ADOPTION OF 3D PRINTING TECHNOLOGY IN SRI LANKA'S CONSTRUCTION INDUSTRY

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Abstract: The construction industry does have a history of embracing new technologies more slowly than other sectors. 3D construction is a revolutionary technology that has recently identified as a possible technology with the potential to enhance the construction industry's effectiveness and efficiency. This research attempts to provide strategies for integrating this technology into the Sri Lankan construction industry. Using NVIVO, a literature review was carried out and recorded. First, a prototype questionnaire survey was conducted based on findings from the literature, followed by a regular questionnaire survey with 39 professionals with 5 to 20 years of experience to identify bottlenecks and enablers. In addition to the questionnaire, interviews were conducted with three experts with more than 30 years of professional experience to validate its outcomes. "Workforce unprepared to engage with 3D printing," "lack of standards or rules for 3D printing technology," and "high investment requirements" were the top three reported impediments. As enablers, design flexibility, cost advantages, and time savings were highlighted. As a final objective, three strategies were identified: "Conduct training for industry staff on how to interact with 3D printing," "facilitate the collaborative approach (partnering)," and "Construction industry to establish a new set of standards, guidelines, rules and regulations pertaining to adaptation of 3D printing into construction industry."

Keywords: *3D printing, Construction industry, technology, Sri Lanka*

1. Introduction

The world is changing dramatically as a result of technological advancements (Casini, M., 2022a, Casini, M., 2022b). Developing technology and investing in new technologies is a positive step an industry or a nation may take to progress (Chen, X. et al., 2021, Wang, L., 2021). Given the tremendous advancement of new technologies, innovation will continue to be the primary source of corporate advancement in the future. Consequently, technological advancements play a crucial role in a company's approach to commercial success and in the process of addressing customer requirements (Kothman, I. and Faber, N., 2016, Chadha, U. et al., 2022). 3D printing is one of these new technologies that is already being adopted by a variety of sectors and nations around the world. The definition of the term '3D' is that the object or structure is exhibited in three dimensions; adding 'Printing' to the term '3D' refers to the process of manufacturing a three-dimensional structure using a printer (Adepoju, O., 2022, Chadha, U. et al., 2022).

In the construction sector, 3D printing is a technology used to manufacture structures using a completely automated equipment (Malik, A. et al., 2022). Using recently introduced 3D printing technology, it is simple to manufacture complex structures that would be practically difficult to construct by manually. This technology is still in its adolescence, but 3D printing can be used to construct individual building components or the entire structure simultaneously (Ko, C.-H., 2021, Casini, M., 2022b). The process of 3D printing involves a CAD or BIM program instructing the printer on what to print. The 3D printer then begins to lay down materials according on the software's report (Du, X. and Sun, L., 2021, Casini, M., 2022c).

WASP, an Italian company, has considered progressing this technology even further by producing the world's largest 3D printer by combining renewable sources such as solar or wind power with locally available materials, thereby allowing areas without access to electricity to construct using this technology (Hambach, M. et al., 2019, Holt, C. et al., 2019, Casini, M., 2022b, Casini, M., 2022e). Adopting this type of advanced technology in a developing nation like Sri Lanka sounds even more like an insurmountable obstacle. In order to attain both effectiveness and efficiency, it is essential to introduce and implement '3D Printing' technology to the domestic construction industry. Initially, some building components can be prefabricated and then installed.

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2. Literature Review

2.1. INTRODUCTION
Charles Hull, an American physicist widely regarded as the "Father of 3D printing," constructed the first commercial 3D printing equipment in 1986 (Giacomelli, P. and Smedberg, A., 2014, Holt, C. et al., 2019). By laying down successive layers of a specific material until the entire object is created, 3D printing can create physical structures from digital geometric representations through the addition of material in a continuous manner (Giacomelli, P. and Smedberg, A., 2014, Gaudillière, N. et al., 2019). 3D printing was one of the most sophisticated technology, and it was initially complex and expensive. However, as time progressed, 3D printing became more ubiquitous in everyday life, with printers being deployed in a spectrum of companies (Adepoju, O., 2022, Casini, M., 2022b, Chadha, U. et al., 2022, Malik, A. et al., 2022).

