Jayasena, M.P.T.C., Disaratna, P.A.P.V.D.S. and Victar, H.C., 2023. Construction innovation towards sustainable construction project success in Sri Lanka. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 407-419. DOI: https://doi.org/10.31705/WCS.2023.34. Available from: https://ciobwcs.com/papers/

CONSTRUCTION INNOVATION TOWARDS SUSTAINABLE CONSTRUCTION PROJECT SUCCESS IN SRI LANKA

M.P.T.C. Jayasena[1], P.A.P.V.D.S. Disaratna[2] and H.C. Victar [3]

ABSTRACT

Sustainable construction is important for creating buildings and structures that have less impact on the environment. To make sustainable construction more effective, new and innovative techniques need to be used. The success of sustainable construction projects depends on how well these innovations are applied. A study was conducted in Sri Lanka to investigate the use of construction innovations in sustainable construction projects and to find ways to improve their success. The study used a qualitative approach, which involved collecting data through semi-structured interviews and use manual content analysis to analyse collected data. However, the study also revealed that the level of innovation application in sustainable construction was not satisfactory in Sri Lanka. Furthermore, this research discovered strategies that can be used to overcome the challenges of sustainable construction projects in Sri Lanka by adopting construction innovations. These strategies include mitigating challenges to innovation adoption and finding ways to increase the use of innovations. By implementing these strategies, sustainable construction projects can be more successful in Sri Lanka leading to less impact on the environment.

Keywords: *Challenges; Construction Innovation; Strategies; Sustainable Construction.*

1. INTRODUCTION

Considerable global attention has been given to "sustainable construction" when the construction industry shifted from the traditional paradigm towards sustainable development (Du Plessis, 2007). Traditional construction practices focus on cost minimisation, performance and quality objectives only but sustainable construction practices also focus on the minimisation of resource depletion, minimisation of environmental degradation and the creation of a healthy built environment (Bachayo et al., 2022). According to Athapaththu and Karunasena (2018), knowledge of construction innovations, technologies and processes is relatively high among higher-level of construction professionals. Nevertheless, sustainable construction evaluation criteria

[1] Undergraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, chamodajayasena@gmail.com
[2] Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, vijithad@uom.lk
[3] Postgraduate, Department of Building Economics, University of Moratuwa, Sri Lanka, victarhc.22@uom.lk

during tendering, searching for cost-effective methods and harmonisation of academic and technical institutions are not at a considerable level.

Furthermore, the authors stated that coordination and harmonisation with academic institutions and technical institutions are rare in the construction industry. In addition to that, the adaptation of construction innovations has become lower due to inadequate innovations to improve sustainable construction. Therefore, research and development play a vital role in sustainable development.

In Sri Lanka, the adoption of sustainable construction practices is still in its early stages (Thalpage & Karunasena, 2016), and construction innovations are not being fully utilised to achieve sustainability (Karunasena et al., 2016; Jayalath & Gunawardhana, 2017; Somachandra & Sylva, 2018). Addressing the existing research gap is of utmost importance, as it is vital to comprehend the obstacles involved in implementing construction innovations in sustainable construction projects for the advancement of Sri Lanka's future development. This research endeavour aims to bridge this gap by offering valuable insights into the challenges hindering the integration of construction innovations within sustainable construction. Furthermore, it seeks to identify and propose effective strategies to overcome these obstacles. The findings of this research will be highly relevant for policymakers, construction professionals, and other stakeholders involved in sustainable construction projects in Sri Lanka. By addressing the challenges in construction innovations to achieve construction goals, this research can help to improve the success of future construction innovations in Sri Lanka and contribute towards achieving global environmental targets.

2. LITERATURE REVIEW

2.1 APPLICATION OF CONSTRUCTION INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS

With the growing economic, social and environmental issues, most of the organisations in the construction sector are focusing on sustainable construction practices (Hertwich & Peters, 2009). Furthermore, sustainable development goals can be achieved through the proper application of construction innovation in design, construction and facility operation (Bynum et al., 2013).

Elegbede and Lateef (2020) defined nanotechnology as the re-engineering of materials by controlling the shape and size at the nanometer scale. Nano cement, nano steel, nano glass, a nano-coat for concrete, nanoparticles for fire protection, nano sensors for concrete structures, and nanomaterials in concrete are examples of the application of nanotechnology on several building materials (Bhuvaneshwari et al., 2011). According to Kutschera et al. (2009), new technologies are adopted in sustainable construction projects to reduce CO_2 emissions during the construction process and energy consumption during the operation. Moreover, the authors suggested that the prevention of natural resources and energy reduction can be attained by producing new nanostructured materials.

