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LEAN ICEBERG MODEL TO MINIMISE BARRIERS FOR DIGITAL TWIN IMPLEMENTATION: SRI LANKAN CONSTRUCTION INDUSTRY PERSPECTIVE

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ABSTRACT

Digital twin technology holds immense potential for the construction industry in developing countries, while providing numerous benefits. Yet, financial, cultural, infrastructural and technological barriers hinder the implementation of digital twin. Researchers have emphasised the importance of considering both visible and invisible barriers of digital twin implementation. 'Lean Iceberg Model' (LIM) emphasises that most of the underlying barriers and problems in a project are invisible and unaddressed, and it is critical to solve these underlying issues to achieve effective implementation. The study aims to develop a LIM to minimise barriers for successful digital twin implementation in the Sri Lankan construction industry. This study adopts an interpretivism stance and employs a qualitative research approach. Semi-structured interviews were conducted with 15 experts chosen through purposive sampling. VBA script was employed to analyse the data. LIM highlights the unseen aspects such as leadership, commitment, employee engagement, and organisational strategy as crucial to the successful digital twin implementation. Thus, a comprehensive approach is required to contemplates the technical aspects with the organisation's overall strategy, employee engagement, and leadership commitment. Moreover, cultural values, norms, leadership, and social networks are also examined to determine their impact on digital twin implementation. A framework for minimising the barriers to the implementation of digital twins in the Sri Lankan construction industry using the LIM has been developed incorporating the findings, which will offer valuable insights for construction industry professionals and policymakers interested in implementing digital twin to improve construction project management.

Keywords: *Barriers; Construction Industry; Digital Twin; Lean Iceberg Model; Sri Lanka.*

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1. INTRODUCTION

The construction industry has been one of the most vital sectors in Sri Lanka's economic development (Perera et al., 2020). However, there are various challenges in the construction industry, such as limited resources, environmental constraints, and a shortage of skilled labour (Silva et al., 2018). Furthermore, the construction industry in Sri Lanka is facing numerous challenges, including low productivity, excessive costs, and limited adoption of modern technologies (Manoharan et al., 2020). Information technology advancements hold enormous potential for the construction industry to face these challenges (You et al., 2020).

Digital twin has emerged as a promising tool in transforming the construction industry. The concept of digital twin technology has revolutionised the construction industry, and its implementation in developing countries have had far-reaching benefits (Sepasgozar et al., 2021). Developing countries have been able to leverage digital twin technology to leapfrog traditional construction methods and adopt more modern and efficient approaches. It can facilitate the digitalisation of various assets, systems, and processes in different sectors related to construction industry (Tchana et al., 2019). Adopting digital twin technology can provide a range of benefits that can help to overcome these challenges and support the growth of the construction industry in developing countries (Shahzad et al., 2022).

Digital twin technology has the potential to address some of these challenges by improving efficiency, reducing costs, and improving collaboration among stakeholders (Singh et al., 2021). This adoption can help accelerate economic development and increase competitiveness in the global market (Melesse et al., 2021). The digital twin concept is primarily based on advanced data and information processing software such as machine learning tools, optimisation and search algorithms, and other AI tools (Badenko et al., 2021). The digital twin concepts refer to a building model that captures real-world data and generates dependable prototypes of the building through technologies such as sensors, drones, lasers, and other wireless technology. The project collects information from multiple sources, such as analytics, algorithms, and artificial intelligence, to continue to understand a project's functionality, functionality, or efficiency, whether built or functional (Akomah et al., 2020). This is possible because of the digital twin notion, a real-time computer version of physical characteristics. Sensors that continually monitor environmental changes and recalculate the quality of current measurements and pictures often create digital data (Khajavi et al., 2019). It can help with planning, tracking, and monitoring, operations and risks, problem identification, improvements, performance improvement, maintenance, and forecasting future resource requirements (Acampa et al., 2020). Moreover, it can enhance process efficiency to increase productivity, reduce energy consumption, and forecast future resource requirements. This technology provides the ability to discover the source of product defects and analyse product efficiency barriers.