2.2. 3D PRINTING TECHNOLOGY IN THE CONSTRUCTION INDUSTRY
The construction industry is one of the most significant contributions to a country's economic development, with a greater economic impact factor and accounting for between 7% and 8.5% of total employment and 9% of world GDP (Casini, M., 2022f). By 2025, worldwide construction investment is projected to reach USD 14 trillion, up from USD 11.4 trillion in 2018 (Nguyen, D.-T. et al., 2022, Shibani, A. et al., 2022). Despite being a significant economic contributor, the construction industry has a long and storied history of conservatism, unwillingness to innovate, and lack of effectiveness in boosting efficiency (Du, X. and Sun, L., 2021, Casini, M., 2022h). Ali, M. H. et al. (2022) expresses concern over the inadequate implementation of 3D printing in the construction industry, considering that this technology is developed to maximize process efficiency. This is the situation regardless of the fact that construction organizations are interested in increasing efficiency (Casini, M., 2022d, Casini, M., 2022e, Wang, R. et al., 2022).
In the construction industry, 3D printing is a technological breakthrough since it revolutionises the industry's operations and substitutes previous technologies (Buchanan, C. and Gardner, L., 2019, Kazemian, A. et al., 2019, Marchment, T. et al., 2019). Conventionally, the worldwide construction business has depended on specifications and 2D drawings to convey material and property specifics, construction information, and performance details (Bentz, D. P. et al., 2019, Xia, M. et al., 2019a). According to Marchment, T. et al. (2019), such specimens are increasingly being replaced with 3D modelling, which is based on a computer-generated program known as Building Information Modelling. In numerous ways, construction companies can utilise 3D printing technology. There will be three distinct phases: 3D printing of architectural models, 3D printing of construction components, and 3D printing of whole building projects (Kothman, I. and Faber, N., 2016, Casini, M., 2022a, Casini, M., 2022b). In the late 1990s, Joseph Pegna suggested to the construction industry a breakthrough concept involving the combination of cement-based materials with 3D printing (Vivek, A. and Hanumantha Rao, C. H., 2022). The completion of the first 3D-printed home in 2014 represented the beginning of a new era in the construction industry and a significant breakthrough throughout the whole construction industry (Casini, M., 2022g, Shibani, A. et al., 2022).

2.3. BENEFITS
The construction business is ideally suited to reap the benefits of 3D printing (Buchanan, C. and Gardner, L., 2019). The most compelling advantage of 3D printing in construction is its ability to raise safety, reduce labor consumption, improve delivery schedules, and enhance design customization (Ali, M. H. et al., 2022, Chadha, U. et al., 2022). This reduction in manpower would save expenses while also enhancing site safety, which is of the utmost importance in hazardous areas (Kothman, I. and Faber, N., 2016, Kazemian, A. et al., 2019). Aside from cost, timeliness, and safety, 3D printing eliminates a number of design constraints (Ko, C.-H., 2021, Chadha, U. et al., 2022). Al Jassmi, H. et al. (2018), Malaeb, Z. et al. (2019) has suggested earlier that automated construction could potentially reduce costly errors and mistakes. In addition, the cost of formwork in construction can account for between 3.5% and 5.4% of the total cost of construction (Buchanan, C. and Gardner, L., 2019, Aghimien, D. et al., 2020, Casini, M., 2022f). By eliminating costly formwork and substituting it with 3D printing technology, not only are expenses and timelines reduced, but so is the amount of trash generated (Gaudillière, N. et al., 2019, Casini, M., 2022a). Holt, C. et al. (2019), Adepoju, O. (2022) has also stated that in addition to saving money on formwork and materials, 3D printing would save money on transportation and installation costs, and it would directly contribute to the reduction of carbon emissions, which pose a threat to global health (Adepoju, O., 2022, Malik, A. et al., 2022). 3D printing can reduce carbon emissions by employing fully electric 3D printers and lowering the amount of resources necessary for transportation, as well as by restricting the number of personnel required, which minimizes the number of vehicles driven to the construction site (Chen, X. et al., 2021).