Figure 1: 3D Concrete Printing Applications in Building

3D concrete printing, also referred to as additive manufacturing is playing a massive role in terms of dealing with the sustainability challenges in the construction industry (Bhattacherjee et al., 2021). Salet et al. (2018) stated that 3D concrete printing is more popular in sustainable construction projects and is used to produce structural concrete elements. Furthermore, the authors mentioned that the 3D-printed pedestrian bridge is one of the recent examples of the application of 3D printing in sustainable constructions in Figure 1. 3D concrete printing can produce complex shapes that are used in passive design (Mechtcherine et al., 2019). In addition to that, Harkouss et al. (2018) claimed that passive design enhances the energy efficiency of a building. Hence, 3D printing can be identified as a sustainable solution in the construction industry (Mechtcherine et al., 2019).

During the past few years, Building Information Modeling (BIM) has become a growing concept in the construction industry (Bynum et al., 2013). Total project quality increase, minimising total project cost and generating accurate quantity take-offs and time schedules are the main advantages of using BIM (Wang, 2012). Azhar (2011) stated that the use of BIM to evaluate various skin options, choose building orientation and conduct daylight studies during the design phase to position the building on the selected site, thus enhancing the sustainability of the construction project. Net-zero energy buildings and carbon emissions reduction have become more popular due to the trend in the construction industry towards sustainable development (Holness, 2008). Therefore, designers require to evaluate the building as a fully integrated dynamic design and construction process. Hence, BIM plays a significant role in sustainable construction projects (Bynum et al., 2013). Intelligence exhibited by software-driven systems and electronic devices to improve the quality and performance in the built environment is known as Artificial intelligence (AI) in buildings (Panchalingam & Chan, 2021). Gilner et al. (2019) stated that actions such as turning off light switches when no one is in the space, granting permission for visitors to enter into designated spaces and contacting authorities and commencing emergency procedures during an emergency such as a bomb blast can be achieved by using an AI. Building Energy Management System is one of the examples of an application of AI in sustainable construction.

3. METHODOLOGY

A qualitative approach is useful when exploring complex phenomena that are difficult to measure or quantify (Hammarberg et al., 2016). Construction innovation project success is a multifaceted and complex phenomenon that can be difficult to capture through quantitative methods due to diverse stakeholders, long-term perspective, complex systems, subjectivity, and data availability. A qualitative approach allows for an in-depth

exploration of the experiences, perspectives, and attitudes of key stakeholders involved in sustainable construction projects in Sri Lanka. Semi-structured interviews are an appropriate method for collecting data from participants with different levels of knowledge and expertise. Semi-structured interviews allow for flexibility in questioning, which can be adapted to each participant's level of expertise and the knowledge in construction industry and sustainability (Creswell & Creswell, 2018). Using a qualitative approach and semi-structured interviews can provide rich and detailed data that can lead to a deeper understanding of application of innovation in sustainable construction projects in Sri Lanka.

According to Etikan et al. (2016), judgment sampling is used in the purposive sampling technique. It is also an intentional choice made to select a participant based on the traits they possess. Thus, the sample is purposefully determined and based on the researcher's judgment about the research aim. Purposive sampling allows the selection of interviewees who are knowledgeable and interested in the selected area of study (Etikan & Bala, 2017). A qualitative survey, according to Jansen (2010), establishes the relevant diversity within that population. Table 1 presents the criteria for defining experts for the research area which is the construction industry.

Table 1: Expert profiles

Coding	Designation	Client	Contractor	Consultant	Years of Experience	Criteria						Accessibility
						Compulsory Qualification		Additional qualifications (Satisfy at least three criteria)				
						C1	C2	A1	A2	A3	A4	
R1	Managing Director	✓			25 years	✓	✓	✓	✓	✓	✓	✓
R2	Construction Manager		✓		20 years	✓	✓	✓	✓	✓	✓	✓
R3	Senior Engineer		✓		15 years	✓	✓	✓	✓	✓	✓	✓
R4	Contract Administrator		✓		17 years	✓	✓	✓		✓	✓	✓
R5	Environmentalist			✓	11 years	✓	✓	✓		✓	✓	✓
R6	Senior Quantity Surveyor	✓			16 years	✓	✓	✓	✓	✓	✓	✓
R7	Director			✓	24 years	✓	✓	✓	✓	✓	✓	✓
R8	Electrical Engineer		✓		16 years	✓	✓	✓	✓	✓	✓	✓
R9	Service Engineer	✓			14 years	✓	✓	✓	✓	✓	✓	✓
R10	Planning Engineer	✓			12 years	✓	✓	✓	✓	✓	✓	✓
R11	Senior Electrical Engineer			✓	18 years	✓	✓	✓	✓	✓	✓	✓
R12	Maintenance Manager	✓			11 years	✓	✓	✓	✓	✓	✓	✓
R13	Senior Architecture			✓	21 years	✓	✓	✓	✓	✓	✓	✓
R14	Senior Facility Manager	✓			14 years	✓	✓	✓	✓	✓	✓	✓
R15	Quality Controller			✓	13 years	✓	✓	✓		✓	✓	✓