Nonetheless, the construction industry has been slow to adopt digital technologies. Several factors contribute to this trend, including the complex nature of construction projects, fragmented supply chains, and the lack of interoperability between different systems (Teisserenc & Sepasgozar, 2021). Implementing the concept of a digital twin requires overcoming a number of technical, sociological, organisational, and commercial barriers. Meanwhile, due to the lack of awareness of modern technology and knowledge transfer, the local industry is not entirely able to meet all this increased technical demand. Furthermore, no deliberate effort appears to have been taken to ensure an adequate level of current technology and knowledge transfer (Kuruwitaarachchi et al., 2020). Yet, various models exist within the construction industry, offering valuable insights into identifying barriers and establishing an effective framework for implementing digital twin technology, such as the SWOT model (Namugenyi et al., 2019; Palomares et al., 2021), the six thinking hats model (Chien, 2020; Göçmen & Coşkun, 2019), the transtheoretical model (Jiménez-Zazo et al., 2020), LIM (Alejandro-Chable et al., 2022; Grigg et al., 2020).

LIM is important for implementing a new concept as it helps to ensure that all of the necessary elements are in place for success. The model shows how the cultural elements of LIM, such as leadership and engagement, are just as important as the technical elements, such as process management and technology (Grigg et al., 2020). LIM emphasises that the majority of underlying barriers and problems of a project are placed invisibly below the surface level and unaddressed, and it is crucial to address these underlying issues to achieve an efficient application. Several researchers have focused on the implementation of digital twins, as seen in studies by (Barricelli et al., 2019; El Jazzar et al., 2020; Neto et al., 2020; Opoku et al., 2023), which have explored their applications in a global context. However, there is a lack of research in the Sri Lankan context (Munasinghe & Pasindu, 2021). Therefore, the study aims to develop a LIM to minimise barriers for successful digital twin implementation in the Sri Lankan construction industry.

2. LITERATURE REVIEW

2.1 DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

A construction project involves coordinating various stakeholders and collecting and managing large amounts of data. Bou-Hatoum et al. (2020) highlighted that a construction project can be compared to a nexus, where different stakeholders interact to accomplish the project from planning to decommissioning. Digitalising various assets, systems, and processes across different industries has been made possible in recent decades due to technological advancements namely, the Internet of things(IoT), artificial intelligence, and cloud computing (Mabkhot et al., 2018). These technologies form the foundation of the digital twin concept, which involves the integration of a virtual object with its physical counterpart throughout the life cycle (Borowski, 2021).

The use of advanced data analytics and artificial intelligence can enable construction companies to make informed decisions, optimise resources, and increase efficiency (Alexopoulos et al., 2020). For instance, real-time data collected through IoT devices can provide insights into the project's progress, allowing the stakeholders to make timely decisions to keep the project on track.

This connection enables real-time monitoring and control of the physical product through its digital twin, allowing for predictive maintenance and simulation-based analysis. As per Grieves and Vickers (2017), a digital twin is a virtual representation of a physical product that can mirror its current state. Hu et al. (2018) stated that the connection between the product and its twin makes it possible to reflect the present status of the physical product to its digital counterpart. The availability of current and historical data on the digital twin enables predictions of future behaviour (Sivalingam et al., 2018). Similarly, Ayani et al. (2018) vindicated that simulations can be run using Digital twins.

The construction sector began to view digital twins as a significant facilitator for its digital transformation, with the potential to improve the industry's dismal digitalisation record (Brilakis et al., 2019). The system has received the least attention within the architectural, engineering, and construction businesses (Ammar & Nassereddine, 2022). Researchers think that the combination of IoT and building information modelling (BIM) prepared the ground for developing a digital twin in the built environment (Davila-Delgado & Oyedele, 2021).

Digital twin construction is also a new mode of construction production management that uses data streaming from a variety of site monitoring technologies and artificial intelligence functions to provide accurate status information while also proactively analysing and optimising ongoing design, planning, and production (Agostinelli et al., 2020). Digital twin construction creates a data-centric way of construction management by combining BIM technologies and procedures, lean construction thinking, the digital twin concept, and artificial intelligence. The digital twin construction offers detailed descriptions of its basic information concepts and data processing routines.

While BIM tools provide excellent representations for product design, they often lack essential features necessary for construction when it comes to Digital Twins (Pan & Zhang, 2021). The stream of monitored data that flows from the physical artefact to the digital processes is essential to the connection between physical and digital twins (Beckman et al., 2021). People monitor building work progress in contemporary, traditional construction practices mostly by direct observation and measurement. This physical labour is time-consuming and prone to mistakes (Cheng & Teizer, 2013).