2.4. TYPES OF 3D PRINTING TECHNOLOGY IN THE CONSTRUCTION INDUSTRY

2.4.1. Contour crafting
When different layers of cement-based paste are trowelled using computer-controlled trowels, the construction crew can achieve a uniform and precise surface finish as intended (Al Jassmi, H. et al., 2018). Contour crafting is the final printing process in construction, and this method makes it possible to automate the installation of plumbing and electrical networks in buildings (Ali, M. H. et al., 2022). Due to its speed and ability to use on-site materials, this printing process has applications ranging from low-income housing or emergency shelters to conceptualize architectural structures (Xia, M. et al., 2019b, Xia, M. et al., 2019a, Ko, C.-H., 2021).

2.4.2. Fused deposition modelling (FDM)
In the fused deposition modelling technique, the printing material is provided by a heated extruder, which then moves in the X and Y directions to deposit the material precisely to create the 3D model (Rajan, K. M. et al., 2022). In addition to polymers, metals can be used as printing materials, although there are disadvantages, such as the risk of oxidation during the laying process (Al Jassmi, H. et al., 2018, Casini, M., 2022a).

2.4.3. Extrusion based system
The extrusion-based technology is comparable to the fused deposition modelling (FDM) technique, which employs a nozzle mounted on a gantry crane or a 6-axis robotic arm to extrude cementitious material in order to print a structure layer by layer (Nematollahi, B. et al., 2019). The focus of this upgraded technology is on-site applications for manufacturing large-scale elements with complicated geometry, and this technology has the potential to make a significant positive contribution to the construction industry while simultaneously enhancing effectiveness and efficiency (Nematollahi, B. et al., 2019, Ur Rehman, A. and Sglavo, V. M., 2021).

2.5. APPLICATIONS OF 3D PRINTING IN CONSTRUCTION
Numerous applications of 3D printing technologies have been demonstrated to date, including the fabrication of building components on-site and off-site, using industrial robots or gantry systems (Marchment, T. et al., 2019). Additionally, it has been demonstrated to the industry that 3D printing technologies could have been used to fabricate any type of structure, including houses, building components, bridges, and civil infrastructure (Chadha, U. et al., 2022). Within twenty-four hours, the Russian company 'Apis Cor' 3D-printed a 38-square-meter home worth at $10,134 (Adepoju, O., 2022, Casini, M., 2022a). Casini, M. (2022a) elaborates that the house was built entirely on-site utilising a mobile 3D printer and a concrete mixture, with windows, fixtures, and furnishings added once the 3D printing process has been completed. The printer, which functioned similarly to a crane, assembled every component of the house (Shakir, Q. M., 2019). The entire construction was constructed as a homogeneous unit, from the exterior to the interior, including all walls and partitions (Chen, X. et al., 2021). Apis cor also constructed a 9-meter-tall, 640-square-meter office building in Dubai, which is the world's largest 3D-printed structure to date Casini, M. (2022a). The work was reportedly done with half the amount of standard manpower and 60% less wastage (Malik, A. et al., 2022). The structure was constructed substantially faster than a conventional construction project, particularly the 3D-printed pieces, which took only two weeks to manufacture on-site (Rajan, K. M. et al., 2022).

'HuaShang Tengda', a Chinese construction business, has challenged the conventional construction method by constructing a 400-square-meter, two-story, 3D-printed house in one and a half months, which is practically impossible with the usage of the normal construction method (Nerella, V. N. and Mechtcherine, V., 2019, Sanjayan, J. G. and Nematollahi, B., 2019). The same researcher elaborates that the two-story house was built entirely on-site using a process that is unlike existing 3D printing construction techniques (Holt, C. et al., 2019, Adepoju, O., 2022). After years of research, the construction team and industry specialists developed a breakthrough approach and improved characteristics of a printer with a forked extruder that simultaneously pours concrete on both sides of the structural material, engulfing it and encasing it firmly within the walls (Nerella, V. N. and Mechtcherine, V., 2019). Before printing over it with a massive 3D printer, the crew erects the home frame, complete with rebar reinforcement and plumbing lines (Sanjayan, J. G. and Nematollahi, B., 2019). The five-story apartment complex constructed utilising 3D printing at Winsun is touted to be the world's tallest 3D-printed structure (Holt, C. et al., 2019). The various components of the structure were printed as prefabricated sections off-site, then moved to the construction site and assembled (Malik, A. et al., 2022). Windows, doors, and other finishing touches were installed using conventional procedures (Buchanan, C. and Gardner, L., 2019).