C1: Knowledge and a better understanding of sustainable construction and construction innovation
C2: More than 10 years of experience related sustainable construction
A1: Graduate in a construction-related discipline
A2: A Postgraduate degree related to construction management
A3: Corporate Member of a Professional Institution
A4: Practical Experience/Research Experience in sustainable or innovative construction

When selecting the purposive sample, as per the criteria given in Table 1, every expert must fulfil the above compulsory qualifications and at least two additional qualifications must be fulfilled. These criteria ensure that experts in sustainable construction possess a solid foundation of knowledge and experience, as well as specialised expertise in the field. Fifteen experts were interviewed between 45-60 minutes using prepared interview guideline and analysed them according to the experts' opinions through manual content analysis. Most of the interviews carried out through online platform, namely Zoom and rest of interviews were done physically.

4. RESEARCH FINDINGS

Research findings indicate that the application of innovations in construction projects in Sri Lanka faces significant challenges. These challenges include inadequate investment in research and development, a lack of skilled labour and training, limited access to modern construction equipment and technologies, and an absence of supportive policies and regulations. To overcome these challenges, suitable strategies include increasing investment in research and development, promoting skill development and training programs, adopting modern construction methods and technologies, promoting awareness and education on sustainable construction practices, and implementing supportive policies and regulations that encourage innovation and sustainable development. The successful implementation of these strategies can facilitate the adoption of innovative practices in construction projects, leading to more efficient, sustainable, and resilient construction practices in Sri Lanka.

4.1 CHALLENGES IN APPLICATION OF INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS IN SRI LANKA

In Sri Lanka, the application of innovation in sustainable construction projects is currently at an unsatisfactory level, according to research. Sustainable construction projects can be influenced by innovations, but the implementation of such innovations has not been widespread in Sri Lanka. Innovation in sustainable construction can involve the use of new technologies, materials, and processes that lead to better environmental, social, and economic outcomes. By adopting such innovations, construction projects can improve their efficiency, reduce waste and carbon emissions, and provide better working conditions for workers.

Overall, increasing the application of innovation in sustainable construction projects in Sri Lanka has the potential to improve the success of such projects, and help the country achieve its sustainable development goals. By adopting innovative solutions, Sri Lanka can reduce its environmental footprint, improve the lives of its citizens, and support its economic development sustainably and equitably. According to the interviewees' suggestions here listed challenges in the application of innovations in sustainable construction projects in Sri Lanka. Figure 2 presents the findings of challenges in the application of innovations in sustainable construction projects in Sri Lanka.

CHALLENGES IN THE APPLICATION OF INNOVATIONS IN SUSTAINABLE CONSTRUCTION PROJECTS IN SRI LANKA

Nanotechnology
- High initial investment costs, which can be a significant barrier for small and medium-sized construction companies that may not have the financial resources to invest in nanotechnology
- Limited awareness and understanding of the benefits and potential of nanotechnology in the construction industry, which can result in scepticism and reluctance to adopt the technology
- Limited availability of nanomaterials in Sri Lanka, which can make it difficult to access and use these materials in construction projects
- Lack of specialised technical expertise and skilled workers to operate and maintain nanotechnology equipment and processes
- Limited research and development in the application of nanotechnology to sustainable construction in Sri Lanka, which can make it difficult to develop and implement innovative solutions
- Regulatory barriers and restrictions on the use of nanotechnology in Sri Lanka, including limitations on the use of certain nanomaterials and concerns about potential health and environmental risks associated with the technology
- Concerns about the long-term durability and performance of nanomaterials in construction applications, as well as the potential risks associated with their disposal at the end of their lifecycle

3D Concrete Printing
- Lack of awareness about the benefits
- High initial costs associated with acquiring 3D printing technology and equipment
- Limited availability of 3D printing infrastructure and support services
- Lack of regulatory framework in Sri Lanka for the use of 3D printing technology in construction
- Insufficient availability of suitable raw materials
- Technical challenges related to the durability and strength of 3D-printed concrete structures
- Limited research and development efforts
- Lack of skilled personnel trained and its use in construction
- Perceptions of 3D concrete printing as experimental or untested technology
- Reliance on traditional construction methods and a preference for familiar techniques among construction professionals in Sri Lanka