2.2 BENEFITS OF DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

Digital twin technology provides significant benefits to the construction industry as shown in Table 1.

Table.1: Benefits of digital twin in construction

No	Benefits	References
01	Enhanced collaboration	[1][2][3]
02	Higher accuracy	[4][5]
03	Real-time responsiveness	[6][7][8]
04	Safety monitoring	[9]
05	Health monitoring of structures	[10]
06	Cost-saving by avoiding rework	[11][12]
07	Reducing human errors and data entry errors	[13]

Sources: [1] Wang et al. (2021), [2] Ozturk (2021), [3] Tao et al. (2022), [4] Zheng et al. (2019), [5] Lim et al. (2020), [6] Ma et al. (2020), [7] Jiang et al. (2021), [8] Peng et al. (2020), [9] Jiang et al. (2022), [10] Liu et al. (2020), [11] Piroumian (2021), [12] Warke et al. (2021), [13] Sepasgozar et al. (2020)

Digital twins enhance collaboration by providing a platform for stakeholders to interact and share information, leading to better collaboration between teams (Wang et al., 2021). By enabling design validation and testing, Digital twins ensure that the final product is accurate, reliable, and efficient (Zhang et al., 2021). Data is collected through sensors and other monitoring devices embedded within the structure and is then transmitted to the virtual model in real-time (Ma et al., 2020). Through accessing to this real-time data, stakeholders can quickly identify and respond to issues as they arise, leading to increased efficiency and productivity (Jiang et al., 2021). Digital twins can be used to monitor the safety of structures in real-time (Liu et al., 2020), identifying potential hazards before they become a problem, which can reduce the risk of accidents and injuries, promoting safety in the workplace (Jiang et al., 2022). Digital twins can automatically collect and process data, reducing the risk of data entry errors that can lead to inaccuracies and delays (Sepasgozar et al., 2020).

Digital twin technology offers various industries a wide range of benefits, including enhanced collaboration, greater accuracy, real-time response, high security, health monitoring of structures, cost savings, and error reduction. These benefits make digital twin technology an attractive solution for companies seeking to improve their operational efficiency, reduce costs, and increase productivity.

2.3 BARRIERS TO IMPLEMENTATION OF DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

There are several barriers to the implementation of digital twin in the construction industry, such as ethical issues, security and privacy concerns, development costs, uneven distribution of resources, and technical limitations, and digital twin technology has the potential to revolutionise the construction industry by improving efficiency, accuracy, and cost-effectiveness. Table 2 illustrates the barriers to the implementation of digital twin in the construction industry.

Table 2: Barriers to the implementation of digital twin in the construction industry

No	Barriers	References
1	Technological	[1] [2] [3] [4]
2	Social	[5] [6] [7]
3	Organisational culture	[5] [8] [9] [10]
4	Financial	[5] [11] [12]
5	Machine learning techniques	[5] [13] [14]
6	System optimisation	[5] [15] [16]
7	Search algorithms (for assessing and exploring potential forward-looking building plans)	[5] [1]
8	Existing construction management systems and procedures	[17]
9	Computer Literacy	[17] [18]

Sources: [1] (Sacks et al., 2020), [2] (Yevu et al., 2021), [3] (Peansupap & Walker, 2006), [4] (Yevu et al., 2022), [5] (Wanasinghe et al., 2020), [6] (Drummond & Coulet, 2022), [7] (Qi & Tao, 2018), [8] (Neto et al., 2020), [9] (Khasanov & Krasnov, 2019), [10] (Agrawal et al., 2022), [11] (VanDerHorn & Mahadevan, 2021), [12] (Boschert & Rosen, 2016), [13] (Priyanka et al., 2022), [14] (Min et al., 2019), [15] (Lim et al., 2020), [16] (Barni et al., 2018), [17] (Zomer et al., 2020), [18] (Kretschmann, 2015).

Implementing digital twin construction will necessitate overcoming several technological, social, organisational, and commercial obstacles. Machine learning techniques, optimisation, search algorithms , and other AI tools are crucial to digital twin development (Sacks, Girolami, et al., 2020). It can be difficult to modify existing construction management systems and procedures and the personnel competent in their application. This has been experienced with the advances such as lean construction and BIM (Zomer et al., 2020). Construction Tech start-up enterprises with access to venture funding and personnel with the necessary AI capabilities will be better positioned to innovate in the transition to digital twin construction than traditional construction companies (Sacks, Girolami, et al., 2020). There are several concerns and challenges when focusing on the improvement of lean construction with the use of digital twin construction (Barricelli et al., 2019).