3. Aim and Objectives

The aim is to identify existing constraints and provide solutions to overcome them in order to facilitate the incorporation of 3D printing technology into the construction industry. To achieve the abovementioned aim, objectives 1, 2, and 3 were defined, including determining the impact of 3D printing in the global construction sector. Examine the current methodology, enabling factors, and barriers to the use of this technology in the construction industry, and identify techniques to overcome impediments to the adoption of 3D printing in the construction industry.

4. Methodology

To assess the study's background, current barriers, and enabling elements, a review of the literature from 2018 to the present was conducted and analysed using "NVIVO". Afterwards, a prototype questioner survey was conducted to finalise questions for the regular questioner, based on literature findings and with the assistance of industry professionals with more than 20 years of experience. The questionnaire was distributed to 60 individuals, and 39 of them responded. Approximately 41% of the 39 respondents were Quantity Surveyors, 31% were Engineers, and 18% and 10% were Architects and project managers, respectively. Three industry professionals with more than 30 years of experience were interviewed to validate the survey's findings. The acquired demographical and contextual data were analysed with the use of data processing software and a simple statistical model.

5. Data Presentation

5.1. QUANTITATIVE DATA PRESENTATION OF QUESTIONNAIRE SURVEY AND LITRETURE SURVEY

5.1.1. Respondent analysis

Table 1 displays a cross-section of demographic data and summarises it as follows: highest academic or professional qualification, years of experience in the field after receiving their highest academic or professional qualification, profession, and occupation. 21 out of 39 participants (54 %) have fewer than ten years of industry experience. 12 respondents (31%) have 10 to 20 years of construction experience, 6 respondents (15%) have 20 to 30 years of construction experience, and none of the respondents have more than 30 years of building experience. 23 responders (59%) have a bachelor's degree, 10 (26%) have a master's degree, 5 (13%) have a diploma certificate, and 1 (2%) have a doctoral degree. According to these statistics, the majority of participants hold a bachelor's degree, whereas a doctorate is the least common. The overwhelming majority of attendees were Quantity Surveyors (41%). According to the survey, the majority of respondents were from the western province (73%). The contracting organisation had the highest recorded percentage of employees aged 44 years or older. According to the survey, majority respondents work in the private sector (82%).

Table 1 - Respondent Analysis

Qualification & Experience	Diploma		Bachelors		Masters			PHD
Occupation & Profession	<10	10-20	<10	10-22	<10	10-20	20-30	10-20
Contractor								
Quantity Surveyor	-	-	6	2	-	1	-	-
Civil Engineer	-	1	1	-	-	1	1	1
Architect	-	-	1	-	-	-	-	-
Project Manager	-	-	-	1	-	-	1	-
Consultant								
Quantity Surveyor	1	-	2	1	-	-	-	-
Civil Engineer	-	-	1	1	-	-	1	-
Architect	-	-	3	1	-	-	-	-
Project Manager	-	-	-	-	-	2	-	-
Employee								
Quantity Surveyor	2	-	1	-	-	-	-	-
Civil Engineer	1	-	1	1	-	1	-	-
Architect	-	-	-	-	1	-	1	-

5.1.2. Analysis of enablers in adopting 3D printing to The Construction industry of Sri Lanka

The elements facilitating the introduction of 3D printing technology in Sri Lanka's construction industry are outlined below. From a literature review, eight important enablers were identified, and participants were asked to score them on a Likert scale from 1 to 8, with 1 being the most significant. The results of the questioner survey are displayed in table 2.

According to the literature review, enabling factor 2 (Reduce construction costs) is the most prevalent, since twenty out of sixty research articles emphasise it. In addition, according to earlier research, 'can construct complex structures' (enabling factor 6) is the second most prominent enabling factor, as it has been one of the prominent points of discussion in 14 studies. 'Improves sustainability' (enabling factor 5) and 'Increases health and safety' (enabling factor 8) have the same score, making them the third most significant element according to previous research, since each topic has been discussed in ten out of sixty study publications.