BIM
- Lack of standardisation and uniformity in the application of BIM technology in the construction industry in Sri Lanka, which can lead to confusion and difficulties in collaboration between different stakeholders
- Limited awareness and understanding of the benefits and potential of BIM technology in the construction industry, which can result in scepticism and reluctance to adopt the technology
- Limited access to BIM software and related technologies, which can make it difficult for construction companies in Sri Lanka to implement BIM effectively
- Lack of specialised technical expertise and skilled workers to operate and maintain BIM software
- Limited integration of BIM technology into existing construction processes and workflows, which can make it difficult to justify the investment in the technology
- Resistance to change from traditional construction practices, which can make it difficult to introduce and implement BIM technology effectively

AI
- Limited investment in research and development
- Limited availability of relevant data and information for AI analysis
- Fragmented nature of the construction industry
- Limited government support and policies to promote
- Shortage of skilled professionals with the necessary technical expertise
- High initial costs and capital expenditure for implementing AI
- Resistance to change and adoption of new technologies by industry professionals
- Limited awareness and education about the benefits and potential applications of
- Uncertainty about the reliability and accuracy of AI-generated data and analysis
- Limited availability of AI-related infrastructure and support services

Robotics
- Limited awareness and understanding of the benefits and potential of robotics
- High initial investment costs
- Lack of specialised technical expertise to operate and maintain
- Limited government support and incentives to encourage the adoption of robotics technology
- Cultural barriers and resistance to the adoption of robotics technology by construction workers
- Lack of suitable infrastructure and changes required to the existing infrastructure in Sri Lanka to accommodate the use of robotics technology

Drone Technology
- Concerns about data privacy and security, as well as safety issues related to the operation of drones in urban environments
- Limited integration of drone technology into existing construction processes and workflows, which can make it difficult to justify the investment in the technology
- Limited awareness and understanding of the benefits, which can result in scepticism and reluctance to adopt the technology
- High initial investment costs, which can be a significant barrier for small and medium-sized construction companies that may not have the financial resources to invest
- Lack of specialised technical expertise and skilled operators to operate and maintain drone technology, as well as a shortage of drone service providers in Sri Lanka.
- Regulatory barriers and restrictions on the use of drones in Sri Lanka, including limited drone flight areas and restrictions on the use of drones for commercial purposes
- Limited infrastructure for drone technology, including the need for suitable landing and take-off areas, and the availability of reliable and high-speed internet connectivity

3D Printed Houses
- Uncertainty about the reliability, durability, and quality of 3D printed structures for long-term use in Sri Lanka's climate and environment
- Limited availability of appropriate 3D printing materials and technology infrastructure
- Lack of government support and policies to promote the adoption
- Limited collaboration and partnerships between construction professionals, technology experts, and other stakeholders in the industry to drive innovation and adoption
- Limited investment in research and development of 3D printing technology
- Lack of awareness and education about the potential benefits
- High initial costs and capital expenditure for implementations
- Fragmented nature of the construction industry in Sri Lanka
- Resistance to change and adoption of new construction technologies by industry professionals
- Limited availability of skilled professionals with the necessary technical expertise to operate and maintain for construction purposes

Figure 2: Challenges in the application of innovations in sustainable construction projects in Sri Lanka

The majority of the respondents identified the unavailability of technology as the major barrier to the application of nanotechnology in Sri Lankan sustainable construction projects. **R3, R5** and **R12** explained that the unavailability of skilled workers is a reason for the lack of application of nanotechnology in Sri Lankan sustainable construction projects. Further, **R8** stated, *"Nano cement, nano concrete and other materials made using nanotechnology are popular and used in Germany, United Kingdom and South Korea. But in our country nanotechnology is not popular in the construction industry. Because we do not have the technology and skilled workers with good knowledge on nanotechnology".* R2 and R6 have identified that attitude of the client and the attitude of the consultant has prevented the application of nanotechnology in Sri Lankan sustainable construction projects. **R6** stated, *"Clients and consultants in Sri Lanka do not pay much attention to nanotechnology. According to my point of view that is the main reason".* Nevertheless, **R5** and **R11** declared that applications of nanotechnology are available in Sri Lanka. Furthermore, **R15** expressed, *"Nanotechnology is not widely used in Sri Lanka. But certain materials that are made using nanotechnology are used in some sustainable construction projects".*

R9 and **R10** highlighted that most of the time clients in Sri Lanka select traditional construction methods rather than using innovative methods such as 3D concrete printing due to a lack of technically capable professionals with sound knowledge of novel technologies. **R2** and **R7** emphasised that the usage of 3D concrete printing in sustainable construction projects is restricted by the complexity of the process. Further, **R15** stated, *"Process of constructing buildings using 3D concrete printing is complex. Because small concrete parts print separately and join together to build large components. So, most of the clients and contractors do not consider using 3D concrete printing for their constructions".*