The mitigation of these barriers can be achieved by applying lean construction principles, which serve as a viable approach within the construction industry's framework, emphasising collaboration, communication, and continuous improvement. By involving all stakeholders in the construction process and encouraging open communication, lean construction can reduce misunderstandings and delays.

2.4 LEAN CONSTRUCTION AND DIGITAL TWIN

Lean construction is an approach which helps to decrease the duration of the project, whole life cycle cost of the project, and non-value adding activities with the intention to increase the quality of the project and health and safety, adapting to continuous improvement, improvement in labour performance, more satisfaction, and better value for an employer (Parameswaran & Ranadewa., 2021). Lean culture is an essential aspect that determines how things are done in a company and are influenced by the management system (Iranmanesh et al., 2019). Culture represents the conventions and values of a company (Tarurhor & Emudainohwo, 2020). Organisations that adopted lean practices reported that companies with a high adoption of lean culture throughout the organisation implemented lean techniques more effectively than those with a low adoption of lean culture that just used lean principles on the shop floor (Aberdeen Group, 2006). Lack of knowledge about lean practices is a major barrier to gaining the competitive advantage of lean construction. (Parameswaran & Ranadewa., 2023). The digital twin is a highly impactful technology that organisations can utilise to improve their processes and reduce wastage (Psarommatis & May, 2022). Digital twin is a powerful tool that enables organisations to optimise their processes, reduce waste, and improve overall performance (Julien & Hamzaoui, 2023). The use of digital twin as a lean tool is extensively studied and has been effective in various industries. The key to leveraging digital twin as a lean tool is to ensure that organisations have access to the necessary technology and expertise to implement it effectively (Barkokebas et al., 2023).

2.5 LIM TO MINIMISE BARRIERS IN DIGITAL TWIN IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

Figure 1 shows the visible and invisible aspects of the LIM. The visible features are those above the waterline in the iceberg model, whereas the unseen aspects are those below the waterline. Technology tools, techniques, and processes are located above the waterline and are simple to visualise, comprehend, and implement. Strategy and alignment, leadership and behaviour, and engagement are the suppressed underlying concepts (Pearce & Pons, 2017).

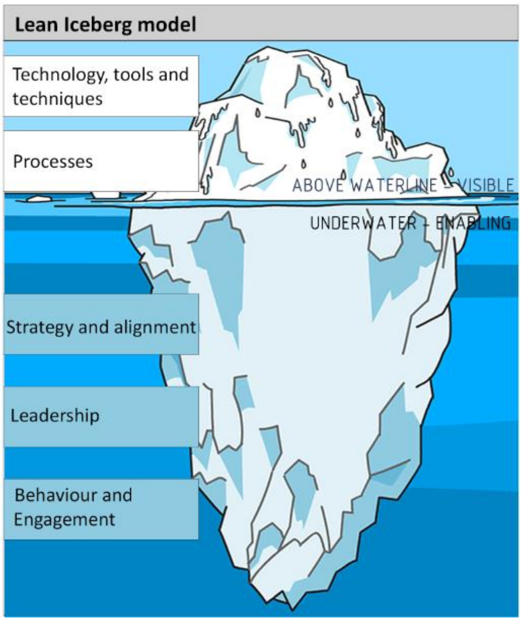

Figure 1: Lean Iceberg Model

Technologies, tools, and techniques demonstrate the visible features of the LIM that are utilised to optimise the digital twin process (Ivanov et al., 2020). These are the technological tools required for digital twin implementation, such as simulation software, sensors, and data analytics tools (Pearce & Pons, 2013). These tools enable the creation of digital replicas of physical assets and processes, allowing for optimisation and continuous improvement (Kostromin & Feoktistov, 2020). In the LIM for digital twin implementation, the processes refer to the series of activities required to implement and utilise digital twin technology (Bao et al., 2019).

With the implementation of digital twin technology, many organisations are looking to leverage its potential benefits. However, as with any modern technology, several barriers need to be overcome for successful implementation. From the literature, various barriers have been identified, and those are technological, social, cultural, financial, machine learning techniques, system optimisation, search algorithms, existing construction management system and procedure, and computer literacy. Therefore, the framework is developed with the analysed findings of the study.

