INTEGRATION OF DIGITAL TWIN AND CIRCULAR ECONOMY PRINCIPLES TO ACHIEVE CONSTRUCTION PROJECT SUCCESS IN INDIA

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Abstract

The introduction chapter has provided a detailed background of the dissertation and its problem along with detailed statistical representation has been provided. Research aims and objectives have been provided to outline the main prospects of the dissertation. The research questions have been structured aligning with research objectives. Based on the chosen topic, the significance of the study has been provided in a detailed manner. India's construction projects may proceed much more easily if digital twin technologies and a cycle economy are included. The Internet of Things (IoT) and artificial intelligence (AI) are necessary for them to create virtual replicas of actual objects and procedures. People may check them at any time and alter them immediately. The evaluation of the literature discusses the advantages and disadvantages of this connection as well as ways to improve its performance in India. By taking a fresh perspective, they may come up with innovative, environmentally friendly construction methods. Beyond secondary sources, surveys with key players in the area provide depth and insight to the study. For the purpose of gathering quantitative data, a survey was carried out using a Likert scale and SPSS. The dataset, which consisted of eight items with 51 responses, was analysed using SPSS for descriptive statistics, correlation analysis, and regression analysis. The findings of the relevant study are presented in this section. The discussion in Chapter 3 applies theme analysis to the qualitative information obtained from document analysis or interview data. This investigation supports the validity of topical patterns that are frequently used to link digital twins and circular economy concepts in Indian building projects. When discussing the findings, special emphasis is paid to the most recent research and suggestions for incorporating sustainable construction methods in the context of India. This paper thoroughly concludes the potential benefits of digital technologies collaborating with the circular economy in the building sector. Overall, the study's findings are encouraging and may help to further resource-conscious or environmentally friendly building practices. A correlation study revealed a method that took into account the intimate connections between a number of digital technologies and the main tenets of the circular economy.

Acknowledgement

"INTEGRATION OF DIGITAL TWIN AND CIRCULAR ECONOMY PRINCIPLES TO ACHIEVE CONSTRUCTION PROJECT SUCCESS IN INDIA" is the subject of the present study. I am expressing my appreciation to all of the lecturers that helped me finish this research. I would want to express my gratitude to my professors for their help each time I ran across a problem while conducting my research. In addition, I want to express my gratitude to my classmates for helping me get over all of my academic obstacles. I want to express my gratitude to my friends and family for providing moral encouragement.

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Chapter 1: Introduction

1.1 Background

Technological integration of digital twins has successfully enhanced the feasibility value of the global construction industry positively. Digital twin has been created by integrating data from "Building information Modelling (BIM)," "sensors" and "Internet of Things (IoT)" devices (Linkedin.com, 2023). The projection value of this technology is that it has allowed users to monitor, simulate and analyse physical assets by providing valuable insights. It has built the gap between the digital and physical world by capturing real-time data and supporting overall decision-making prospects. Integration of digital twin technology has contributed to the success of construction projects in India contributing its circular economy principles.

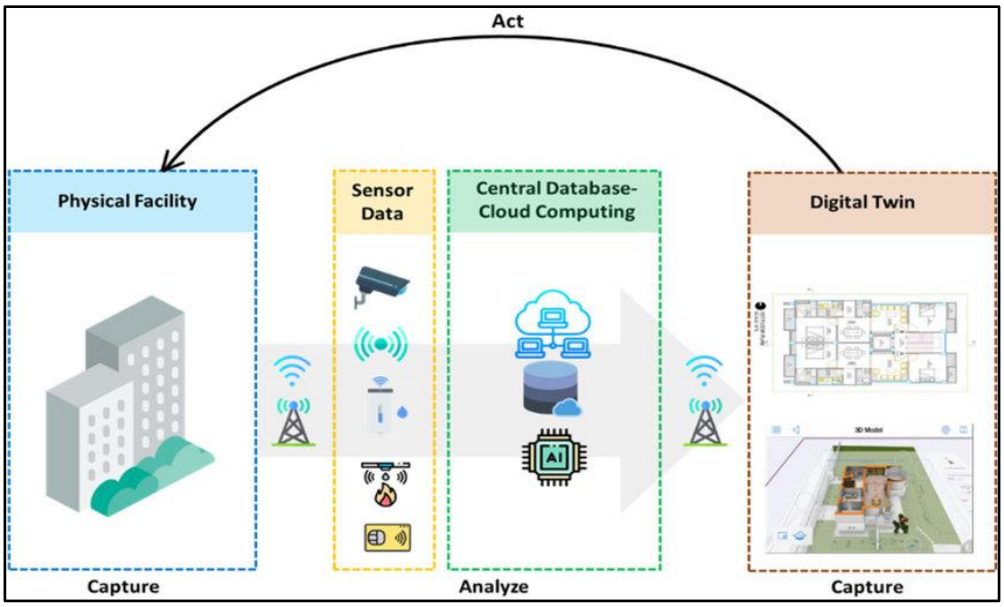

Figure 1.1: Implementation of digital twin in construction

(Source: Jazzar *et al.* 2020)

Incorporation of digital twins has provided sustainability within the construction industry increasing its success prospect in the competitive marketplace. The principles of circular economy are based on three prospects in the construction industry: "reduce," "recycle" and "reuse (Ellenmacarthurfoundation.org, 2024). It has globally supported the purpose of recycling materials and evaluated the overall value of the circular economy in the dynamic business environment. The reusable materials of construction projects in India will be responsible for generating 40% of energy by 2050 (Mittal, 2023). Therefore, it can be stated

that the positive value of digital twin technology can influence the prospect of a circular economy effectively.

1.2 Research problem

The problem of the research is to identify the technological challenges Indian construction is encountering which is responsible for the growth of the circular economy. It has been reported that the use of digital twins has increased 9.2% since December, 2022 suggesting a positive impact (Gupta, 2024). It can be stated that digital twin has increased the production value with its leading technological prospect by fostering monetization. It also includes the calculation method of monitoring critical components which eventually led to operational efficiency and promotion of sustainability standards. The integration prospect of digital twins can be categorised into four segments such as “3D geometric model”, “real-time data integration”, “analytics and simulation” and “communication interface” (Sharon, 2023). The progression value of digital twins has guided digital technology and established its value. Thus, it can be stated that the appropriate implication of digital technology has ensured the success of construction projects in an effective manner.

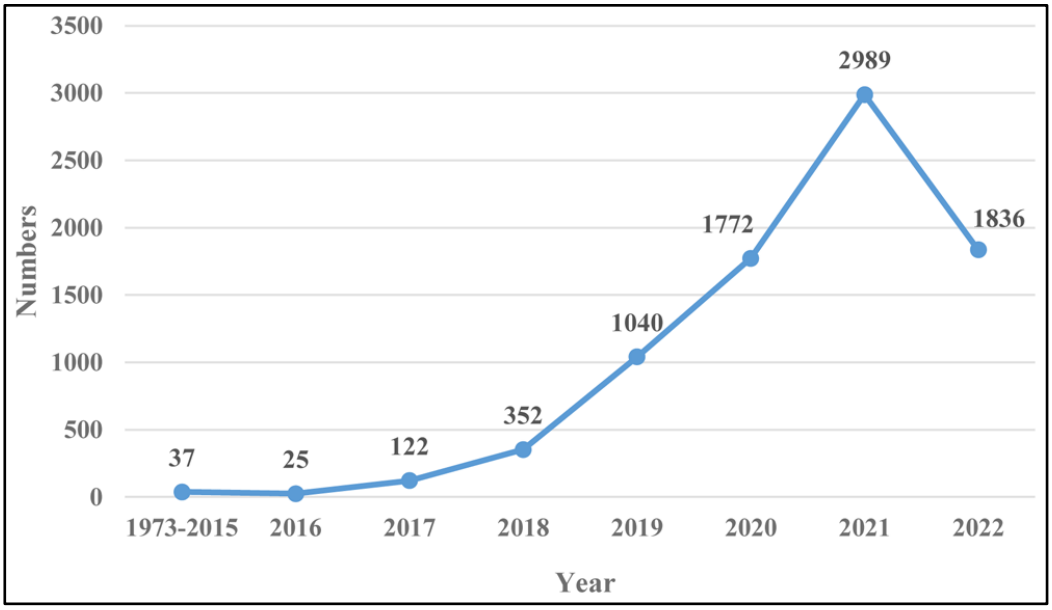

Figure 1.2: Application of digital twin in the construction industry

(Source: Su *et al.* 2022)

The approach of the circular economy has impacted the production value within the construction industry in the dynamic business environment. It has been reported that 36% of the construction industry has been able to save carbon emission and material consumption by following the concept of circular economy (Oneplanetnetwork.org, 2024). The potential

integration has helped in developing the performative value of the construction industry and maintained life cycle appropriately. Exploring innovative models of value chain and regenerative systems has supported the successful completion of construction projects in the competitive marketplace. Incorporation of circular economy within the construction industry has resulted in a 60% non-hazardous demolition waste and supported the value of recycling (Oneclicklca.com, 2023). The public procurement process has benefited from the incorporation of an effective circular economy and completion of recovery targets. The below mentioned picture depicts India's output to the construction industry from the circular economy. It has demonstrated the overall value of construction materials and remediation of reused materials with integration of digital twins.

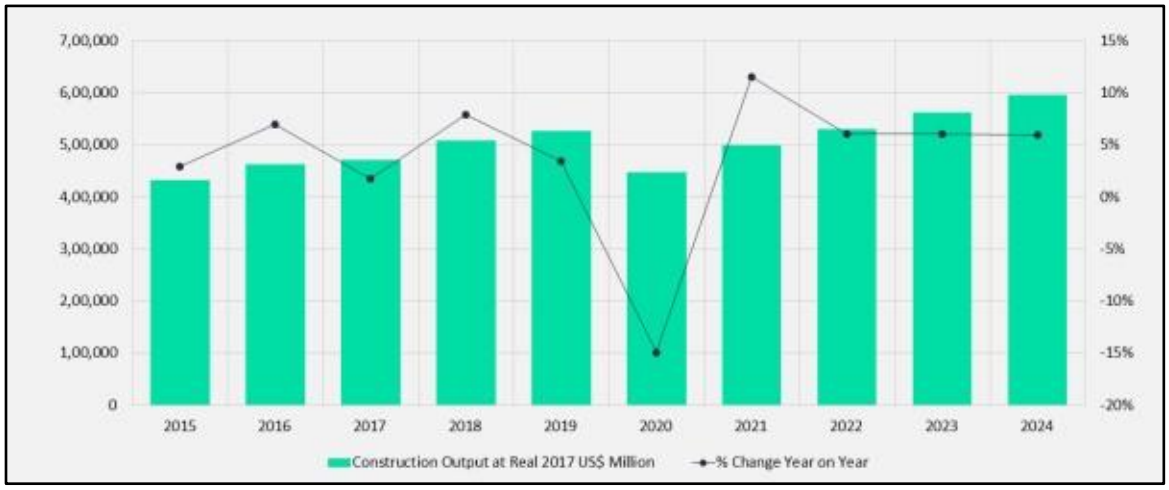

Figure 1.3: India's output to construction industry for circular economy

(Source: Architectandinteriorsindia.com, 2020)

1.3 Aim and objectives

The aim of the research is to examine the prospects for integrating digital twin and circular economy principles in order to achieve project success in India. The objectives of the research are as follows:

- To analyse the concept of digital twin, circular economy principles, and project success.
- To examine the challenges and strategies of the digital twin which has influenced the success of the construction industry and helped in building a circular economy.
- To determine the method of the research by comprehensive value of digital twin and circular economy of construction projects
- To evaluate the impact of digital twin technology and principles of circular economy in achieving project success

1.4 Research questions

The research questions for the dissertation are as follows:

- How does the concept of the digital twin contribute to achieving a circular economy, particularly in construction projects within India?
- How have the challenges and strategies of digital twins influenced the success of the construction industry and facilitated the development of a circular economy?
- Which research methodologies can be used to comprehensively assess the value of digital twin technology and its contribution to circular economy within construction projects?
- How does the integration of digital twin technology and circular economy principles impact the success of construction projects in India?

1.5 Significance of the study

Based on the expansion of the construction industry, this research is intended to explore the importance of digital twin technology and consolidated principles of the circular economy. The innovative approach of digital twin technology has influenced sustainability, efficiency and cost-effectiveness of construction projects (Tuhaise *et al.* 2023). It can be stated that this research is focused on evaluating the positive impact of digital twin technology and the circular economy in enhancing construction projects in India. Detailed analysis on the challenges and strategies regarding the digital twin technology can provide effective project outcomes in the competitive marketplace. Therefore, this research can help in facilitating the transition of digital technology in the construction industry by helping India to become resilient over the course of time.