In Sri Lanka, AI is being applied in several areas, including predictive maintenance, quality control, safety monitoring, and design optimisation. Predictive maintenance involves using AI to monitor and analyse data from construction equipment to detect potential maintenance issues, thereby reducing downtime and increasing productivity. Although the application of AI in the Sri Lankan construction industry is still in its early stages, its potential for improving efficiency, productivity, and safety is significant. Moreover, **R15** presented a moderately similar opinion to the literature findings as *"Automatic light control systems, motion sensors in bathrooms and Building Energy Management systems are used in sustainable buildings in Sri Lanka. According to my point of view, those applications are examples of application of AI in sustainable constructions".* In addition to that **R3** and **R4** emphasised application of AI in sustainable construction projects is lesser compared to other countries. Even though the majority of the respondents stated that AI is applied in sustainable construction projects, **R11** explained that AI is not used in Sri Lankan construction industry. Further, the respondent mentioned reasons such as the unavailability of experts, requirement of more investments, the high initial cost, and the unavailability of technology to justify the opinion of **R1**.

Only respondent **R10** has identified 3D-printed houses as an innovation that is used in sustainable construction projects in the world. Furthermore, the respondent explained that 3D-printed houses and 3D concrete printing are not similar. Moreover, **R1** stated, *"3D concrete printing is a part of 3D printed houses".* However, **R1** stated that 3D-printed houses are not used in Sri Lankan context. Further, the respondent explained that the lack

of technology and lack of experience of the workers are the main reasons that avoid the application of 3D concrete printed houses in Sri Lanka. In addition, **R11** stated, *"The attitude of clients and professionals in the construction industry is also a reason for the lack of usage of 3D-printed houses".* Moreover, the respondent mentioned that clients in Sri Lanka tend to use traditional methods rather than using innovations. Reasons for the lack of usage of 3D Printed Houses in Sri Lankan sustainable constructions were identified through the semi-structured interview. Table 6 summarises the reasons given by the interviewees.

R2, R3, R5 and **R7** have accepted that construction robotics is an innovation that is used in sustainable constructions in the world. According to **R3**, the application of robotic technology in construction projects provide benefits such as reducing cost due to high productivity, reducing labour cost, reducing costs related to safety systems and reducing construction waste. **R2, R3** and **R7** agreed that robotic technology is applied to sustainable construction projects in Sri Lanka. Moreover, respondents stated that bricklaying robots, unmanned ground vehicles and heavy material handling robots are used in Sri Lanka.

Only **R8** accepted that drone technology is an innovation that is applied for sustainable construction projects in the world. Further, **R8** explained the importance of drone technology in construction industry *"Drone technology is very important to construction industry. Because if you want to inspect areas which are difficult to reach, you can use AR to inspect and capture photographs. It will help to minimise accidents in construction sites and provide safety for workers".* Drones can be used to conduct site surveys, allowing for a more accurate understanding of the site and any potential challenges before construction begins. They can also be used to monitor the progress of construction projects, providing construction teams with real-time updates on the status of the project and identifying any issues that need to be addressed. Drones can be used for the inspection of hard-to-reach or dangerous areas, such as bridges or tall buildings, allowing for detailed and precise inspections without putting workers in harm's way. Additionally, drones can be used for environmental monitoring, tracking the progress of reforestation or monitoring water quality.

R8 stated, "BIM is not used 100% for sustainable construction projects in Sri Lanka. But to a certain extent BIM is used in Sri Lanka. 5D BIM software is also used in some projects in our country". According to the majority of the respondents, BIM is not used for the entire construction project in Sri Lanka. Nevertheless, BIM is used in certain parts of the construction process or certain aspects of the construction project. According to **R3, R6** and **R8**, nowadays 2D and 3D BIM software are more popular in Sri Lanka and used for designing purposes of sustainable construction. **R2, R4** and **R8** stated that BIM-based software is used while preparing estimates for sustainable construction projects. Further, **R4, R7** and **R8** described that BIM technology can be applied for project planning and cost management purposes. BIM technology can be used to generate accurate quantity take-offs and cost estimates for the building materials and labour required to construct the building. In addition, **R8** mentioned that BIM technology is used in the construction phase of sustainable construction projects to check the progress of construction work and to provide tracking of better cost control. However, **R1** and **R5** stated that BIM is not used in Sri Lanka. Further, **R1** stated, "After construction is complete, BIM technology can be used to support ongoing facility management and maintenance, including the tracking of maintenance schedules, equipment, and asset

management, and other key tasks". In addition to that, **R9** and **R12** highlighted the lack of knowledge and high initial cost as the main reasons for the lack of application of BIM technology in Sri Lanka.