3. METHODOLOGY

To explore the theoretical understanding of the concept of digital twins and LIM in the Sri Lankan context, a review of the literature was conducted. The study aimed to gather different perspectives from experts in the field and therefore adopted an interpretivism stance. To achieve this, a qualitative approach was employed as the research approach. The empirical data was collected through semi-structured interviews with experts in Sri Lanka who were selected through purposive sampling. The use of semi-structured interviews is preferred in qualitative research as it allows for a structured flow of questions to be asked of the interviewees. To gather data, fifteen (15) expert interviews were conducted and analysed using a VBA script. Excel VBA script is used to analyse content in a systematic and efficient manner. The findings of this study provide a deeper understanding of the implementation of digital twins in the Sri Lankan construction industry and are useful for future research on the topic. As mentioned, expert interviews were conducted with experts who have knowledge of the implementation of digital twin or developing and implement expert systems. Table 3 illustrates the profile of the experts.

Table 3: Profile of the experts

Details (Expert)	**Profession**	**Designation**	**Organisation type**	**Field of expertise**	**Experience in the industry**
E1	Quantity Surveying	Quantity Surveyor	Consultant	BIM and Quantity Surveying	4 years
E2	Quantity Surveying	Quantity Surveyor	Contactor	BIM and Digital Twin	4 years
E3	Quantity Surveying	Quantity Surveyor	Contractor	BIM and Quantity Surveying	4 years
E4	Quantity Surveying	Quantity Surveyor	Contractor	BIM and Quantity Surveying	4 years
E5	Engineering	General Manager	Contractor	BIM and Project Management	20 years
E6	Software Engineering	Team leader	BIM tools provider	BIM	4 years
E7	Software Engineering	Team leader	BIM tools provider	BIM	5 years
E8	Software Engineering	Team leader	AI developer	IoT and AI	10 years
E9	Software Engineering	General manager	AI developer	IoT and AI	8 years
E10	Software Engineering	Software Engineer	AI developer	IoT and AI	4 years
E11	Software Engineering	Software Engineer	AI developer	IoT and AI	5 years
E12	Software Engineering	Software Engineer	AI developer	IoT and AI	5 years
E13	Software Engineering	Software Engineer	AI developer	IoT and AI	4 years
E14	Software Engineering	Software Engineer	AI developer	Project implementing	3 years
E15	Project management	Project Manager	Software Developer	Project implementing	3 years

4. ANALYSIS

4.1 BARRIERS TO IMPLEMENTING DIGITAL TWIN IN THE CONSTRUCTION INDUSTRY

When it comes to the implementation of the digital twin in Sri Lanka, several barriers were discovered through the literature and expert interviews. These barriers must be overcome for the successful implementation of digital twin. Table 4 vividly shows the barriers to implementing digital twin depending on the empirical findings.

Table 4: Barriers to implementing a digital twin in the construction industry.

Description	Count	Expert Index
Financial barriers	12	E1,E2,E3,E4,E6,E7,E9,E10,E11,E12,E13,E15
Limited infrastructure	8	E1,E5,E9,E10,E12,E13,E14,E15
Organisational culture barriers	8	E2,E6,E7,E9,E11,E12,E13,E15
Complexity	5	E4,E5,E7,E8,E11
Technological barriers	5	E2,E3,E7,E8,E11
Regulatory barriers	2	E5,E14
Limited understanding of the potential benefits	2	E1,E10

Financial barriers were cited as a significant obstacle to implementing a digital twin in the construction industry by twelve respondents. E1 emphasised, "*Digital twin requires specialised hardware, software, and data, which can be expensive to purchase and maintain". Furthermore, E8 insisted, "Cost of training personnel to use and manage it. Additionally, there may be ongoing costs associated with data storage, security, and network infrastructure in Sri Lanka".* All other experts mentioned the purchase and maintenance cost of specialised hardware, software, data, data storage, security, and network infrastructure and the cost of the professionals. Eight experts mentioned many issues that pop up with the limited infrastructure. Such as issues in data transferring, slow performance, noised and inaccurate data, limited scalability, and security issues. E1 elaborated that "*a 'digital twin' requires a robust and reliable internet and data infrastructure to function effectively. If these are not widely available, it may be difficult to implement digital twins*". E5 stated, "*Limited infrastructure may make it difficult to ensure the security of the data being transmitted and stored, increasing the risk of data breaches and other security issues".* Further, E12 insisted, "*If the data collecting and transmission infrastructure is inadequate, it may be difficult to collect enough data to generate an accurate digital twin model".*