1.6 Structure of the study

Chapters	Content
Introduction	The background of the dissertation and its problem along with detailed statistical representation has been provided. Research aims and objectives have been provided to outline the main prospects of the dissertation. The research questions have been

	structured aligning with research objectives. Based on the chosen topic, the significance of the study has been provided in a detailed manner.
Literature Review	The detailed literature review has been outlined based on scholarly articles. Theoretical review has been provided based on the digital twin and circular economy regarding the construction industry. Based on the research objectives the objectives of literature review has been provided in a detailed manner.
Research methodology	The research methodology has been provided with detailed research design and data collection method to understand the overall prospect of the research. Justification for each and every factor, data analysis techniques and ethical consideration have been provided to support the research.
Research findings and discussion	Based on the collected data, the research data will be evaluated to understand the comprehensive value of digital twin and circular economy in the construction industry of India. This chapter has an enhanced route to provide a project management plan to provide a realistic project timeline plan and achieve milestones in a detailed manner.
Summary conclusion and recommendations	Overall summarisation of the dissertation and recommendations of the dissertation of the chapter has been provided. The enhanced route of this chapter consists of research beneficiaries and dissemination prospects. It has been provided

	to provide a consideration of the academic research community.

Table 1.1: Structure of the dissertation

(Source: Self-created)

Chapter 2. Literature Review

2.1. Introduction

The thought of a cycle economy and digital twin technologies could help India's building projects go a lot more smoothly. They need cutting edge technologies like AI and the Internet of Things (IoT) to make virtual copies of real things and processes. People can change them right away and check them whenever they want. The circular economy, on the other hand, lets people keep track of and cut down on waste at every step and when new methods are used, building jobs go more smoothly and last longer. In India, the building business uses both digital twins and the cycle economy. For instance, initiatives like the Smart Cities Mission and the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) emphasize the use of digital technologies for urban development and infrastructure projects. These initiatives encourage the adoption of innovative technologies such as digital twins to improve planning, design, and construction processes. While there might not be specific studies on the combined use of digital twins and the circular economy, reports from organizations like the Confederation of Indian Industry (CII) or consulting firms such as PwC or KPMG might offer insights into trends and practices in the Indian construction industry, including aspects related to digitalization and sustainability. Now the topic talks about the good and bad things about this link and how to make it work better in India. They can find new, green ways to build when they look at things from different points of view. In time, things will get better.

2.2 Introduction to Digital Twin and Circular Economy Concepts

Digital Twin:

A digital twin is another word for a production line that is one way to see how things have changed, find issues that need to be fixed, and make everything work better is to use a digital twin. If people make a digital copy of something real, they can turn it into a digital twin. AI, the Internet of Things (IoT), and data analytics can all be used together to create a digital copy of something that already exists. According to Qi *et al.* (2021) the computer twin works, looks, and acts just like the real computer. People can use digital twins to run a business, get medical care, build towns, and keep track of infrastructure, among other things. This enhances the efficiency of the production process. Analyse health data to provide prognostications of potential outcomes, thereby constructing digital replicas of patients that can assist physicians

in devising individualised treatment strategies. On the other hand, Liu *et al.* (2021) said that digital twins have a wide range of applications. They provide the opportunity to schedule repairs in advance, thereby reducing unexpected issues and the associated expenses. Based on facts, they come up with ideas that improve systems and jobs. Now everything works faster and better. People can get ideas and try new things in a virtual world before they do them in real life.

Circular Economy:

The circular economy aims to transform production and consumption to promote environmentally-friendly practices and resource reuse. Resources are quickly depleted to sustain a market. They are cleaned and reused instead of being discarded. Promote reuse of items and address deficiencies in natural systems to reduce waste and environmental contamination. According to Wang et al. (2022) creating durable, repairable, and reusable objects helps achieve this goal. People can repair and repurpose items, while businesses can use innovative approaches like product-as-a-service and share platforms.

A circular approach that benefits the business and stakeholders by using fewer resources is better to reduce depletion. It improves their well-being. Greenhouse gas emissions occur during production, consumption, and waste disposal, trapping heat in the Earth's atmosphere. A circular economy promotes innovative business practices, cross-sector collaboration, and local sourcing. On the other hand, Bhatti *et al.* (2021) said that support groups enhance strength, generate ideas, and create employment opportunities. Circle economies and digital twins can help solve complex challenges. Digital twins simulate and analyse objects or systems online to improve efficiency and quality. In the circular economy, products are made and used differently, leading to longer-lasting and more durable products. Combining these ideas can make them stronger. Potentially leads to a better and safer future.

2.3 The development and application of digital twin technology in the construction

The technology known as "digital twin" has brought about a significant transformation in project planning, production, and administration. It holds great importance in the field of construction. Digital twins are exact duplicates that are safely kept in a cloud-based environment. They offer expertise, chances for enhancement, and aid in reducing risks during the construction process. According to Rasheed *et al.* (2020) they assist construction experts in accurately visualising and simulating projects prior to commencement. It aids in their strategic

planning. Playing with models and tools reveals various ways to create things. People can change their plans to make them more useful and last longer based on habits of loss or conflict. Digital twins make production easy because they can see and change things in real time. People can learn about the environment, growth, resource usage, and IoT tools. It helps with planning, tracking, and ensuring safety and quality standards. On the other hand, Jiang *et al.* (2021) said that mistakes not following rules can be quickly seen and fixed by anyone. Less delays and price hikes occur. Many like modular building and prefabrication as new construction methods. Real-time simulations help building teams increase productivity, work faster, and manage supply lines more effectively. It improves efficiency and quality.

The implementation of digital twins has revolutionised the administration and maintenance of buildings. Digital twins gather data from production processes and link it to tools used for managing facilities. This strategy offers administrators valuable information about the functionality and performance of the facility. Smart algorithms forecast equipment failures, provide recommendations for energy efficiency, and prolong the lifespan of building systems. It enhances overall welfare and decreases company expenditures. Building project methods have been revolutionised by digital twins. During building projects, digital twins are generated to accurately reproduce physical elements and processes, allowing for convenient access and usage. It will assist them in formulating more effective tactics, enhancing job site operations, and overseeing the facility. Technological advancements will enhance the intelligence and efficiency of the construction business.

2.4 The principles and practices of the circular economy in the construction industry

It is possible for them to perform a significantly more effective job of managing resources and taking care of the world if they implement the concepts and practices of the circular economy. Both the length of time something will last and the ease with which it can be disassembled are taken into consideration in this method of planning. According to Alcaraz and Lopez, (2022) this not only helps to maintain the items in better condition but also makes it simple to disassemble them whenever they feel like it. When people choose to construct things in modules, it is much simpler to disassemble them. By increasing the likelihood that goods will be used again, this helps to reduce the amount of waste that is produced. If people are aware that they are able to do so, they are more inclined to save and repair things that they have found on construction sites or in ancient residences. Steel, wood, and concrete are examples of materials that are not thrown away by people since they have a long lifespan. On the other

hand, Agrawal *et al.* (2022) said that on modern construction sites, which are equipped with effective waste management and recycling systems, they are utilised instead. Construction that is done off-site and through prefabrication is becoming increasingly popular as a result of the fact that it is more cost-effective, expedites the building process, and is better for the environment. When service providers are provided with resources and tools by building projects, the providers then lease or rent those resources and tools back to the contractors. According to Madubuike *et al.* (2022) the appropriate phrase for this is "Platform as a Service," or PaaS for short. This way of thinking can help people come up with great ideas that other people will want to hear over and over. So that open supply lines can work well, people should be able to live together without any problems. If people do it this way, they can see and understand how things change over time. This process makes sure that the right things are bought, used, and stored. On the other hand, Melesse *et al*. (2020) said that if the construction industry adhered to these guidelines and carried out its operations in this manner, it would be able to reduce the amount of harm it caused to the environment, safeguard vital resources, and make the built environment more durable in general. The world of business can also benefit from fresh ideas and find solutions to problems more quickly with the help of this strategy.

2.5 Benefits and Impacts of Integrating Digital Twin and Circular Economy principles in Construction

When digital twin technology and ideas from the cycle economy are combined, the entire building process has the potential to result in improvements in many different ways. All of these things contribute to the improvement of design and planning by allowing everyone to rehearse and create prototypes of building projects that are extremely detailed. According to Corvellec *et al.* (2022) people will then be able to select the most environmentally friendly things that will last for a very long period. It is possible to observe how objects are being utilised at the present time with digital twins. People use what they currently have and recycle to reduce the amount of waste they produce. Also, it is beneficial to the circular economy. Using this straightforward approach, people are able to plan a whole project taking into consideration how to make the most effective use of resources right from the beginning. Additionally, the digital twins facilitate improved collaboration between the construction teams, service providers, and labourers. Due to the fact that this makes work go more rapidly, jobs are completed more quickly. The utilisation of circular economy concepts in digital twins, such as prefabrication and modular construction, results in a reduction in the costs of construction and a speedier completion of projects. On the other hand, Barreiro-Gen and

Lozano, (2020) said that with the help of digital twins, construction workers are able to observe how the building is coming together and determine which components require attention in terms of repairs. To put it another way, there are actions that can be made to make something last for a longer period of time. To ensure that objects continue to be useful and helpful throughout time, it is important to take care of them with the concepts of the circular economy in mind. Furthermore, they make it simpler to operate websites by displaying the amount of electricity that they consume and the degree to which they are responsible for the environment at the present moment. People are more likely to fix things and run the building in eco-friendly ways, which saves money and is better for the earth in the long run. When digital twin technology and circular economy ideas are used together, the building business does better work and hurts the earth less. People in the area can grow their businesses and come up with new ones by working together. These changes help the homes last longer and keep the area healthy all around.

Benefits	**Variables**	**References**
Improved Design and Planning	Detailed rehearsal and prototyping of building projects	(Corvellec *et al*. 2022)
	Selection of environmentally friendly materials	
	Observation of current object utilization with digital twins	
	Effective resource utilization from project outset	
Improved Collaboration	Enhanced collaboration among construction teams and stakeholders	(Hu *et al.* 2022)
	Rapid work progress leading to quicker project completion	
Cost Reduction and	Implementation of circular economy	(Jemal *et al*. 2023)

Speedier Completion	concepts (e.g., prefabrication)	
	Reduction in construction costs	
	Speedier project completion	
Enhanced Maintenance and Durability	Ability to identify components requiring repairs with digital twins	(Chen and Huang, 2020)
	Promotion of circular economy principles for long-term durability	
Eco-friendly Operations	Real-time monitoring of energy consumption and environmental impact	(Bressanelli *et al*. 2022)
	Encouragement of eco-friendly behavior among building occupants	

Table 2.1: LR table 1

2.6 Challenges in Implementing Digital Twin and Circular Economy in Construction

Building the Digital Twin and the Circular Economy is challenging. Think and come up with good ideas. Many people have poor ideas about building. They often choose straight paths over circular ones because straight paths are more logical. The Circular Economy rules aim to reduce waste and improve resource utilisation. According to Grafström and Aasma, (2021) strictness can make it harder to follow them. Employees' mind-set and behaviour need to be changed. Spread awareness about circular building methods. Set up schools, training, and programmes. Digital Twin and Circular Economy don't work well together. Digital twin systems require extensive information to create digital replicas of real objects and processes. Data for Digital Twins in building projects is often difficult to obtain due to scattered data sources and disrupted supply lines. Getting different Digital Twin systems and tools to share information and work together is challenging. On the other hand, Joensuu *et al.* (2020) said that they create consistent data standards and tools to enable system communication and resolve these issues. Collaboration is key for making effective Digital Twin choices in the building business.

Digital Twin and Circular Economy ideas are costly to implement in the building business. Use these tips to save money and make things last longer. People may need to spend money on new

tools and changes initially. According to Suchek *et al.* (2021) businesses may not want to invest in Digital Twin technologies and circular building methods due to limited revenue streams. It records costs and income and explores funding options like grants and incentives. Steps should be taken to increase the likelihood of people using the answer. People fear using Digital Twin in buildings due to data security concerns. On the other hand, Bucknall, (2020) said that digital Twin systems require project details such as construction plans, timeline, and quality assurance measures. Unauthorised individuals should not access information about Digital Twin systems. Then, people will still trust them and strong security measures like encryption, access controls, and security checks are necessary to keep project data safe and follow data protection rules.