4.2 SUITABLE STRATEGIES TO OVERCOME ABOVE IDENTIFIED CHALLENGES IN CONSTRUCTION INNOVATIONS PROJECTS IN SRI LANKA

According to respondents' arguments, to improve the success of sustainable construction projects in Sri Lanka, several strategies can be adopted through construction innovations. One of the key strategies is to focus on green building practices that prioritise energy efficiency, water conservation, and the use of sustainable materials. This can include incorporating renewable energy sources such as solar, wind, and hydropower to reduce reliance on non-renewable sources. Another important strategy is to adopt green transportation practices that encourage the use of public transport and reduce carbon emissions. Other construction innovations such as BIM, 3D printing, and offsite construction techniques can also improve the efficiency of the construction process and reduce waste. Additionally, strategies such as using biophilic design, improving indoor air quality, and utilising rainwater harvesting can improve the overall sustainability and durability of a building. By adopting these and other strategies, sustainable construction projects in Sri Lanka can achieve greater success in meeting the country's economic and environmental goals. Table 2 illustrates the strategies to improve the success of sustainable construction projects in Sri Lanka by adopting construction innovations.

Table 2: Suitable strategies to overcome challenges in construction innovations projects in Sri Lanka

No	Strategies to Improve the Success of Sustainable Construction Projects in Sri Lanka Through Adopting Construction Innovations
01	Conduct a thorough feasibility study before embarking on any construction project, taking into account the specific needs and resources of the local community.
02	Involve local communities in the planning process to ensure that their needs are being met.
03	Incorporate sustainable design principles into the project from the outset, such as using renewable energy sources and eco-friendly materials.
04	Implement a green building certification program, such as LEED or Green Star, to ensure that the project meets established sustainability standards.
05	Use energy-efficient building techniques, such as passive solar design, to reduce energy consumption.
06	Utilise renewable energy sources, such as solar or wind power, to reduce the reliance on fossil fuels.
07	Incorporate rainwater harvesting and greywater recycling systems into the design to conserve water.
08	Implement waste management systems that prioritise reducing, reusing, and recycling materials.
09	Use sustainable materials, such as bamboo, that are locally sourced and have a low environmental impact.
10	Adopt modular construction techniques to reduce waste and improve efficiency.
11	Implement BIM technology to improve project planning, design, and collaboration.
12	Utilise 3D printing technology to reduce construction waste and improve efficiency.
13	Implement drone technology for site inspections, project planning, and monitoring.
14	Use green roofs and walls to reduce the urban heat island effect and improve air quality.
15	Implement energy-efficient lighting systems, such as LED lights, to reduce energy consumption.
16	Use natural ventilation systems, such as passive cooling, to reduce the need for air conditioning.
17	Install smart building technology to optimise energy usage and improve the overall performance of the building.
18	Use recycled materials, such as reclaimed wood, to reduce the need for new resources.

No	Strategies to Improve the Success of Sustainable Construction Projects in Sri Lanka Through Adopting Construction Innovations
19	Incorporate biophilic design principles to connect people with nature and improve overall well-being.
20	Implement strategies to reduce embodied carbon, such as using low-carbon cement.
21	Adopt offsite construction techniques, such as prefabrication, to improve efficiency and reduce construction waste.
22	Use green building materials, such as low-VOC paints and adhesives, to improve indoor air quality.
23	Use thermal insulation materials, such as aerogel, to reduce energy consumption.
24	Implement natural ventilation and daylighting systems to reduce the need for artificial lighting and HVAC systems.
25	Use permeable paving and rain gardens to reduce stormwater runoff and improve water quality.
26	Implement energy recovery systems to capture and reuse waste heat.
27	Use shading devices, such as louvres and blinds, to reduce solar heat gain and improve comfort.
28	Implement a green transportation plan, such as providing bike storage and promoting public transit use, to reduce emissions.
29	Use a life cycle assessment (LCA) to evaluate the environmental impact of the building throughout its life cycle.
30	Establish a post-occupancy evaluation program to assess the performance of the building and identify areas for improvement.