The organisational cultural barrier was mentioned by the eight experts. E1 emphasised, "*Digital twins may need a change in how people work and communicate. If there is a reluctance to change or a lack of awareness of the benefits of digital twins, adoption may be hampered".* As the E2 and E12 view, "*Employees may be confused about what a digital twin is and how it may be utilised, resulting in a lack of engagement with the project*". Further, E11 mentioned, "*Employees may be reluctant to the concept of a digital twin and the changes it may bring, making acceptance and implementation difficult*". Five experts pointed out the complexity of the digital twin as a barrier to implementation. E5 emphasised that '*Digital twins can be complex to create and maintain, requiring specialised skills and expertis'.* Further, E14 explained, "*The complexity of a digital twin varies according to the system being modelled as well as the amount of detail and accuracy required. The number of variables and interactions in the system, the necessity for real-time data and updates, and the integration of numerous data sources are all factors that might contribute to complexity".* The view of the complexity of E8 and E4 of the digital twin is the level of autonomy, and the decision-making capabilities necessary in the digital twin might influence complexity.

Five respondents stated technological barriers as the barriers to digital twin implementation. From the experts' standpoint, companies need access to the necessary hardware, software, and reliable data communication method to use digital twins. If these technologies are not widely available or are too expensive in Sri Lanka, it may be difficult for companies to adopt digital twins. Regulatory barriers, E5 insisted, "*National and international norms and standards may apply to digital twins. If these restrictions are unclear or difficult to follow, digital twin adoption may be hampered*". Limited understanding of potential benefits, E1 emphasised: "*Digital twin is a complex technology, and it can be difficult for some companies to understand how they can be used to benefit their operations. This lack of understanding may make it difficult to justify the investment in the digital twin*". Technical barriers, organisational culture barriers, and finical barriers were pre-identified during the literature review. The LIM provides a comprehensive approach to the implementation of digital twins. The five phases of the framework, namely technologies tools and techniques, process, strategy, leadership and behaviour, and engagement, are interconnected and interdependent. Successful implementation of the digital twin requires a holistic approach that addresses all these phases.

4.2 PATTERN MATCHING FOR THE BARRIERS

Comparing the study's findings with existing knowledge can also help identify gaps in the literature and suggest areas for future research. Table 5 shows the barriers, which have been identified the literature and during the data analysis.

Table 5: Empirical and literature findings for barriers

Description	**Count**	**Expert Index**
* Financial barriers | ***Literature***	12	E1, E2,E3,E4,E6,E7,E9, E10, E11,E12,E13,E15
Limited infrastructure	8	E1, E9,E10,E5,E12,E14, E15, E13
* Organisational Cultural barriers | ***Literature***	8	E6, 12,E2,E7,E9,E11,E15, E13
Complexity	5	E5, E8, E4,E14,E15
* Technological barriers | ***Literature***	5	E2, E3,E7,E8,E11
Regulatory barriers	2	E5, E14
Limited understanding of the potential benefits	2	E1, E10
** Social | ***Literature***	-	Not recognised by experts
** Machine learning techniques | ***Literature***	-	Not recognised by experts
** System optimisation | ***Literature***	-	Not recognised by experts
** Search algorithms | ***Literature***	-	Not recognised by experts
** Existing construction management systems and procedures | ***Literature***	-	Not recognised by experts
** Computer Literacy | ***Literature***	-	Not recognised by experts

In Table 5, marked (*) rows show confluence barriers that have been identified in the literature and mentioned during the data collection. Marked (**) show the identified in the literature review phase.

