Elsevier. https://doi.org/10.1016/B978-0-443-15672-4.00012-7

Shahzad, Q., Umair, M., & Waqar, S. (2022). Bibliographic analysis on 3D printing in the building and construction industry: Printing systems, material properties, challenges, and future trends. *Journal of Sustainable Construction Materials and Technologies*, *7*(3), 198–220. https://doi.org/10.47481/jscmt.1143239

Shaker, A., Khader, N., Reiter, L., & Anton, A. (2021). *3D Printed Concrete Tectonics*. 420–427. https://doi.org/10.52842/conf.acadia.2021.420

Tay, Y. W. D., Panda, B., Paul, S. C., Mohamed, N. A. N., Tan, M. J., & Leong, K. F. (2017). 3D printing trends in building and construction industry: a review. In *Virtual and Physical Prototyping* (Vol. 12, Issue 3, pp. 261–276). Taylor and Francis Ltd. https://doi.org/10.1080/17452759.2017.1326724

Tu, H., Wei, Z., Bahrami, A., Kahla, N. B., Ahmad, A., & Özkılıç, Y. O. (2023). Recent advancements and future trends in 3D concrete printing using waste materials. Developments in the Built Environment, 16, 100187. https://doi.org/10.1016/j.dibe.2023.100187

Wang, J., Liu, Z., Hou, J., & Ge, M. (2024). Research Progress and Trend Analysis of Concrete 3D Printing Technology Based on CiteSpace. *Buildings*, *14*(4), 989. https://doi.org/10.3390/buildings14040989

Waqar, A., Alrasheed, K. A., & Benjeddou, O. (2024). Enhancing construction management outcomes through the mitigation of robotics implementation barriers: A sustainable practice model. *Environmental Challenges*, *16*, 100989. https://doi.org/10.1016/j.envc.2024.100989

Windapo, A. O., & Cattell, K. (2013). The South African Construction Industry: Perceptions of Key Challenges Facing Its Performance, Development and Growth. In *Journal of Construction in Developing Countries* (Vol. 18, Issue 2).

Xiao, J., Xu, Z., Xiao, A., Wang, X., & Skare, M. (2024). Overcoming barriers and seizing opportunities in the innovative adoption of next-generation digital technologies. *Journal of Innovation & Knowledge*, *9*(4), 100622. https://doi.org/10.1016/j.jik.2024.100622

Xiao, J., Liu, H., Ding, T., & Ma, G. (2021). 3D printed concrete components and structures: an overview. *Sustainable Structures*, *1*(2). https://doi.org/10.54113/j.sust.2021.000006

Xu, J., & Ding, L. (2018). Volume - forming 3D concrete printing using a variable - diameter square nozzle. *Creative Construction Conference 2018 - Proceedings*, 104–113. https://doi.org/10.3311/CCC2018-015