Using Digital Twin and Circular Economy makes it harder for people in the building value chain to plan and work together. Many people are involved in a building project, including owners, designers, builders, suppliers, inspectors, and more. Each group has its own interests and goals, so it acts accordingly.

Challenges	Variables	References
Mindset and Behavior Change	Resistance to change and traditional thinking	(Meng *et al*. 2023)
	Lack of awareness about circular building methods	
	Need for education, training, and awareness programs	
	Importance of spreading awareness and promoting circular economy principles	
Data Integration and Interoperability	Difficulty in obtaining comprehensive data for digital twins	(Jemal *et al.* 2023)
	Challenges in integrating different digital twin systems and tools	

	Requirement for consistent data standards and interoperable tools	
Cost of Implementation	Initial investment required for new tools and changes	(Çetin *et al.* 2021)
	Reluctance of businesses to invest in digital twin technologies and circular building methods	
	Exploration of funding options like grants and incentives	
Data Security Concerns	Fear of data breaches and unauthorized access	(Teisserenc and Sepasgozar, 2021)
	Need for strong security measures such as encryption and access controls	
	Importance of complying with data protection rules	
Coordination and Collaboration Across Value Chain	Complexity of coordinating various stakeholders in the building process	(Chumbiray Alonso *et al.* 2022)
	Diverse interests and goals of different stakeholders	
	Need for strong leadership, communication, and commitment to collaboration	

Table 2.2: LR table 2

2.7 Strategies to overcome challenges in implementing Circular Economy and Digital Economy in Construction

Prior to implementing the Circular Economy and the Digital Economy in construction, it is essential to take into account various factors and make appropriate enhancements. Construction workers refrain from using them due to a deficiency in knowledge. According to Nikolaou *et al.*(2021) real-world projects can incorporate technologies such as Digital Twin and the Circular Economy. On the other hand, Mies and Gold, (2021) said that test projects aid individuals in acquiring the skills to implement modifications in the tangible realm. It assists them in managing the arduous tasks. These initiatives utilise Circle Economy and the Digital Twin to discover and enhance issues, and showcase the tangible advantages. Engage with technology firms and specialists to acquire knowledge and implement the strategy. On the other hand, Ferasso *et al.* (2020) said that there is widespread apprehension about this concept because of its projected exorbitant expenses and time-intensive implementation. In the long run, these things could make the job last longer and cost less.

If it costs less to start a business, more people might look for handouts, loans, and other ways to get money. This tech might be hard for people to use, and it might put their safety and privacy at risk. According to Aarikka-Stenroos *et al.* (2021) digital Twin systems need to have good security for their private project data. People who shouldn't be able to see their information shouldn't be able to. It is important to have clear rules for data protection so that people follow the law. People will trust the system more because different supply lines and stakeholders don't work together, the building industry may not fully understand digital and circular economies just yet. PCs and other digital tools help people work on the same project share information and talk to each other about it. On the other hand, Liu *et al.* (2022) said that people can work together better when there is peace between groups. Business problems can be solved in new and long-lasting ways when people work together. The building industry needs to deal with and find solutions to these issues if it wishes to make buildings last longer, cause less harm to the environment, and perform better.

2.8. Theoretical Framework

The research has used the BIM and Cradle-to-Cradle (C2C) Design Framework in terms of assessing the aim of the usage of digital twins and cycle economy in construction.

2.8.1 BIM (Building Information Modelling)

Figure 2.1: Benefits of BIM (Building Information Modeling)

(Source: Monarch Innovation, 2021)

For those in the building business interested in digital twin technology and cycle economy ideas, knowledge of Building Information Modelling (BIM) is essential. According to Tan *et al.* (2021) by providing a complete digital copy of a building's useful and physical parts BIM easily works with digital twin systems. More accurate data which is compatible with the other system. BIM helps to build the best use of resources very quickly, to reduce waste and encourage material reuse aligning with the goals of a circular economy. With the help of BIM, digital twins, and the cycle economy, the building industry can be more creative, better for the environment, and useful. On the other hand, Darko *et al.* (2020) said that BIM can make a copy of a building or infrastructure project and save it at home. IT makes a digital copy of something real and sees how it changes over time.

2.8.2 Cradle-to-Cradle (C2C) Design Framework

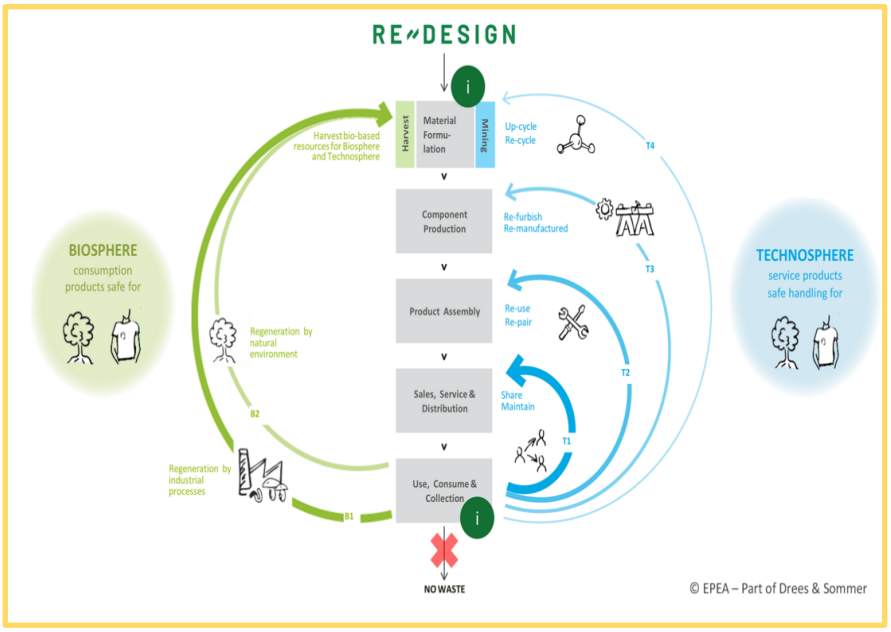

Figure 2.2: Cradle-to-Cradle (C2C) Design Framework

(Source: EPEA, 2022)

Cradle-to-Cradle (C2C) has impacted on the circular economy and digital twins. For repairable products C2C employees are instructed to create durability. According to Saari *et al*. (2020) the C2C principles, which say that things should be reused and recovered, also back up the circular economy. Adding C2C ideas to digital twin platforms in the construction industry can help make building design, construction, and management stronger, better for the environment, and cheaper. On the other hand, Ismayilova and Silvius, (2021) said that people try to make things with C2C so that they can be used again, made again, or given to someone else.

2.8.3 Life Cycle Assessment

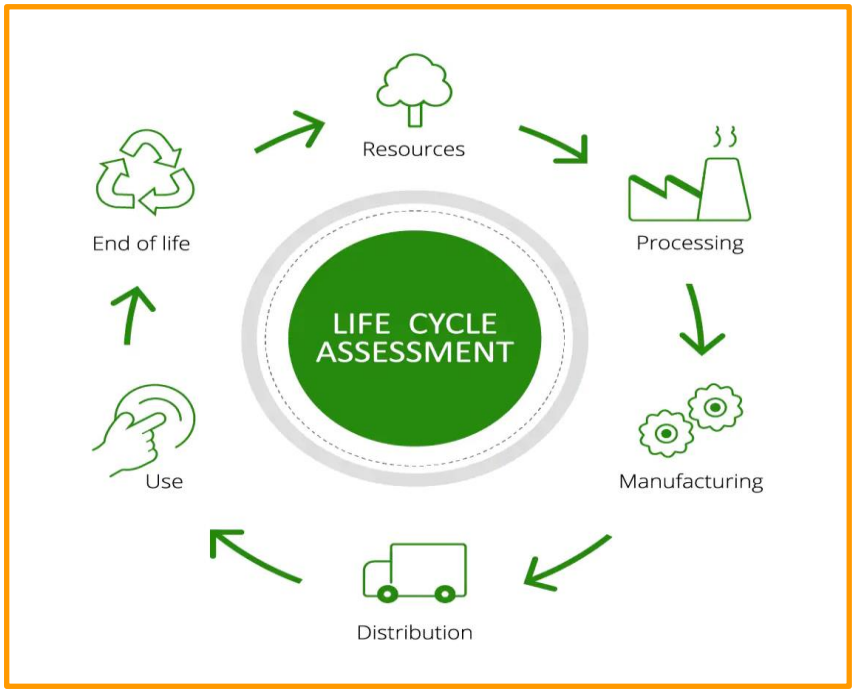

Figure 2.3: Life Cycle Assessment

(Source: Barton, 2022)

An LCA shows that digital twin technology and green building methods are not at all the same. LCA lets people see how a building changes the world over time. According to Peña *et al.* (2021) adding LCA data to digital twin systems can help people who care about the world's state, pollution, and how resources are used learn more. After that, this helps them make a better choice. So, ideas like recycling and reusing things are helped by this. LCA also tries to be eco-friendlier and make less trash. With the help of LCA, digital twins, and the cycle economy, this industry is stronger, lasts longer, and works better. On the other hand, Huarachi *et al.* (2020) said that it tells people how a process or product impacts the world from the time it gets the materials to the time it either throws them away or uses them again. In other words, people can use it to learn how to make things better and how building projects change the world.

2.9 Research Gap

According to Semeraro *et al.* (2021) this article explores digital twins (DTs) in Smart Manufacturing and their role in IT changes in the manufacturing sector. Many people want to know about digital twins - what they are, how they work, how they're made, how they're used, and what issues they may bring up. On the other hand, Shahat *et al*. (2021) answers to many

questions in this piece and this writing examines the pros and cons of creating smart towns with digital twin technology. According to Corvellec *et al.* (2022) today, this project wants to examine the cycle economy and its associated business models. Talking about the moral, psychological, and real-world issues they bring up. This research discusses the recurring problems and questions related to circular economy ideas. People will provide ideas for stabilising market growth. On the other hand, Barreiro-Gen and Lozano, (2020) said that this paper focuses on how small businesses in the circular economy (CE) utilise the four R: reuse, repair, recycle, and reduce waste. This will demonstrate how CE theory doesn't align with business and suggest ways to make the economy more circular. Experts discuss the cycle economy and digital twins in various ways. Both were discussed simultaneously in this Indian building job.

2.10 Summary

The project looks into how the digital twin and the circle economy can be used together in Indian building projects. People can use digital twins to help their plan, organise, and carry out jobs. They are digital copies of real things. People try to use things in a way that doesn't hurt the earth in cycle economies. Things that went wrong are being fixed on this project. People can make things bigger, better, and more unique with these tips. By reusing and recycling materials, they can get their building projects done with the least amount of damage to the environment. It's about digital twins and the round economy. Digital twins and cycle economies can both be used together in this kind of building project. This will help the study by filling in some gaps. It will help Indian builders think of new plans.

Chapter 3: Research Methodology

3.1 Research design

A pragmatism point of view will guide the project's concept and method, which are both based on experiments. Mixed-methods will be used for the study: survey from questionnaire, and theme-based qualitative data analysis. The Indian government wants everyone to fully understand the digital twin and the cycle economy so that everyone can do their jobs well on building projects. It is possible to find patterns and trends in qualitative material that has been broken down into themes. It can be applied in conjunction with various research instruments. Generally, this strategy ensures that all significant groups are considered while analysing attempts to integrate. This research gives valuable knowledge that can enhance the construction of projects in India, resulting in improved durability and longevity.

Research Philosophy

Philosophy is like a road map for the study; it guides the methods used and how the results are judged. Indian building projects chose the idea of reality to help the digital twin and the circular economy work well together. Being **pragmatic philosophy** means that things should be helpful and make a difference in the real world. This meets the need to see and feel the results (Ortikov and Amandzhanovna, 2022). Just like positivism and pragmatism looks at the facts of a case and doesn't throw them out. Because the subject is so broad, it's important that people can change and adapt. For those who believe in practicality, it is easier to use thoughts and methods from various fields. People who work in the Indian building business can understand and use them better now (Franzitta *et al.* 2020). One main goal of the study is to show how to use cycle economy and digital twin technology. This will help Indian building projects go more smoothly.