Table 2 - Results of questioner survey

Enabler	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8
Design flexibility	12	10	3	3	3	2	2	4
Reduce construction costs	6	9	8	6	4	2	3	1
Reduce the skilled labor shortage	8	7	3	8	3	5	3	2
Reduce construction duration	3	4	10	9	8	5	-	-
Increases quality	2	1	6	4	5	5	7	9
Improves sustainability	1	2	3	5	8	9	10	1
Increases health and safety	2	2	3	2	3	9	10	8
Can construct complex structures	5	4	3	2	4	3	4	14

5.1.3. Analysis of barriers in adopting 3D printing to the construction industry of Sri Lanka

The barriers to the adoption of 3D printing technology from a worldwide viewpoint and based on the available literature are listed in table 4 in descending order, and the relevance of these barriers to the Sri Lankan construction industry is given in table 5 in descending order of significance. On a Likert scale ranging from 1 to 7, with 1 being the most significant, participants were asked to rank observed impediments in order of importance to identify which they considered to be the most significant for the sector.

Table 3 - Ranking of identified barriers from the literature survey

Identified barriers according to literature survey	Significance according to literature survey
No standard guidelines for 3D concrete printing	1
High Investing Costs in 3D Printing	2
Lack of awareness of the benefits of 3D printing	3
Cultural resistance to change	4
Material scarcity	5
Workforce not trained to work with 3D printing	6
No influence/encouragement from government	7

Table 4 - Ranking of identified barriers according to questioner survey

Barrier	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7
Workforce not trained to work with 3D printing	21	7	3	4	2	1	1
No standard guidelines for 3D concrete printing	4	16	11	3	3	1	1
High Investing Costs in 3D Printing	8	5	15	7	2	2	-
No influence/encouragement from government	2	2	3	9	15	6	2
Material scarcity	3	4	3	5	4	13	7
Lack of awareness of the benefits of 3D printing	1	3	2	4	10	12	7
Cultural resistance to change	-	2	2	7	3	4	21

5.1.4 Summary of the questionnaire survey

A majority of respondents identified design flexibility, construction cost reduction, and construction time reduction as the strongest enablers. There are no standard criteria for 3D printing in Sri Lanka's construction industry, and the costs of investing in 3D printing equipment are prohibitively expensive. Respondents to the survey were asked to recommend solutions to address some of these obstacles. According to the respondents, a workforce inexperienced to deal with 3D printing is a barrier; consequently, 90% of respondents proposed conducting a 3D printing skills development programme. The absence of standard guidelines for 3D printing in Sri Lanka was identified as a significant impediment, and in response, 79% of respondents stated that adapting international criteria to the domestic construction industry may resolve the problem. Seventy-nine percent of participants advocated implementing this technology through a partnership in order to overcome the obstacle of expensive 3D printing technology investment prices. In the final question of the survey, participants were asked, "Do you believe that implementing 3D printing technology in Sri Lanka's construction industry would lend a hand in overcoming this situation?" Ninety-two percent of respondents agreed with the statement and responded affirmatively.

5.2. QUALITATIVE DATA ANALYSIS FROM EXPERT INTERVIEW

5.2.1. Importance of adoption of 3D printing to the construction industry

According to participant A, the adoption of 3D printing in the construction industry is a long-awaited technological improvement that will reduce the overall cost of the project. In other words, this improvement will enable contractors to construct structures with lower expenditures compared to non-use of 3D printing technology, while allowing a higher level of competition in the long run throughout the entire construction industry and boosting the overall economic health of the country. Considering the current economic condition of the country, the same participant stated that the speed of money circulation throughout the nation is highly dependent on the health of the construction sector, implying that sudden changes in monetary or physical policy without adequate planning will consequence in an economic tsunami.

Participant B feels optimistic about the possibilities of reaping benefits from 3D printing. Important aspect of this technological advancement is its capacity to expand designers' creativity and reduce dependencies or capacity constraints throughout the construction phase as well as the planning phase of the project. Additionally, this technological advancement would reduce the burden of workforce management and related issues, logistical difficulties, and weather-related dependencies during the construction phase, allowing the project team to dedicate more resources to enhancing or adding value to the project.