Respondent **R1** stated that the drawbacks of the fragmented nature of the construction industry can be mitigated by introducing strict guidelines and frameworks to improve coordination and collaboration between parties. Further, **R2** expressed that the drawback of the fragmented nature of the construction industry can be mitigated through promoting innovation and modern technologies and increasing awareness of construction innovation among the parties involved in sustainable construction. Interviewees **R5** and **R7** also introduced a similar view to respondent **R2**. As stated by interviewee **R5** *"Institutions in Sri Lankan construction industry like CIDA and green building council need to take the leadership and responsibility to improve coordination and to increase the awareness of innovation among all the parties involved in the sustainable construction project".* Furthermore, interviewee **R3** highlighted that lack of communication between project individuals and groups due to the fragmented nature of the construction industry can be minimised by adopting proper project management techniques. Hence, **R3** recognised adopting proper project management techniques as a strategy to mitigate drawbacks of the fragmented nature of the construction industry. Interviewee **R4** expressed that clashes due to the fragmented nature of the construction industry can be minimised by adopting novel technologies and techniques. Respondent **R8** also agreed to the view of **R4** and stated *"There may be clashes and coordination issues due to the fragmented nature of the construction industry. Due to those issues, implementation of innovation to sustainable construction projects may be difficult. So, newer technologies like BIM can be used to mitigate those issues. According to my point of view, using innovation against barriers to apply innovation in construction is the best strategy to mitigate those barriers"*. However, respondent **R6** claimed that the fragmented nature of construction industry is not a barrier to applying innovation to sustainable construction projects.

Implementing strategies that prioritise green transportation options, such as promoting public transit use and providing safe bike storage, can have a significant impact on reducing the carbon footprint of a building or development. Moreover, initiatives that focus on sustainable transportation also improve the overall durability and accessibility of the building. Several construction innovations can be adopted to improve the efficiency of the construction process and reduce waste. BIM technology, for instance, can help to

improve project planning, design, and collaboration. 3D printing and offsite construction techniques can reduce the amount of waste generated during the construction process, while also improving efficiency and reducing costs. Other strategies, such as using biophilic design principles, improving indoor air quality, and utilising rainwater harvesting can also improve the overall sustainability and durability of a building. The biophilic design emphasises the connection between humans and nature and can be incorporated through the use of natural materials, green roofs, and other design features. Improving indoor air quality can be achieved by using low-VOC paints and adhesives, improving ventilation systems, and other strategies. Rainwater harvesting systems can also help reduce water consumption and promote a more sustainable approach to water management.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the global context of sustainable construction projects, applications of construction innovations such as nanotechnology, 3D concrete printing, BIM and AI were investigated through the literature review. In addition to the aforementioned innovations, respondents have mentioned several other innovations such as 3D printed houses, virtual reality, robotics and drone technology that are used in sustainable construction projects in the world. Application of innovations that are recognised under the literature and interviews in Sri Lankan sustainable construction projects were investigated by analysing the finding of the semi-structured interview. According to the outcomes of the analysis, the application of innovations in sustainable construction is at an unsatisfactory level in Sri Lanka. These innovations include but are not limited to robotics and drone technology, which can improve productivity, efficiency, safety, and quality in construction projects. To maximise the benefits of these innovations, it is important to implement strategies such as investing in training for workers, promoting collaboration between different stakeholders in the construction industry, and creating regulatory frameworks that support the adoption of these technologies. Furthermore, sustainable construction projects should be designed with a holistic approach that considers environmental, social, and economic factors. By implementing these strategies, Sri Lanka can create a more sustainable and prosperous future, benefiting both the construction industry and society at large.

Based on the investigation of construction innovation towards sustainable construction project success in Sri Lanka, the following recommendations can be made:

1. Encourage stakeholders in the construction industry to embrace innovation as a key driver of sustainable construction project success. This can be done by providing education and training on the benefits of construction innovation and its potential applications.
2. Foster collaboration between different stakeholders in the construction industry, such as architects, engineers, contractors, and building owners, to promote the exchange of ideas and the development of innovative solutions.
3. Create regulatory frameworks that support the adoption of construction innovation and sustainable practices. This can include incentives for sustainable construction, tax breaks, and building codes that require the use of sustainable materials and practices.
4. Support research and development in sustainable construction innovation to facilitate the development of new technologies and practices that can be applied to construction projects in Sri Lanka.

5. Provide training and education programs to workers in the construction industry, so that they can acquire the skills and knowledge necessary to implement sustainable construction practices and technologies.
6. Encourage the use of a holistic approach to sustainable construction, considering environmental, social, and economic factors in the design and execution of construction projects.

By implementing these recommendations, Sri Lanka can successfully adopt construction innovation to achieve sustainable construction project success, contributing to a more sustainable and prosperous future for the country.

6. REFERENCES

Athapaththu, K. I., & Karunasena, G. (2018). Framework for sustainable construction practices in Sri Lanka. *Built Environment Project and Asset Management*, *8*(1), 51-63.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering*, *11*(3), 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127

Bachayo, A., Memon, A. H., Hussain, M., Rahman, I. A., & Ahmed, S. J. (2022). Risk level of design and procurement factors causing construction waste generation. *Journal of Applied Engineering Sciences*, *12*(1), 11–16. https://doi.org/10.2478/jaes-2022-0002

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, Chennai, India

Bhuvaneshwari, B., Sasmal, S., & Iyer, N. R. (2011, July). Nanoscience to nanotechnology for civil engineering: proof of concepts. In *Proceedings of the 4th WSEAS International Conference on Energy and Development - Environment - Biomedicine (GEMESED'11)* (pp. 230-235).