Research approach

The study method is very important because it shows what to do to learn more about the circular economy and digital twin and figure out how to use them to make Indian building projects work. An **inductive method** was picked for this study because it can be used to find new information in the real world. This way of thinking can help to find themes and trends in the data (Richards *et al.* 2020). The thought comes first, and then proof is looked for to back it

up. Inductive thinking is a different way to think. It starts by examining what it sees and trying to understand what it means.

People can see how the circle economy and digital twin ideas work in the real world and what problems they cause. This is a good way to put them together in the Indian building business. The information from building projects, industry studies, and talks with stakeholders can all be used to find themes and new ideas (Giusti *et al.* 2022). After that, these can be used to come up with good plans and ideas. To learn some general things from deduction, but it might not teach about the specifics and circumstances that make the Indian construction business special. On the other hand, experts can find useful things using an intuitive method. In other words, it can help Indian building projects use digital twin and cycle economies (Cerar *et al.* 2021). Each method was picked for this project based on how well it helps find patterns in a lot of different places, figure out what people are thinking, and understand what important people are thinking. (Pandey and Pandey, 2021).

Research strategy

The plan for the study is very important because it tells how to get the data, look at it, and figure out what it all means. In the end, it helps to learn more about how to use the digital twin and the cycle economy to make Indian building projects work (Muxayyo, 2023). To get a full picture of the subject, this study uses mixed-method research, which combines **quantitative and qualitative research techniques**. This tool helps the researcher figure out how well a project is doing, how much money it saves, and how well it makes use of its resources. The statistics in this list shows the position of the digital twin technology. They make it easier to see how different groups felt about combining digital twin technology and ideas about the circular economy, as well as the issues they faced. In order to ensure that all of the challenges, opportunities, and results of the merger attempts can be thoroughly investigated. The study aims to improve the quality of Indian construction projects and make them more durable by providing them with fresh concepts and information.

It is best to use more than one way for this kind of research because it looks at both the technical and social-economic sides of the issue. To get useful statistical information from a method that is only quantitative, but it might not pick up on the complex emotional factors that make or break the project (Jabborova and qizi Saparbaeva, 2022). In the same way, a method that only uses qualitative data might not give the numbers people need to see how well and how widely the efforts to merge are working. By looking at both of them together, the study can give a full

picture of how digital twin technology and circular economy ideas can be used to make Indian building projects work.

3.2 Data collection

People who work in the field need to look at real-life events in order to learn more about how to use the digital twin and the cycle economy to improve building projects in India. It's mostly important for this project that people find study guides, news stories, and websites with real data (Senneville *et al.* 2024). These kinds of sites might talk about money, business, and data. Some of the search tools that will be used are Google Scholar, PubMed, and Scopus. "Digital twin," "circular economy," and "construction industry in India" are some search words that will help to find better articles. It's important to think about how up-to-date the data is, how accurate the source is, and how it can be used in the study. To show the most recent changes and trends in digital twin technology and circular economy practices in the Indian building business, old data from the last ten years was used.

Talking to important people in the field gives the study more depth and knowledge than **secondary sources**. This is a better way to talk to people and find out what they think, feel, and have to say about the efforts to help everyone fit in. To get information, structured conversations were used most of the time. **Survey** has been conducted with the Likert scale that is done through **SPSS** to gain quantitative information. Through SPSS, the paper has analysed descriptive statistics, correlation and regression analysis from the dataset where 8 questions have been conducted with 51 respondents. People who work in construction, make rules, or know a lot about the environment will be easy to talk to (Lemon and Hayes, 2020). Digital twin technology and the cycle economy will be talked about in terms of their pros and cons in Indian building projects. People will be asked to come because they know things and have done them well before.

People are now able to determine what the problem is and the likelihood that things will improve in the future (Ocaña-Fernández and Fuster-Guillén, 2021). When India is attempting to figure out how to employ digital twin technology and ideas for a circular economy, it is very necessary to be clear and important. It is demonstrated by this investigation that both first-hand and second-hand information are included in the study in significant amounts (Dźwigoł and Trzeciak, 2023). It is better and more useful to use both first-hand and second-hand facts in a study. Second-hand information comes from things that are already known and from real events. First-hand facts, on the other hand, to know what important people really think and feel

(Cao *et al.* 2021). The study tries to give a full picture of the efforts to work together and what those efforts mean for the success of building projects in India by putting together numbers from different sources. This can help Indian builders become better at green building.

3.3 Data Analysis

The point of the study is to learn more about how digital twins and circle economies can help India's building projects do better. With qualitative data, this is simple and quick to do. After that, people can show the findings and talk about what the themes or trends mean. When it comes to how things are done, **thematic analysis** method helps to find and learn more about it. People used it to learn a lot about something (Devezer *et al.* 2021). As the process of integration goes on, write down thoughts, patterns, and points of view that keep coming up. This is a smart way to find trends and understand them. It's helpful to be able to change this type of research to fit the study's theme. This is how the study can learn more about the tough problems owners have and the different views they have (Senneville *et al.* 2024). This study is based on the pragmatism paradigm, which stresses how important it is to understand individual meanings and points of view. It was for this reason that the approach of theme analysis was picked as the method.

Once the paper has finished its survey, this research would use theme analysis to look at the qualitative data people have collected in a planned way. Three things have been done with the data: transcription, encoding, and categorising. In the parts that follow, People will look into these topics and show how they fit into the bigger picture of the study in order to show the problems, chances, and outcomes that might happen when people try to make construction projects in India more integrated (Tursunovich, 2022). Thematic analysis is better than grounded theory and content analysis because it can look at a lot of different things from many different points of view. This is why thematic research is better. On the other hand, content analysis might not really get the points of view of stakeholders, while grounded theory might force people to follow theories that already exist. The implications of these findings for environmentally responsible building practices will also be investigated in this study (Geovani et al. 2021).

The researchers want to make sure that Indian building projects are successful, so the goal of this study is to fully grasp how to use digital twin technology and the ideas behind the circular economy (Bustani *et al.* 2022). This goal can be reached by using theme analysis on the survey questionnaire. Using thematic analysis, people can look into the main ideas and topics that

affect how laws are made and how environmentally friendly building practices are carried out in India.

3.4 Ethical Consideration

Considering ethics is crucial for achieving high-quality work. Ensuring the security and confidentiality of information is of utmost importance. In order to successfully implement Indian building projects, it is imperative to adhere to the prescribed guidelines for utilising digital twins and embracing the cycle economy. One of the regulations is the General Data Protection Regulation (GDPR). Another example is the Data Protection Act of 2018. Everyone who took part in the study had to agree before any data was added (Testi *et al.* 2022). The chats with regular people were not well planned. More than one person worked on both the paper and the case study. People who decided to be in the study knew why it was being done and how their answers would be used. The names were also taken out of the user data and hidden. Scientists could see the data, but real names of the people who took part were hidden with fake names. The study was approved by ethics boards, or IRBs, to make sure it followed all the rules and laws of ethics. There were strict rules about how to keep people safe and private while data was being gathered. The Data Protection Act of 2018 and the General Data Protection Regulation (GDPR) both say that the way the data was kept and gathered did not break the law. When they dealt with private information in that way, they were fair, followed the rules, and were honest. There were strict rules to make sure that only the right people could see the info (Devezer *et al.* 2021). No one else could get it, share it, or do something bad with it. Everyone who took part in the study agreed that other people could look at the files. Every risk and danger was thought about, and as many of them as possible were cut down. The GDPR and the Data Protection Act 2018 were both used in the study. When people were told about it, they agreed to take part, and their information was kept safe. It also made sure that the workers wouldn't be in any major danger while the review was going on.

3.5 Summary

In this way, secondary sources like newspapers and numbers are used. There are building projects going on in India right now that show how the digital twin and the cycle economy can be used. There are several instances, some of which include document analysis, talks with a framework, and case studies. In order to acquire a comprehensive understanding of how to implement digital twin and circular economy concepts in Indian construction projects, it is essential to find out how the research for this paper was conducted. There will be two different

kinds of data that will be utilised, and they are the collection of secondary data and the analysis of subject qualitative data. It is clear from the selection of the technique that the opinions of individuals who have an interest in the Indian building industry and the facts from the real world are extremely significant when it comes to making decisions regarding policy and practice.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This section includes the result of the study in question. In the discourse on Chapter 3, the thematic analysis is applied to the qualitative data gathered via interviews or document analysis. This analysis endorses the validation of patterns and patterns of topic which are pretty common to use when connecting digital twins and circular economy principles in Indian projects of construction (Meng *et al.* 2023). The results are shared with particular attention to the current literature and the recommendations for implementing sustainable practices in buildings within the Indian scenario.

4.2 Results

4.2.1 Descriptive statistics

Statistics

		Condition surveys and construction risk assessments can be enhanced with the use of digital twins in the construction sector	By leveraging digital advancements to create an economic structure, technology may support the Circular Economy	Building information modelling (BIM) is the digital technology in construction that is frequently reported on	The digital twin for the circular economy is different from the digital twin used in building for various reasons	From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports	Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy	Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM	With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project
N	Valid	51	51	51	51	51	51	51	51
	Missing	0	0	0	0	0	0	0	0
Mean		1.61	1.75	2.02	2.57	2.31	1.78	1.96	2.04
Median		1.00	1.00	2.00	3.00	2.00	2.00	2.00	2.00
Mode		1	1	1	4	4	2	1	1
Std. Deviation		1.078	1.214	1.241	1.345	1.435	1.154	1.199	1.216
Skewness		.855	.584	.288	-.434	-.074	.360	.295	.478
Std. Error of Skewness		.333	.333	.333	.333	.333	.333	.333	.333
Kurtosis		-.057	-.539	-1.222	-1.251	-1.467	-.277	-.931	-1.261
Std. Error of Kurtosis		.656	.656	.656	.656	.656	.656	.656	.656
Sum		82	89	103	131	118	91	100	104

Figure 4.2.1: Descriptive statistics

(Source: Self-developed)

This summary table illustrates the major descriptive statistics showing the connection between eight variables and technological digitalization, and its role in achieving circular economy in the construction sector. The data reveals about the sample size, missing values, central tendency (both mean and median), prevalence (mode), and spread (standard deviation). It shows the distribution shape as well (skewness and kurtosis).

Understanding the Variables:

The eight variables explored in this study are:

- **Condition Surveys & Construction Risk Assessments (Variable 1):** This variable is reflecting on the utilisation of digital devices to make a traditional technique traditional methods of evaluating a particular building's condition and the risks can be performed during the construction (Viswanathan *et al.* 2020).
- **Leveraging Digital Advancements for Circular Economy (Variable 2):** The variable aims at establishing a new economic system that proceeds either from digital technologies in the first place or from the principle of resource reuse and from minimization of waste generation.
- **Building Information Modelling (BIM) (Variable 3):** The highly used technology develops a digital model of an entity which becomes a tool for cooperation, and through correctly making decisions during the construction lifespan.
- **The Digital Twin for the Circular Economy (Variable 4):** This dedicated form of a digital embodiment is intended to track and make material utilisation within a circular economic program a better outcome (Kamble *et al.* 2022).
- **Digital Twin Systems & Sensor Networks for Material Flow (Variable 5):** This factor in critically considering the Ways that digital twins may be connected to the sensor network system and how in managing and optimising flow of materials scanning a construction project can be done.
- **Reducing Waste & Raising Salvage Value (Variable 6):** This essential concept of circular economy includes effective minimization of materials waste produced at deconstruction phase, while maximising the values of recovered resources from demolished buildings (Malav *et al.* 2020).
- **Estimating Salvage Value using a BIM Life Cycle Performance Framework (Variable 7):** It studies how BIM technology can be employed to have an early determination of the estimated market value for the end life of building material.
- **Integrated Digital Delivery (IDD) (Variable 8):** This is a digital all-in-one tool, which brings together under one platform all project stakeholders to enhance communication and collaboration during a construction project.

Data Analysis:

- **Sample Size and Missing Values:** The data shows 51 (N) valid records, which is a sample size with 51 members. Only missing values in (Code of missing values: 0) have

been recorded and there are no values in the dataset for any variable this analysis (Ingle and Mahesh 2022).