The final participant in the expert interview has a slightly different perspective than the others. Focus of participant C is on reducing waste, enhancing sustainability, and transforming the construction sector into a more environmentally friendly industry, while maintaining faith that this technology will continue to develop to enhance its compatibility with a vast array of materials in the near future in order to access a vast array of capabilities. Increasing compatibility with developing technologies like as BIM and ML in order to reach a fully autonomous industry, such as the automobile industry, throughout obtaining further effectiveness and efficiency in the long term.

5.2.2 Barriers identified in adopting 3D printing to the construction industry

The participants were shown the results of the ranking of barriers, and they were asked to re rank them and select the top three. Participant A selected the barriers workforce is not trained to work with 3D printing, higher investment cost of 3D printing technology and the cultural resistance to change. When asked from participant A to justify this he stated that the labour and staff of the Sri Lankan construction industry is not trained to cope with this technology. He sees this as one of the main barriers. And he also states that here are no training programmes which are specialized in 3D printing, to the higher investment cost of the technology barrier he mentioned that as of his knowledge introducing this technology now where there is a big crisis in Sri Lanka is the main barrier participant A sees here. He elaborated further that this technology is a big investment and at this time the government can't even advance this technology. So, since this is a bigger investment, he see this as the main barrier. For the cultural resistance to change barrier he elaborated that Sri Lanka is a very much traditional country. The expert further says that we as Sri Lankans don't like to think and work out of the tradition. So, when looking to the construction also it can be looked in similar way. There will be many people disliking this because of the tradition. Many would like to stick to traditional method. Apart from these barriers I asked him whether he have some other suggestions for barriers. The only suggestion participant A had was that many industry workers will lose its job.

Next in the interview with participant B he also chose almost same barriers as participant A. The only barrier which was different from participant A was that participant B chose the no standard guidelines for 3D printing in construction industry of Sri Lanka barrier not the cultural resistance to change barrier. He then justified why he chose these barriers. First the workforce not trained to work with 3D printing barrier was addressed. He stated that the workers in construction and staff like the civil engineers, mechanical engineers, electrical engineers, plumbing engineers, architects, quantity surveyors and project managers has not worked with this technology. So, they must be trained to work with 3D printing in the construction industry. For the barrier higher investment cost of the technology participant B stated that the industry cannot invest a huge amount of money right now due to the prevailing situation of the country. The industry is at risk of getting to collapse. So, B see this as a huge challenge to invest money on such an expensive technology. As for the third barrier no standard guidelines for 3D printing in construction industry of Sri Lanka he stated that by looking in the law side, there are no specific laws, contract conditions, principles, guidelines in with respect to this technology.

Participant C's identified top barriers were the same as participant B. The justifications were in some ways slightly different. For the workforce not trained to work with 3D printing barrier he stated that this is a new technology, there have been no training and education given on the use of 3D printing in the construction industry of Sri Lanka. So, it's a challenge to train the workforce to cope with 3D printing technology in the construction industry. As the next barrier participant C chose the higher investment cost of the technology. He too stated that due to the current situation in the country and restrictions established by government in order to overcome this economic crisis investing a very high cost in this technology is very challenging. The next barrier is the no standard guidelines for 3D printing in construction industry of Sri Lanka. For this participant C justified that since this technology is not used in the construction industry of Sri Lanka earlier there are no standards and regulations established. Participant C also at the end stated that it's a lot on educating people. It's a different type of planning and building and it's also different to the contractor, its different for the electrician, its different to everybody involved. All these trades need to learn and how to cope with this technology to make the best of it, to see the potential it can have for these individual trades and in making the construction safer and more efficient. This education and diffusion of the process will take some time. Since its brand new the expert thinks that there will be more questions raised on scalability, testing, and standards. The only thing he sees to overcome here in this dispute is to them about the global 3D printing technology in the construction industry and its benefits.