4.3 LIM TO MINIMISE BARRIERS IN DIGITAL TWIN IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

Upon integrating the empirical findings of the study, the following model has been formulated and presented in Figure 2. Sankey diagrams provide a powerful tool for understanding and visualising the interconnections between different components of a system in the final framework (Riehmann et al., 2005). The model aims to provide a comprehensive understanding of the observed facts and the findings discovered and to facilitate further investigations in the field. The development of the model was based on the analysis of the collected data and the identification of the underlying patterns and relationships among the variables. As maintained a greater value of connections to invisible elements than visible elements (Eranga et al., 2022). The relationship had been formulated with the findings of the above analysis. Several authors disclosed technological barriers (Peansupap & Walker, 2006; Yevu et al., 2021, 2022;), organisational cultural barriers (Agrawal et al., 2022; Khasanov & Krasnov, 2019; Neto et al., 2020; Wanasinghe et al., 2020) and system optimisation (Barni et al., 2018; Lim et al., 2020; Wanasinghe et al., 2020) as the main barriers in the implementation of digital twin. It is evident from the LIM that the significance of the invisible elements is greater than that of the visible elements. The model emphasises that a significant portion of an organisation's strategy, leadership, behaviours, and engagement are not immediately apparent or observable, and thus may be overlooked or undervalued. Therefore, a comprehensive understanding of an organisation's dynamics necessitates appreciating these intangible yet crucial components.

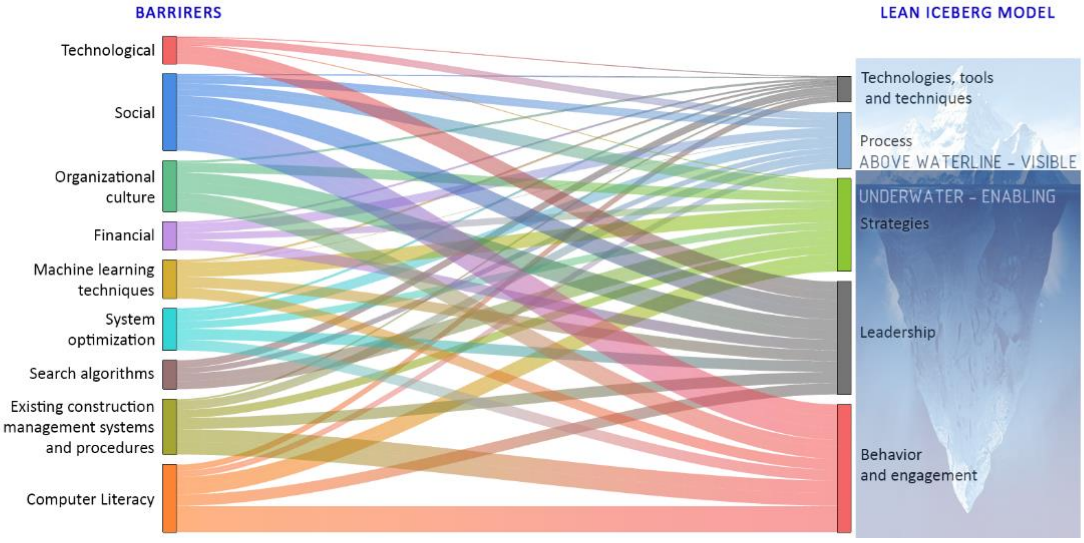

Figure 2: LIM relationship to minimise barriers in digital twin implementation.

5. CONCLUSIONS

Various barriers, including technological, organisational culture, and system optimisation, hinder implementing the digital twin. Literature findings have identified these barriers. Furthermore, the LIM has been used to analyse the connections between visible and invisible elements in the industry, revealing that the latter is more significant in determining an organisation's success in implementing digital twin. LIM highlights the importance of understanding intangible elements such as an organisation's strategy, leadership, behaviours, and engagement, which are often overlooked but crucial in achieving success in digital twin implementation. Therefore, a comprehensive understanding of an organisation's dynamics requires careful consideration of both visible and invisible elements to overcome the barriers and successfully implement the digital twin.

Empirical findings have revealed that financial barriers are the major barriers to the implementation of digital twins in Sri Lanka. This is due to the excessive cost of purchasing and maintaining specialised hardware, software, and data, as well as the cost of training personnel to use and manage them. Limited infrastructure and organisational cultural barriers were also identified as significant obstacles, as they can affect data transfer, slow performance, accuracy, scalability, and security issues. Complexity and technological barriers were also mentioned, as companies need access to the necessary hardware, software, and reliable data communication methods. Regulatory barriers and a limited understanding of potential benefit**s** identified as potential barriers to digital twin adoption. These findings indicate that firms need to address these barriers to successfully implement digital twins in Sri Lanka. Accordingy, the further research will be conducted to propose strategies through the LIM to minimise barriers to digital twin implementation in the Sri Lankan construction industry.

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