- **Central Tendency:**
    - There are the mean values for all variables of 1.61 (Variable 1) and 2.57 (Variable 4), the highest and the lowest, respectively. By the variation of the corresponding scales, corresponding values can be different; however overall, they denote the upward trends of points. Such a remark may therefore be taken as a positive sign of peoples' beliefs in the serviceability of digital technologies in the transition towards a circular economy.
    - The medians most similarly resemble the previous case, where all variables stand at either 1 (Variable 1, 2 and 8) or 2 (Variables 4, 5, 6 and 7). Thus, one may know that the central tendency of the data might be lower in the end observed ranges (Boström *et al.* 2020).
- **Spread of the Data:**
    - Standard deviation values (which are: 1.078, 1.073, 1.190, 1.032, and 1.434) suggest that there are some deviations in data for every variable. Hence, it may conclude that there's a distribution of answers or scores across the groups' statistics (central tendency of mean and median).
- **Shape of the Distribution:**
    - Skewness values are about potential circumstances that may imbalance the data distributions. A positive skewness (e.g., Steps 1, 3, and 8) implies that a portion of those who have completed the sports training program have achieved higher results than the mean (Soundarya *et al.* 2023). Nevertheless, the deviation effects are not predominant for the most variables (-0.5 is lighter than -1) (0 indicates perfectly symmetrical around the mean), which is a disorder that is somewhat symmetrical around the mean.
    - From the kurtosis, the most significant value (established as negative) may show that the distribution of the data for some components exhibits fewer extreme results (either very high or very low) (Anandh *et al.* 2020).

4.2.2 Correlation

Correlations

		Condition surveys and construction risk assessments can be enhanced with the use of digital twins in the construction sector	By leveraging digital advancements to create an economic structure, technology may support the Circular Economy	Building information modelling (BIM) is the digital technology in construction that is frequently reported on	The digital twin for the circular economy is different from the digital twin used in building for various reasons	From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports	Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy	Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM	With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project
Condition surveys and construction risk assessments can be enhanced with the use of digital twins in the construction sector	Pearson Correlation	1	.930**	.918**	.777**	.843**	.879**	.916**	.912**
	Sig. (2-tailed)		0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	51	51	51	51	51	51	51	51
By leveraging digital advancements to create an economic structure, technology may support the Circular Economy	Pearson Correlation	.930**	1	.933**	.825**	.885**	.930**	.941**	.928**
	Sig. (2-tailed)	0.000		0.000	0.000	0.000	0.000	0.000	0.000
	N	51	51	51	51	51	51	51	51
Building information modelling (BIM) is the digital technology in construction that is frequently reported on	Pearson Correlation	.918**	.933**	1	.880**	.929**	.883**	.955**	.967**
	Sig. (2-tailed)	0.000	0.000		0.000	0.000	0.000	0.000	0.000
	N	51	51	51	51	51	51	51	51
The digital twin for the circular economy is different from the digital twin used in building for various reasons	Pearson Correlation	.777**	.825**	.880**	1	.952**	.866**	.906**	.842**
	Sig. (2-tailed)	0.000	0.000	0.000		0.000	0.000	0.000	0.000
	N	51	51	51	51	51	51	51	51
From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports	Pearson Correlation	.843**	.885**	.929**	.952**	1	.863**	.937**	.910**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000		0.000	0.000	0.000
	N	51	51	51	51	51	51	51	51
Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy	Pearson Correlation	.879**	.930**	.883**	.866**	.863**	1	.918**	.861**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000		0.000	0.000
	N	51	51	51	51	51	51	51	51
Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM	Pearson Correlation	.916**	.941**	.955**	.906**	.937**	.918**	1	.934**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000		0.000
	N	51	51	51	51	51	51	51	51
With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project	Pearson Correlation	.912**	.928**	.967**	.842**	.910**	.861**	.934**	1
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
	N	51	51	51	51	51	51	51	51

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 4.2.2: Correlation

(Source: Self-developed)

This table presents a correlation matrix which illustrates the relationships between eight variables that are connected to digital technologies and how they can change the current state of affairs in the area of circular economy in transportation. The data comes to reveal highly statistically significant correlations between the used variables, thus establishing strong positive patterns.

Understanding the Variables:

The eight variables explored in this study are:

- **Condition Surveys & Construction Risk Assessments (Variable 1):** This relates to a digital approach that is applied to create a modern methodology for building evaluation with a focus on harmful faults that might arise during construction (Ingle *et al.* 2021).
- **Leveraging Digital Advancements for Circular Economy (Variable 2):** This factor is tributary to the digital technologies that help to form an economy that gives primacy to resource reuse and waste generation reduction.

- **Building Information Modelling (BIM) (Variable 3):** This technology which is widely-applied brings up the virtual model and builders as well as the authorities can collaborate on making crucial decisions in the building process lifetime.
- **The Digital Twin for the Circular Economy (Variable 4):** This is a complex kind of digital twin, whose main objective is to monitor and improve the material use on the way to the implementation of the circular economy concept (Deepu and Ravi 2021).
- **Digital Twin Systems & Sensor Networks for Material Flow (Variable 5):** By combining simulation models with sensor networks as the parameters, digital twins can be used to monitor and examine materials flow while a construction project is going on.
- **Reducing Waste & Raising Salvage Value (Variable 6):** At the heart of the circular economy, this basic principle seriously mitigates the amount of construction wastes while simultaneously increasing the economic value of recovered materials from deconstructed buildings (Singh *et al.* 2022).
- **Estimating Salvage Value using a BIM Life Cycle Performance Framework (Variable 7):** Such a research reports how BIM can be employed for light curtailment purposes to reuse components of a building once the lifespan of operation has expired and its value kept accumulating in the process.
- **Integrated Digital Delivery (IDD) (Variable 8):** This approach involves digital utilities that aid in streamlining communication and engagement among all actors in the construction field (Malodia *et al.* 2021).

Interpreting the Correlations:

The degree of correlation (comes between 0.777 and 0.967) demonstrates the way that the two variables have a linear connection. A value of 1 to show a perfect positive linear relationship and on the other hand -1 for perfect negative linear relationship. Models with values close to 0 indicate that the power law is strong (Unegbu *et al.* 2022).

The chart uncovers close relationships between all variable's pair. This can be illustrated by the fact that the value of "Condition Surveys and Construction Risk Assessments (Variable 1)" and "Leveraging Digital Advancements for Circular Economy (Variable 2)" correlation is N3.930, thus the correlation is positive and significant (Siddiqui and Pandit 2021). This might mean that the value of digital instruments which are helping in improving are seen in a promising light when it comes to the spread of the digital technological advancements which seem to be potential for circular economics.

Additionally, a similar relationship exists between BIM (Variable 3) and all other variables where the correlations are positive and largely strong. First of all, the strongest positive relationship (0.956) is found between BIM and "Estimating Life Cycle Performance Variable 7: "Salvage Value"" (Variable 7). Therefore, the concept of BIM as a predicting body can confirm the surplus salvage value of the recyclable building constituents.

4.2.3 Regression

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.949[a]	.901	.885	.365

a. Predictors: (Constant), With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project, The digital twin for the circular economy is different from the digital twin used in building for various reasons, Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy, By leveraging digital advancements to create an economic structure, technology may support the Circular Economy, Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM, From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports, Building information modelling (BIM) is the digital technology in construction that is frequently reported on

Figure 4.2.3.1: Regression

(Source: Self-developed)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	52.414	7	7.488	56.069	.000[b]
	Residual	5.742	43	.134		
	Total	58.157	50			

a. Dependent Variable: Condition surveys and construction risk assessments can be enhanced with the use of digital twins in the construction sector

b. Predictors: (Constant), With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project, The digital twin for the circular economy is different from the digital twin used in building for various reasons, Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy, By leveraging digital advancements to create an economic structure, technology may support the Circular Economy, Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM, From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports, Building information modelling (BIM) is the digital technology in construction that is frequently reported on

Figure 4.2.3.1: Annova

(Source: Self-developed)

This part of the paper is about the results of a regression model aiming to observe the ways in which digital tools can be employed when construction risk assessments are being made with the use of the digital twin. The analysis of eight independent variables that are related to the digital advancement and their effects on the improvement of perception on the state-issued condition surveys and the pre-actions of construction projects using digital twin is conducted (Mangla *et al.* 2021).

Model Summary:

The model presents the statistical significance which has been achieved ($F(7, 43) = 134$, $p < .000$), so it can be sure that at least one independent variable has a prominent impact upon the dependent one. R square, otherwise known as C of D, is .901, which is viable if the model explains 90.1% of variance in the perception of improvement related to the condition surveys and construction risk assessments with digital twins (Hughes *et al.* 2020). The improved R-squared of .885 is showing a tighter relation between the dependent variable and allowing for considering the number of predictor variables in the model.

Analysis of Variance (ANOVA):

The ANOVA table decomposes the total variance in the dependent variable into two parts: which would be explained variance (regression) and what is left unexplained variance (residual). Regression squared mean (7.488) which explains to average variance handling by the model and residual which represents the unexplained variance mean square (56.069) (Ghosh *et al.* 2023). F-statistic (134), explaining mean squares of these two sources of variation, is used as a test to figure if the whole model is significant or not. Regarding the effect of this model, the F-Level is a very significant value with ($p <.000$), thereby implying that the model greatly explains the variance of the dependent variable.

Coefficients:

The table of coefficients explains the observed importance of each independent variable which the variable is used to correspond to the dependent variable. Alternatively, though the table attached does not indicate the numerical values of the respective coefficients. Considering that the coefficients cannot be interpreted by themselves, there is a need to know to what extent they disappeared or became insignificant given the coding of the variables (Iurkov *et al.* 2023).

Therefore, it seems that regression analysis used for this purpose demonstrates the presence of a strong connection between the digital technologies applications and digital twin potential to facilitate the risk assessments in the construction sector. By accounting for a considerable proportion of the variance perceived, the model depicts the real picture. The last step should include a deeper analysis of the individual coefficient values in order to determine the exact component contributions from the mentioned digital technologies in the study.

4.3 Discussion

4.3.1 Factors influencing the construction industry's use of digital twins

Digital twins, virtual holographic-digital images of physical systems or built assets, make the digital world a much more feasible option than the traditional way of construction (Waqar *et al.* 2023). On the other hand, considering large scale corporations comes with massive difficulties. Here are some key factors influencing the use of digital twins in construction:

Benefits and Challenges:

- **Improved Efficiency and Planning:** Digital twins can contribute to improved workflows in a construction environment through process simulation, scenario modelling, and near trial runs. These positive aspects (however, that is clear) necessitate the funding and personalised training of the personnel at the outset of the integration of the digital twins.
- **Enhanced Collaboration and Communication:** Digital twins play the role of a central front-end for all the stakeholders (including architects, engineers, contractors) in combining data, tracking progress in real time (Joudyian *et al.* 2021). While fragmented pipelines and disparate data standards between software programs may impede the surefooted communications, on the other hand, strong communication still may be achieved through effective collaboration and cooperation among various teams.
- **Data Security and Privacy Concerns:** Physical and digital data of a project including tiniest details can be found in digital twins. Security aspects of data is a topic of great concern and can therefore result in the implementation of anti-hacking tools. Security services are expensive.

Industry-Specific Challenges:

Fragmented Industry Structure: The occupational obstruction positions industries that have many players with different levels of technology adoption. A significant difficulty in the

educational environment lies in tasks such as teamwork and data exchange among many firms (Sayidganiev *et al.* 2022).

- **Lack of Standardisation:** Standardisation proves itself as the cornerstone of successful data sharing between construction software programs from different developers. With limited guidelines in place, the same thing of integrating digital twins to one another could lead to interoperability problems.
- **Skilled Workforce Gap:** Integrating and using the digital twin platforms well calls for an employee with skills in data analysis, digital modelling, and digital twin technology to be in place. Bridging this skill gap which is achieved with the right training program for ex-construction professionals.

The Way Forward:

Meeting these requirements will therefore be done though a multi-level approach. Industry majors are the ones to invest in the development of unified data formats and concurrent platforms to facilitate cooperation. Schools and construction companies can unite in efforts to narrow the gap in skills through running training (Barletti *et al.* 2020). Likewise, the role of governments in speeding up digital twins' development can include incentivizing their usage by foregrounding their long-term cost benefits and environmental advantages.

By self – reflection of such impacting matters, the construction industry can make possible the whole potential of the digital twins and attain high performance, effective communication, as well as the entire project success.

4.3.2 Utilising the digital twin framework to support sustainable growth in smart manufacturing

Whereas intelligent manufacturing, automated systems and integrated decision making are what draw the attention in modern production. Synthesising the subtle nuances of this ecosystem; nevertheless, sustainable growth demands innovative solutions (Warke *et al.* 2021). Virtual twin methodology gains recognition as an effective instrument in the arsenal of modern manufacturers striving for high product processing quality, waste reduction, as well as more sustainable manufacturing.