5.2.3 Techniques to overcome impediments to the adoption of 3D printing

Participant A chose the barriers workforce is not trained to work with 3D printing, Higher investment cost of 3D printing technology and the cultural resistance to change. For these the strategies that he proposed to overcome was for the workforce is not trained to work with 3D printing is that He states that in this barrier it is the best to conduct training programmes for both labour and staff. There are no existing training programmes on 3D printing in Sri Lanka. The expert states that they must make or start a new programme. For the next barrier Higher investment cost of 3D printing technology, he proposed to for this the contractors can make a partnership with the technology manufacturers in order to buy and adopt this technology or the project can be done by partnering of 2 clients. The strategy proposed by participant A form the barrier cultural resistance to change was "the only solution I see here is to educate the society and move forward".

Participant B proposed similar strategies to overcome some of the similar barriers identified by both of them. For the workforce not trained to work with 3D printing he proposed the same as Participant A which is to establish new training programmes and conduct training for the industry staff on how to cope with 3D printing in construction. As

to overcome the barrier high investment cost for this technology, participant B proposed for the government to provide incentives. For example, cut off tax for this technology. The barrier no standard guidelines for 3D printing in construction industry of Sri Lanka, he proposed to stick to international standards and regulations on 3D printing in Construction. He proposed this in the following statement "Since this is a new technology there are no laws, legislations or standards made to go with this technology. So, sticking with the foreign standards is the best".
The strategy proposed by participant C to overcome not skilled workforce was the same as participants A and B. But for the higher investment cost barrier he proposed that way to go for partnering. He stated that partnering is a great strategy in order to reduce costs and get a good profit. The partnering of the main stakeholders of the project is proposed in order to overcome the following barrier. The strategy proposed to get over with the barrier no standard guidelines for 3D printing in construction industry of Sri Lanka is to establish a new set of standard guidelines and regulations in relation with 3D printing in construction.

6. Conclusion

The objective of the research was to identify and overcome obstacles to the implementation of 3D printing in Sri Lanka's construction industry, as well as to discover solutions to existing challenges. The objective was accomplished by establishing three objectives and identifying the significance and varieties of 3D printing applications based on a literature review. Adoption of new technologies is important because it will serve as a catalyst to improve the construction industry's stability and a country's state of the economy. Time, cost, and quality are the most important aspects of a construction project, and the adoption of 3D printing will have a very positive effect on these parameters. Additionally, the adoption of 3D printing is extremely eco-friendly because it generates minimal pollution. The second purpose was to identify the facilitators and impediments to the domestic construction industry's adoption of 3D printing. Following data analysis and validation, prominent ideologies have been discovered. According to the results, the top three enablers are design flexibility, construction cost reduction, and construction duration reduction. The top three obstacles include an unprepared workforce, a lack of standards and procedures for implementing and governing 3D printing technology, and high investment costs. The purpose was to provide solutions to overcome the identified barriers, including the workforce not trained to work with 3D printing. The planned method is to educate industry personnel on how to employ 3D printing in the construction industry. Secondly, due to the high cost of investing in 3D Printing technology, it was advocated to strengthen the government's structure for partnering and joint ventures in order to increase the availability and accessibility of venture capital. As the absence of acceptable standards or guidelines for 3D printing was regarded as the third most significant barrier, the proposed method was to produce or adopt a suitable set of standards or guidelines.

7. Recommendations

Offering additional time for the incorporation of 3D printing into the construction industry may make it more achievable. There are recommendations for additional research that may be necessary, as well as suggestions for improving this study. The recommended elements can be brought up to date by expanding the literature to incorporate more research and theories in the field of innovation and construction. Overall, the findings can aid in the comprehension of 3D printing and increase the likelihood of its successful implementation in various field of civil engineering. Future research will investigate what project managers, Quantity Surveyors, Civil engineers, and architects really have to learn and do to adopt 3D printing technology in the construction industry, how to integrate the differences between the construction and manufacturing industries, how to manage the supply chain for 3D printed projects, assisting governing bodies in developing a framework for 3D printing building standards, and incorporating automatic reinforcement into 3D printed structures. The unique ability of 3D printing to bring residential construction closer to the design needs of end users, reduce waste compared to conventional construction procedures, and better inventive design is afforded to construction enterprises by 3D printing. Consequently, the future study can emphasise how the contractor might utilise 3D printing to take advantage of its numerous benefits in diverse construction projects. Future study should also focus on expanding the sample size to improve the reliability of the survey results.

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