Bynum, P., Issa, R. R. A., & Olbina, S. (2013). Building information modeling in support of sustainable design and construction. *Journal of Construction Engineering and Management*, *139*(1), 24–34. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000560

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

Du Plessis, C. (2007). A strategic framework for sustainable construction in developing countries. *Construction Management and Economics*, *25*(1), 67–76. https://doi.org/10.1080/01446190600601313

Elegbede, J. A., & Lateef, A. (2020). Nanotechnology in the built environment for sustainable development. *IOP Conference Series: Materials Science and Engineering*, *805*, 012044. https://doi.org/10.1088/1757-899X/805/1/012044

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Statistics*, *5*(1), 1-4. https://doi.org/10.11648/j.ajtas.20160501.11

Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, *5*(6), 215-217. https://doi.org/10.15406/bbij.2017.05.00149

Gilner, E., Galuszka, A., & Grychowski, T. (2019). Application of artificial intelligence in sustainable building design—optimisation methods. In *2019 24th International conference on methods and models in automation and robotics (MMAR)*. (pp.81–86). Miedzyzdroje, Poland. https://doi.org/10.1109/MMAR.2019.8864698

Hammarberg, K., Kirkman, M., & de Lacey, S. (2016). Qualitative research methods: When to use them and how to judge them. *Human Reproduction*, *31*(3), 498–501. https://doi.org/10.1093/humrep/dev334

Harkouss, F., Fardoun, F., & Biwole, P. H. (2018). Multi-objective optimization methodology for net zero energy buildings. *Journal of Building Engineering*, *16*, 57–71. https://doi.org/10.1016/j.jobe.2017.12.003

Hertwich, E. G., & Peters, G. P. (2009). Carbon footprint of nations: A global, trade-linked analysis. *Environmental Science & Technology*, *43*(16), 6414–6420. https://doi.org/10.1021/es803496a

Holness, G. V. R. (2008). BIM Building Information Modeling gaining momentum. *ASHRAE Journal*, *50*(6).

Jansen, H. (2010). The logic of qualitative survey research and its position in the field of social research methods. *Forum: Qualitative Social Research, 11*(2), https://doi.org/10.17169/fqs-11.2.1450

Jayalath, A., & Gunawardhana, T. (2017, October). Towards sustainable constructions: Trends in Sri Lankan construction industry-A review. In *International Conference on Real Estate Management and Valuation (ICREMV- 2017)*, (pp. 137-143). Colombo, Sri Lanka.

Karunasena, G., Rathnayake, U., & Senarathne, D. (2016). Integrating sustainability concepts and value planning for sustainable construction. *Built Environment Project and Asset Management*, *6*(2), 125-138. https://doi.org/10.1108/BEPAM-09-2014-0047

Kutschera, M., Breiner, T., Wiese, H., Leitl, M., & Bräu, M. (2009). Nano-modification of building materials for sustainable construction. In Z. Bittnar, P. J. M. Bartos, J. Němeček, V. Šmilauer, & J. Zeman (Eds.), *Nanotechnology in Construction 3*, (pp. 275–280). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-00980-8_36

Mechtcherine, V., Nerella, V. N., Will, F., Näther, M., Otto, J., & Krause, M. (2019). Large-scale digital concrete construction – CONPrint3D concept for on-site, monolithic 3D printing. *Automation in Construction*, *107*, 102933. https://doi.org/10.1016/j.autcon.2019.102933

Panchalingam, R., & Chan, K. C. (2021). A state-of-the-art review on artificial intelligence for smart buildings. *Intelligent Buildings International*, *13*(4), 203–226. https://doi.org/10.1080/17508975.2019.1613219

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

Somachandra, V., & Sylva, K. (2018). "Ethical management practice" as a CSR tool to ensure the corporate sustainability of construction industry: a conceptual review. In *International Conference on Technology Management (INCOTEM)*, (pp. 25-31). University of Moratuwa, Colombo, Sri Lanka.

Thalpage, R., & Karunasena, G. (2016). Approaches to foster green building constructions in Sri Lanka. In Y.G. Sandanayake, G.I. Karunasena & T. Ramachandra (Eds.), *Greening environment, eco-innovations & entrepreneurship* (pp. 70-78). Ceylon Institute of Builders, Sri Lanka.

Wang, X. (2012). BIM Handbook: A guide to Building Information Modeling for owners, managers, designers, engineers and contractors. *Construction Economics and Building*, *12*(3), 101–102. https://doi.org/10.5130/AJCEB.v12i3.2749