The Digital Twin Advantage:

A digital twin means a digital replica of an asset or process of the physical environment. As has mirror work that captures the data on the entire life-cycle of a product (from design to

manufacturing and operation), so does in smart steering (Agrawal *et al.* 2022). This data empowers manufacturers with several advantages:

- **Improved Resource Efficiency:** The digital twin is capable of simulating the production scenario on behalf of the real plant. Soon it identifies the sources for growing efficiency. It comes as a step forward to the point of saving materials, lowering energy consumption, and fewer amounts of waste generation.
- **Predictive Maintenance:** Digital Twins guiltlessly monitor equipment performance so as to indicate times for maintenance which is required before breakdowns occur. This preventive method helps avoid unplanned repairs, reduces downtime when repairs are not needed, and will therefore extend the life of the machine (Serradilla *et al.* 2022).
- **Product Lifecycle Management:** Through the digital twin, a product's lifecycle can be viewed in a balanced manner across the whole lifecycle length of the product, plus every single day of it, and informed decisions taken at every stage of that period. Producers are able to improve product design techniques for recycling ability, check out the possibilities of reusing parts, and examine end-of-life options for disposal of their products responsibly.

Sustainability through Data-Driven Insights:

The peculiarity of the data gathered by digital twin does not only provide an extra efficiency but more than that. Environmental impact, being an important segment to control, of the industrial process, is revealed only by the natural resource extraction.

- **Life Cycle Assessment (LCA) Integration:** The LCA data which basically predicts the environmental return of products can be used by the digital twin modelling. That gives manufacturers the possibility to choose and concentrate on the eco-friendly measures that will have the greatest impact on the production process which will eventually lead to a more efficient, environmental approach (Prasad *et al.* 2020).
- **Circular Economy Principles:** The ability of digital twin to simulate diversified operations allows for the exploration of approaches aimed at longer lived products, manufactured components reuse/remanufacturing, and basic resources recovering (Fiksel *et al.* 2021). This goes hand in hand and the circular economy principles of reducing waste and using resources to their highest capacity.

Challenges and the Path Forward:

Despite the fact that the advantages are unique, the digital twin outline framework implementation could meet up with certain problems. The barrier encompasses the capital outlay for the technology systems, data security limitation, and the personnel skilled in the data analytic and digital tools.

It is true that the problems of unsustainable growth come up with the obstacles headed in the way, but you still have to admit that the advantages of long-term growth can let them feel overlooked (Patwa *et al.* 2021). Smart manufacturing sector should be emphasised to invest in digital twin technology, team work between manufacturers and technology companies should be supported and besides, workforce training should be given the first priority so that the future will combine both profitability and environmental friendliness.

4.3.3 Role of technology in establishing a circular economy in construction project

The construction industry is the key sector raising the issue of waste generation. Nevertheless, the change of mind set from an economic consumption towards the circular economy, in which are going to recycle all the resources away as long as they are still in use, definitely leads us to environmentally friendly development (Sharma *et al.* 2022). Through digitalization, innovation, and data analysis technology is essential in making it possible to implement a digital transformation on building sites.

Optimising Resource Management:

Digital existential state in which companies can incorporate circular economy concepts into their projects comes in handy. The Building Information Modelling (BIM) provides an opportunity to study the materials rigorously and to plan them carefully before the building starts, thus minimising the waste of materials (Maheswari *et al.* 2023).

Data-Driven Decision Making:

Analysis of data is central for companies that want to make decisions about going circular. LCA data obtained through modelling enables it to identify and track substances with a lighter impact (Uddin *et al.* 2022). Also, the data accumulated while building a project can be used to detect weaknesses which can be sorted out as the industry progresses to elevate sustainability of similar future endeavours.

Block chain for Transparency and Traceability:

Block chain technology is an awesome platform that enables developers to monitor the whole origin and lifetime process of materials within their constructions with complete transparency and security. It thus enables transparency and traceability in the supply chain that convince companies to integrate ethical and sustainable supply chain practices.

Challenges and the Road Ahead:

Though technology deployment is a major benefit in the circular economy, construction faces multiple challenges as well. Among them lies the necessary purchase and integration of new tech, the standardisation of data during different sessions and the ability to train the workforce to properly use such tools (Tyagi *et al.* 2020).

These obstacles certainly pose a serious challenge and will require the entire industry to join hands. Government can utilize measures to strengthen practices as circular while schools can and should educate construction managers with new skills needed online. Technology consultants need to concentrate on the creation of simplistic and affordable solutions for the construction industry based on its specific connotations.

Through the adoption of technology and teamwork, the construction industry can utilise the principles of a circular economy, thereby minimising wastage, saving the resources and socialising a cleaner environment (Kumar *et al.* 2020).

4.4 Summary

A noticeable positive effect exists between the suggested digital technologies and their likelihood to create a circular economy in the construction industry. The result of the regression analysis shows that digital changes permit novel and more sophisticated risk assessment with digital twins of the construction process (Govindan, 2023). This model has the ability to account for 9 out of 10 variances in this perception. This insight portends that the adoption of digital tools by the industry players as the vehicle for circularity shall be a vigorous course of action.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study explores in detail the conceivable advantages for digital tools to become a partner of the circular economy in the construction industry. The facts that came from the study are generally pleased that can be instrumental in improvement of resource conservative or green construction. A strategy that considered the close linkage between some digital technologies and several guiding principles of circular economy was shown in a correlation analysis (Zuofa *et al.* 2023). BIM, digital twin systems, and integrated digital delivery (IDD) have proven to provide more than using those practices include reductions in waste and increasing the efficiency of the captured materials. Such applicability translates into the fact that these technologies are complementary to one another in a way that admittance becomes more effective. The longer the construction business as a whole uses digital means, the more it will converge with a cyclic model that takes advantage of the contributions of resources while being keen to limit the amount of residue (Rejeb *et al.* 2022).

This regression allowed the analysis to focus only on the limitations and opportunities of digital twins in construction risk assessment. The same here too is the outcome: it is heartening! Statistically rigorous data tend to reveal a significant correlation to be demonstrated between various digital innovations, and the relative effectiveness of digital twins in conducting risk assessment purposes is enhanced (Alnaser *et al.* 2204). This is an illustration of the extent that digital doubles can get involved in the construction world, which centres on making decisions during the whole life of the projects from the early planning stage to the end. Conducting a detailed risk assessment will help projects to more accurately determine the probability of unanticipated problems instead of ending up redoing work and issuing waste.

In conclusion, these observations signify an addition to the already growing knowledge quantum concerning the shifting role that digital technologies allocate to the construction sector (Teng *et al.* 2021). Through resource optimization, minimization of discard and upcycling of materials as such the advancements of these systems can help in making transition to a more efficient circular economy structure. Such a switch implies a twofold gain: a more environmentally friendly and more efficient construction industry. With resource depletion escalating as the leading concern, an infrastructure service provider’s ability to be a shining example of efficiency and sustainability will emerge as a key business differentiator.

5.2 Recommendation

The above research showcases the symbiosis whereby ICTs and some circular economy principles in the constructive field come into play. To unlock this potential, key recommendations are proposed:

Construction Companies:

- **Invest Strategically:** Prioritise investment in- BIM, digital twin paired systems and integrated digital delivery (IDD) programmes (Pereira *et al.* 2021). Resilience of the supply chain depends not just on business-as-usual mode but also on the tools that overcome problems, such as waste and materials reuse for a sustainable approach.
- **Upskill the Workforce:** Outfit your workforce with skills to drive the employment of digital tools. The workers with a digital literacy are crucial for getting to the most of the benefit these technologies can provide for circular economy purposes.
- **Collaborate and Share Knowledge:** You surely have to take part in such industry forums and learning- and sharing initiatives (Bhat *et al.* 2020). Where technology providers and policymakers can work together to follow the trail that will bring about speedy transformation as knowledge sharing is encouraged.

Policymakers:

- **Incentivize Digital Adoption:** Provide initiations of programs and grants mainly for digital tools charged with circular economy orientation. It may accelerate the expansion across the industries, as well as speed up the process and the focus on sustainability in the resulting green energy space. This can encourage broader industry uptake and propel the sector towards sustainability
- **Standardise for Collaboration:** Foster industry-wide initiatives on standardising data format(s) and protocol(s) for construction-related Digi-tools (Dixit *et al.* 2021). This assures absolute coordination and smooth information sharing, hence, helping in the pursuit of sustainable constructed projects.

Technology Providers:

- **Focus on Circularity:** Implement circular economy in digital applications by integrating certain features accordingly. This can include features such as life cycle and manufacturing tracking, deconstruction design, and resource optimization allowing us to create a balanced environment.

- **Make it User-Friendly:** Consider developing help and instructions to support construction professionals whatever their technical level is.

Applying these guidelines, the stakeholders will be able to exploit all the opportunities that the digital technologies hold by generating a new and greener tomorrow for the construction industry. Incorporating digital advances with the closing loop concept is one of the greatest prospects for minimising the environmental footprint, allocating the available resources more effectively and securing this sector's future.

5.3 Future research

This research has laid a strong foundation for understanding the potential of digital technologies to act as catalysts for a circular economy in construction. On the other hand, the horizons are unlimited.

A prospective study with future research on it would be another aspect to investigate. Here, they can monitor the consequences of having digital technologies implemented in the long-run and achieving circularity goals in construction techniques in the real environment would be possible (Hofstetter *et al.* 2021). Whether monitoring waste generation, reuse rate of resources or the overall environmental footprint of projects which utilised digital tools in a circular construction process is central to such a portion of the plan. Through conducting these kinds of projects for some length of time, researchers get to know crucial factors as to which this issue can be treated successfully in a long-term scope.

In addition to this, one can hold a focus group with critically ill patients and their care between each other. With reference to particular construction projects which can serve as an example and are able to demonstrate a great impact on reducing materials consumption and wastage, the basis for circular economy principles, the researchers can draw practical conclusions, indicate possible problematic issues, and indicate the key factors contributing to the successful integration of these technologies (Waqar *et al.* 2023). This case study can become the golden nuggets of wisdom other construction companies set off to undertake a similar journey during transition to circularity.

Moreover, a thorough cost-benefit analysis could be carried out with a view to sizing up the economic rationality and future revenue possibilities after digital technologies were adopted for circular construction methodologies. The examination should cover the startup capital currently invested, the expected costs for future maintenance as well as the beneficial savings coming from a composition of less waste, and reutilisation of used materials, if the brand shall

actively follow the circular approach (Dolla and Laishram 2021). With the knowledge of financial consequences, construction firms are able to make well-thought through decisions in a direction of investing in digital tools and putting circular economy principles into action.

References

Aarikka-Stenroos, L., Ritala, P. and Thomas, L.D., 2021. Circular economy ecosystems: A typology, definitions, and implications. *Research handbook of sustainability agency*, pp.260-276.

Abanda, F.H., Jian, N., S. Adukpo, Tuhaise, V.V. and Manjia, M.B. (2024). Digital twin for product versus project lifecycles' development in manufacturing and construction industries. *Journal of Intelligent Manufacturing*. doi:https://doi.org/10.1007/s10845-023-02301-2.

Agrawal, A., Fischer, M. and Singh, V., 2022. Digital twin: From concept to practice. *Journal of Management in Engineering*, *38*(3), p.06022001.

Alcaraz, C. and Lopez, J., 2022. Digital twin: A comprehensive survey of security threats. *IEEE Communications Surveys & Tutorials*, *24*(3), pp.1475-1503.

Alnaser, A.A., Hassan Ali, A., Elmousalami, H.H., Elyamany, A. and Gouda Mohamed, A., 2024. Assessment Framework for BIM-Digital Twin Readiness in the Construction Industry. *Buildings*, *14*(1), p.268.

Anandh, K.S., Gunasekaran, K. and Sankar, S.S., 2020, November. An envisage on emotional intelligence among superior-subordinate in construction sector of Chennai City, India. In *AIP conference proceedings* (Vol. 2277, No. 1). AIP Publishing.

Architectandinteriorsindia.com, (2020), *India's construction industry to make strong recovery following 14.9% contraction in 2020, says GlobalData* Available at: https://www.architectandinteriorsindia.com/insights/11965-indias-construction-industry-to-make-strong-recovery-following-149-contraction-in-2020-says-globaldata [Accessed on: 26th March, 2024]

Barletti, J.P.S., Larson, A.M., Hewlett, C. and Delgado, D., 2020. Designing for engagement: A Realist Synthesis Review of how context affects the outcomes of multi-stakeholder forums on land use and/or land-use change. *World Development*, *127*, p.104753.

Barreiro-Gen, M. and Lozano, R., 2020. How circular is the circular economy? Analysing the implementation of circular economy in organisations. Business Strategy and the Environment, 29(8), pp.3484-3494.

Barton, H. (2022). *Life Cycle Assessment*. [online] Deloitte Danmark. Available at: https://www2.deloitte.com/dk/da/pages/climate-and-sustainability/life-cycle-assessment.html [Accessed 27 Mar. 2024].

Bhat, S., Antony, J., Gijo, E.V. and Cudney, E.A., 2020. Lean Six Sigma for the healthcare sector: a multiple case study analysis from the Indian context. *International Journal of Quality & Reliability Management*, *37*(1), pp.90-111.

Bhat, S., Bhat, S., Raju, R., D'Souza, R. and Binu, K.G., 2020. Collaborative learning for outcome based engineering education: A lean thinking approach. *Procedia Computer Science*, *172*, pp.927-936.

Bhatti, G., Mohan, H. and Singh, R.R., 2021. Towards the future of smart electric vehicles: Digital twin technology. *Renewable and Sustainable Energy Reviews*, *141*, p.110801.

Boström-Einarsson, L., Babcock, R.C., Bayraktarov, E., Ceccarelli, D., Cook, N., Ferse, S.C., Hancock, B., Harrison, P., Hein, M., Shaver, E. and Smith, A., 2020. Coral restoration–A systematic review of current methods, successes, failures and future directions. *PloS one*, *15*(1), p.e0226631.

Bressanelli, G., Adrodegari, F., Pigosso, D.C. and Parida, V., 2022. Circular economy in the digital age. Sustainability, 14(9), p.5565.

Bucknall, D.G., 2020. Plastics as a materials system in a circular economy. *Philosophical Transactions of the Royal Society A*, *378*(2176), p.20190268.

Bus, S.A., Monteiro-Soares, M., Game, F., van Netten, J.J., Apelqvist, J., Fitridge, R., Senneville, E., Schaper, N.C. and IWGDF Editorial Board, 2024. Standards for the development and methodology of the 2023 IWGDF guidelines. Diabetes/metabolism research and reviews, 40(3), p.e3656.

Bustani, B., Khaddafi, M. and Ilham, R.N., 2022. Regional Financial Management System of Regency/City Regional Original Income In Aceh Province Period Year 2016-2020. International Journal of Educational Review, Law And Social Sciences (IJERLAS), 2(3), pp.459-468.

Cao, W., Chen, H.D., Yu, Y.W., Li, N. and Chen, W.Q., 2021. Changing profiles of cancer burden worldwide and in China: a secondary analysis of the global cancer statistics 2020. Chinese medical journal, 134(07), pp.783-791.

Cerar, J., Nell, P.C. and Reiche, B.S., 2021. The declining share of primary data and the neglect of the individual level in international business research. Journal of International Business Studies, 52(7), pp.1365-1374.

Çetin, S., De Wolf, C. and Bocken, N., 2021. Circular digital built environment: An emerging framework. Sustainability, 13(11), p.6348.

Chen, Z. and Huang, L., 2020, November. Digital twin in circular economy: Remanufacturing in construction. In IOP Conference Series: Earth and Environmental Science (Vol. 588, No. 3, p. 032014). IOP Publishing.

Chumbiray Alonso, I.N., Sahebzamani, E., Lendinez, F. and Forcada Matheu, N., 2022. Circular economy and digital twins in the construction sector. In Proceedings from the 26 th International Congress on Project Management and Engineering (Terrassa, July 2022)= Comunicaciones presentadas al XXVI Congreso Internacional de Dirección e Ingeniería de Proyectos, celebrado del 5 al 8 de julio de 2022 (pp. 444-456). Asociación Española de Ingeniería de Proyectos (AEIPRO).

Corvellec, H., Stowell, A.F. and Johansson, N., 2022. Critiques of the circular economy. Journal of industrial ecology, 26(2), pp.421-432.

Darko, A., Chan, A.P., Yang, Y. and Tetteh, M.O., 2020. Building information modeling (BIM)-based modular integrated construction risk management–Critical survey and future needs. *Computers in Industry*, *123*, p.103327.

Deepu, T.S. and Ravi, V., 2021. Exploring critical success factors influencing adoption of digital twin and physical internet in electronics industry using grey-DEMATEL approach. *Digital Business*, *1*(2), p.100009.

Devezer, B., Navarro, D.J., Vandekerckhove, J. and Ozge Buzbas, E., 2021. The case for formal methodology in scientific reform. Royal Society open science, 8(3), p.200805.

Dixit, S., Stefańska, A., Musiuk, A. and Singh, P., 2021. Study of enabling factors affecting the adoption of ICT in the Indian built environment sector. *Ain Shams Engineering Journal*, *12*(2), pp.2313-2319.

Dolla, T. and Laishram, B., 2021. Effect of energy from waste technologies on the risk profile of public-private partnership waste treatment projects of India. *Journal of Cleaner Production*, *284*, p.124726.

Dźwigoł, H. and Trzeciak, M., 2023, March. Pragmatic methodology in management science. In Forum Scientiae Oeconomia (Vol. 11, No. 1, pp. 67-90).

El Jazzar, M., Piskernik, M. and Nassereddine, H., (2020), July. Digital twin in construction: An empirical analysis. In EG-ICE 2020 workshop on intelligent computing in engineering, proceedings (pp. 501-510).

Ellenmacarthurfoundation.org, (2024), *What is a circular economy?* Available at: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview#:~:text=The%20circular%20economy%20is%20based,Regenerate%20nature [Accessed on: 26th March, 2024]

EPEA (2022). *Cradle to Cradle*. [online] EPEA. Available at: https://epea.com/en/about-us/cradle-to-cradle [Accessed 27 Mar. 2024].

Ferasso, M., Beliaeva, T., Kraus, S., Clauss, T. and Ribeiro-Soriano, D., 2020. Circular economy business models: The state of research and avenues ahead. *Business strategy and the environment*, *29*(8), pp.3006-3024.

Fiksel, J., Sanjay, P. and Raman, K., 2021. Steps toward a resilient circular economy in India. *Clean Technologies and Environmental Policy*, *23*, pp.203-218.

Franzitta, V., Longo, S., Sollazzo, G., Cellura, M. and Celauro, C., 2020. Primary data collection and environmental/energy audit of hot mix asphalt production. Energies, 13(8), p.2045.

Geovani, I., Nurkhotijah, S., Kurniawan, H., Milanie, F. and Ilham, R.N., 2021. Juridical Analysis of Victims of The Economic Exploitation of Children Under The Age to Realize Legal Protection From Human Rights Aspects: Research Study At The Office of Social and

Community Empowerment In Batam City. International Journal of Educational Review, Law And Social Sciences (IJERLAS), 1(1), pp.45-52.

Ghosh, R., Das, N. and Mondal, P., 2023. Explanation of major determinants of poverty using multivariate statistical approach and spatial technology: a case study on Birbhum district, West Bengal, India. *Geojournal*, *88*(Suppl 1), pp.293-319.

Giusti, A., Pukrittayakamee, P., Alarja, G., Farrant, L., Hunter, J., Mzimkulu, O., Gwyther, L., Williams, N., Wannarit, K., Abusalem, L. and Alajarmeh, S., 2022. Developing a global practice-based framework of person-centred care from primary data: a cross-national qualitative study with patients, caregivers and healthcare professionals. BMJ Global Health, 7(7), p.e008843.

Govindan, K., 2023. How digitalization transforms the traditional circular economy to a smart circular economy for achieving SDGs and net zero. *Transportation Research Part E: Logistics and Transportation Review*, *177*, p.103147.

Grafström, J. and Aasma, S., 2021. Breaking circular economy barriers. *Journal of cleaner production*, *292*, p.126002.

Gupta S (2024), *Accelerating the adoption of digital twin in India's energy landscape to elevate value and efficiency* Available at: https://energy.economictimes.indiatimes.com/news/oil-and-gas/accelerating-the-adoption-of-digital-twin-in-indias-energy-landscape-to-elevate-value-and-efficiency/107279432 [Accessed on: 26th March, 2024]

Hofstetter, J.S., De Marchi, V., Sarkis, J., Govindan, K., Klassen, R., Ometto, A.R., Spraul, K.S., Bocken, N., Ashton, W.S., Sharma, S. and Jaeger-Erben, M., 2021. From sustainable global value chains to circular economy—different silos, different perspectives, but many opportunities to build bridges. *Circular Economy and Sustainability*, *1*(1), pp.21-47.

Hu, W., Lim, K.Y.H. and Cai, Y., 2022. Digital Twin and Industry 4.0 Enablers in Building and Construction: A Survey. Buildings, 12(11), p.2004.

Huarachi, D.A.R., Piekarski, C.M., Puglieri, F.N. and de Francisco, A.C., 2020. Past and future of Social Life Cycle Assessment: Historical evolution and research trends. *Journal of Cleaner Production*, *264*, p.121506.

Hughes, D.L., Rana, N.P. and Dwivedi, Y.K., 2020. Elucidation of IS project success factors: an interpretive structural modelling approach. *Annals of Operations Research*, *285*, pp.35-66.

Ingle, P.V. and Mahesh, G., 2022. Construction project performance areas for Indian construction projects. *International Journal of Construction Management*, *22*(8), pp.1443-1454.

Ingle, P.V., Mahesh, G. and MD, D., 2021. Identifying the performance areas affecting the project performance for Indian construction projects. *Journal of Engineering, Design and Technology*, *19*(1), pp.1-20.

Ismayilova, A. and Silvius, G., 2021. Cradle-to-cradle in project management: A case study. *International Journal of Circular Economy and Waste Management (IJCEWM)*, *1*(1), pp.54-80.

Iurkov, V., Koval, M. and Zaefarian, G., 2023. How Much Does Domestic Location Matter for B2B Firms' Export Intensity? A Variance Decomposition Study. *Journal of International Marketing*, *31*(4), pp.36-52.

Jabborova, O.M. and qizi Saparbaeva, D.T., 2022. INDEPENDENT EDUCATIONAL METHODOLOGY. American Journal of Pedagogical and Educational Research, 6, pp.30-34.

Jemal, K.M., Kabzhassarova, M., Shaimkhanov, R., Dikhanbayeva, D., Turkyilmaz, A., Durdyev, S. and Karaca, F., 2023. Facilitating circular economy strategies using digital construction tools: framework development. Sustainability, 15(1), p.877.

Jiang, F., Ma, L., Broyd, T. and Chen, K., 2021. Digital twin and its implementations in the civil engineering sector. *Automation in Construction*, *130*, p.103838.

Joensuu, T., Edelman, H. and Saari, A., 2020. Circular economy practices in the built environment. *Journal of cleaner production*, *276*, p.124215.

Joudyian, N., Doshmangir, L., Mahdavi, M., Tabrizi, J.S. and Gordeev, V.S., 2021. Public-private partnerships in primary health care: a scoping review. *BMC health services research*, *21*, pp.1-18.

Kamble, S.S., Gunasekaran, A., Parekh, H., Mani, V., Belhadi, A. and Sharma, R., 2022. Digital twin for sustainable manufacturing supply chains: Current trends, future perspectives,

and an implementation framework. *Technological Forecasting and Social Change*, *176*, p.121448.

Kumar, R., Jha, A., Damodaran, A., Bangwal, D. and Dwivedi, A., 2020. Addressing the challenges to electric vehicle adoption via sharing economy: An Indian perspective. *Management of Environmental Quality: An International Journal*, *32*(1), pp.82-99.

Lemon, L.L. and Hayes, J., 2020. Enhancing trustworthiness of qualitative findings: Using Leximancer for qualitative data analysis triangulation. The Qualitative Report, 25(3), pp.604-614.

Linkedin.com, (2023), *Understanding the Role of Digital Twins in the Construction Industry* Available at: https://www.linkedin.com/pulse/understanding-role-digital-twins-construction/ [Accessed on: 26th March, 2024]

Liu, M., Fang, S., Dong, H. and Xu, C., 2021. Review of digital twins about concepts, technologies, and industrial applications. *Journal of manufacturing systems*, *58*, pp.346-361.

Liu, Q., Trevisan, A.H., Yang, M. and Mascarenhas, J., 2022. A framework of digital technologies for the circular economy: Digital functions and mechanisms. *Business Strategy and the Environment*, *31*(5), pp.2171-2192.

Madubuike, O.C., Anumba, C.J. and Khallaf, R., 2022. A review of digital twin applications in construction. *Journal of Information Technology in Construction*, *27*.

Maheswari, K., William, P., Sharma, G., Ayasrah, F.T.M., Ahmad, A.Y.B., Ramkumar, G. and Shrivastava, A., 2023. Enterprise Human Resource Management Model by Artificial Intelligence to Get Befitted in Psychology of Consumers Towards Digital Technology. *Journal for ReAttach Therapy and Developmental Diversities*, *6*(10s (2)), pp.209-220.

Malav, L.C., Yadav, K.K., Gupta, N., Kumar, S., Sharma, G.K., Krishnan, S., Rezania, S., Kamyab, H., Pham, Q.B., Yadav, S. and Bhattacharyya, S., 2020. A review on municipal solid waste as a renewable source for waste-to-energy project in India: Current practices, challenges, and future opportunities. *Journal of Cleaner Production*, *277*, p.123227.

Malodia, S., Dhir, A., Mishra, M. and Bhatti, Z.A., 2021. Future of e-Government: An integrated conceptual framework. *Technological Forecasting and Social Change*, *173*, p.121102.

Mangla, S.K., Raut, R., Narwane, V.S., Zhang, Z. and Priyadarshinee, P., 2021. Mediating effect of big data analytics on project performance of small and medium enterprises. *Journal of Enterprise Information Management*, *34*(1), pp.168-198.

Melesse, T.Y., Di Pasquale, V. and Riemma, S., 2020. Digital twin models in industrial operations: A systematic literature review. *Procedia Manufacturing*, *42*, pp.267-272.

Meng, X., Das, S. and Meng, J., 2023. Integration of digital twin and circular economy in the construction industry. *Sustainability*, *15*(17), p.13186.

Mies, A. and Gold, S., 2021. Mapping the social dimension of the circular economy. *Journal of Cleaner Production*, *321*, p.128960.

Mittal, V (2023), *How sustainability will shape India's construction industry* Available at: https://economictimes.indiatimes.com/small-biz/sustainability/how-sustainability-will-shape-indias-construction-industry/articleshow/106042273.cms?from=mdr [Accessed on: 26th March, 2024]

Monarch Innovation (2021). *Benefits of Building Information Modeling (BIM) | Monarch Innovation*. [online] Monarch Innovation Pvt Ltd. Available at: https://www.monarch-innovation.com/benefits-of-building-information-modeling [Accessed 27 Mar. 2024].

Muxayyo, R., 2023. METHODOLOGY TO DEVELOPMENT OF STUDENTSWRITING SKILL THROUGH TECHNICAL TEXTS. American Journal of Research in Humanities and Social Sciences, 9, pp.92-94.

Nikolaou, I.E., Jones, N. and Stefanakis, A., 2021. Circular economy and sustainability: the past, the present and the future directions. *Circular Economy and Sustainability*, *1*, pp.1-20.

Ocaña-Fernández, Y. and Fuster-Guillén, D., 2021. The bibliographical review as a research methodology. Revista Tempos e Espaços em Educação, 14(33), pp.e15614-e15614.

Oneclicklca.com, (2023), *An Introduction to Circular Economy principles in construction design* Available at: https://oneclicklca.com/en/resources/articles/an-introduction-to-circular-economy-principles-in-construction-design/#:~:text=For%20construction%20projects%20this%20includes,for%20re%2Duse%20and%20recycling. [Accessed on: 26th March, 2024]

Oneplanetnetwork.org, (2024), *Circularity in the built environment: A focus on India* Available at: https://www.oneplanetnetwork.org/sites/default/files/circularity_in_the_built_environment.pdf [Accessed on: 26th March, 2024]

Ortikov, N.B. and Amandzhanovna, I.D., 2022. Modern Teaching Methodology Of English Science. Journal of Pharmaceutical Negative Results, pp.1839-1846.

Pandey, P. and Pandey, M.M., 2021. Research methodology tools and techniques. Bridge Center.

Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K. and Hingorani, K., 2021. Towards a circular economy: An emerging economies context. *Journal of business research*, *122*, pp.725-735.

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Pires, A.C., Weidema, B., Mieras, E., Wang, F., Fava, J., Canals, L.M.I. and Cordella, M., 2021. Using life cycle assessment to achieve a circular economy. *The International Journal of Life Cycle Assessment*, *26*, pp.215-220.

Pereira, V., Budhwar, P., Temouri, Y., Malik, A. and Tarba, S., 2021. Investigating Investments in agility strategies in overcoming the global financial crisis-The case of Indian IT/BPO offshoring firms. *Journal of International Management*, *27*(1), p.100738.

Prasad, S., Singh, A., Korres, N.E., Rathore, D., Sevda, S. and Pant, D., 2020. Sustainable utilization of crop residues for energy generation: A life cycle assessment (LCA) perspective. *Bioresource technology*, *303*, p.122964.

Qi, Q., Tao, F., Hu, T., Anwer, N., Liu, A., Wei, Y., Wang, L. and Nee, A.Y., 2021. Enabling technologies and tools for digital twin. *Journal of Manufacturing Systems*, *58*, pp.3-21.

Rasheed, A., San, O. and Kvamsdal, T., 2020. Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE access*, *8*, pp.21980-22012.

Rejeb, A., Rejeb, K., Keogh, J.G. and Zailani, S., 2022. Barriers to blockchain adoption in the circular economy: a fuzzy Delphi and best-worst approach. *Sustainability*, *14*(6), p.3611.

Richards, J., Piorkowski, D., Hind, M., Houde, S. and Mojsilović, A., 2020. A methodology for creating AI FactSheets. arXiv preprint arXiv:2006.13796.

Root Analysis (2024). *Digital Twin Market Size, Share, Growth, Trends, Forecast (2035)*. [online] www.rootsanalysis.com. Available at: https://www.rootsanalysis.com/reports/digital-twins-market.html [Accessed 6 Apr. 2024].

Saari, U., Herstatt, C. and Dlugoborskyte, V., 2020. Cradle-to-Cradle Front-End Innovation: Management of the Design Process. *Industry, Innovation and Infrastructure*.

Sayidganiev, Z.S.U., Karimbaev, B.B.U. and Achilov, O.R., 2022. ADVANTAGES AND DISADVANTAGES OF CONSTRUCTION INDUSTRIES. *Academic research in educational sciences*, *3*(Special Issue 2), pp.123-127.

Semeraro, C., Lezoche, M., Panetto, H. and Dassisti, M., 2021. Digital twin paradigm: A systematic literature review. Computers in Industry, 130, p.103469.

Serradilla, O., Zugasti, E., Rodriguez, J. and Zurutuza, U., 2022. Deep learning models for predictive maintenance: a survey, comparison, challenges and prospects. *Applied Intelligence*, *52*(10), pp.10934-10964.

Shahat, E., Hyun, C.T. and Yeom, C., 2021. City digital twin potentials: A review and research agenda. Sustainability, 13(6), p.3386.

Sharma, N., Kalbar, P.P. and Salman, M., 2022. Global review of circular economy and life cycle thinking in building Demolition Waste Management: A way ahead for India. *Building and Environment*, *222*, p.109413.

Sharon, M (2023), *Exploring Digital Twins in Construction* Available at: https://medium.com/@matt-sharon/exploring-digital-twins-in-construction-f8467d1f37c4 [Accessed on: 26th March, 2024]

Siddiqui, A. and Pandit, R.K., 2021. Smart cities in India: linkages with circular economy. In *Sustainability in the Built Environment in the 21st Century: Lessons Learned from India and the Region* (pp. 185-200). Springer International Publishing.

Singh, S., Dasgupta, M.S. and Routroy, S., 2022. Analysis of critical success factors to design e-waste collection policy in India: A fuzzy DEMATEL approach. *Environmental Science and Pollution Research*, *29*(7), pp.10585-10604.

Soundarya Priya, M.G., Anandh, K.S., Prasanna, K., Gunasekaran, K., Daniel, E.I., Szóstak, M. and Sunny, D., 2023. Exploring the factors that influence the work–family interface of construction professionals: an Indian case study. *Buildings*, *13*(6), p.1511.

Su, S., Zhong, R.Y. and Jiang, Y., (2023). Digital twin and its applications in the construction industry: A state-of-art systematic review. Digital Twin, 2, p.15.

Suchek, N., Fernandes, C.I., Kraus, S., Filser, M. and Sjögrén, H., 2021. Innovation and the circular economy: A systematic literature review. *Business Strategy and the Environment*, *30*(8), pp.3686-3702.

Tan, T., Mills, G., Papadonikolaki, E. and Liu, Z., 2021. Combining multi-criteria decision making (MCDM) methods with building information modelling (BIM): A review. *Automation in Construction*, *121*, p.103451.

Teisserenc, B. and Sepasgozar, S., 2021. Adoption of blockchain technology through digital twins in the construction industry 4.0: A PESTELS approach. Buildings, 11(12), p.670.

Teng, S.Y., Touš, M., Leong, W.D., How, B.S., Lam, H.L. and Máša, V., 2021. Recent advances on industrial data-driven energy savings: Digital twins and infrastructures. *Renewable and Sustainable Energy Reviews*, *135*, p.110208.

Testi, M., Ballabio, M., Frontoni, E., Iannello, G., Moccia, S., Soda, P. and Vessio, G., 2022. Mlops: A taxonomy and a methodology. IEEE Access, 10, pp.63606-63618.

Tuhaise, V.V., Tah, J.H.M. and Abanda, F.H., (2023). Technologies for digital twin applications in construction. Automation in Construction, 152, p.104931.

Tursunovich, R.I., 2022. Methodology Of Teaching Riddles And Teaching Foreign Languages Through Them. Journal of new century innovations, 8(1), pp.570-573.

Tyagi, A.K., Nair, M.M., Niladhuri, S. and Abraham, A., 2020. Security, privacy research issues in various computing platforms: A survey and the road ahead. *Journal of Information Assurance & Security*, *15*(1).

Uddin, S., Ong, S. and Lu, H., 2022. Machine learning in project analytics: A data-driven framework and case study. *Scientific reports*, *12*(1), p.15252.

Unegbu, H.C.O., Yawas, D.S. and Dan-Asabe, B., 2022. An investigation of the relationship between project performance measures and project management practices of construction projects for the construction industry in Nigeria. *Journal of King Saud University-Engineering Sciences*, *34*(4), pp.240-249.

Viana, M.L., Hadikusumo, B.H., Mohammad, M.Z. and Kahvandi, Z., 2020. Integrated Project Delivery (IPD): An Updated Review and Analysis Case Study. *Journal of Engineering, Project & Production Management*, *10*(2).

Viswanathan, S.K., Tripathi, K.K. and Jha, K.N., 2020. Influence of risk mitigation measures on international construction project success criteria–a survey of Indian experiences. *Construction Management and Economics*, *38*(3), pp.207-222.

Wang, Z., Gupta, R., Han, K., Wang, H., Ganlath, A., Ammar, N. and Tiwari, P., 2022. Mobility digital twin: Concept, architecture, case study, and future challenges. *IEEE Internet of Things Journal*, *9*(18), pp.17452-17467.

Waqar, A., Othman, I. and Pomares, J.C., 2023. Impact of 3D printing on the overall project success of residential construction projects using structural equation modelling. *International Journal of Environmental Research and Public Health*, *20*(5), p.3800.

Waqar, A., Othman, I., Almujibah, H., Khan, M.B., Alotaibi, S. and Elhassan, A.A., 2023. Factors influencing adoption of digital twin advanced technologies for smart city development: Evidence from Malaysia. *Buildings*, *13*(3), p.775.

Warke, V., Kumar, S., Bongale, A. and Kotecha, K., 2021. Sustainable development of smart manufacturing driven by the digital twin framework: A statistical analysis. *Sustainability*, *13*(18), p.10139.

Yao, J., Yang, Y., Wang, X.-C. and Zhang, X.-P. (2023). Systematic review of digital twin technology and applications. *Visual Computing for Industry, Biomedicine, and Art*, [online] 6(1). doi:https://doi.org/10.1186/s42492-023-00137-4.

Zuofa, T., Ochieng, E.G. and Ode-Ichakpa, I., 2023. An evaluation of determinants influencing the adoption of circular economy principles in Nigerian construction SMEs. *Building Research & Information*, *51*(1), pp.69-84.

APPENDIX

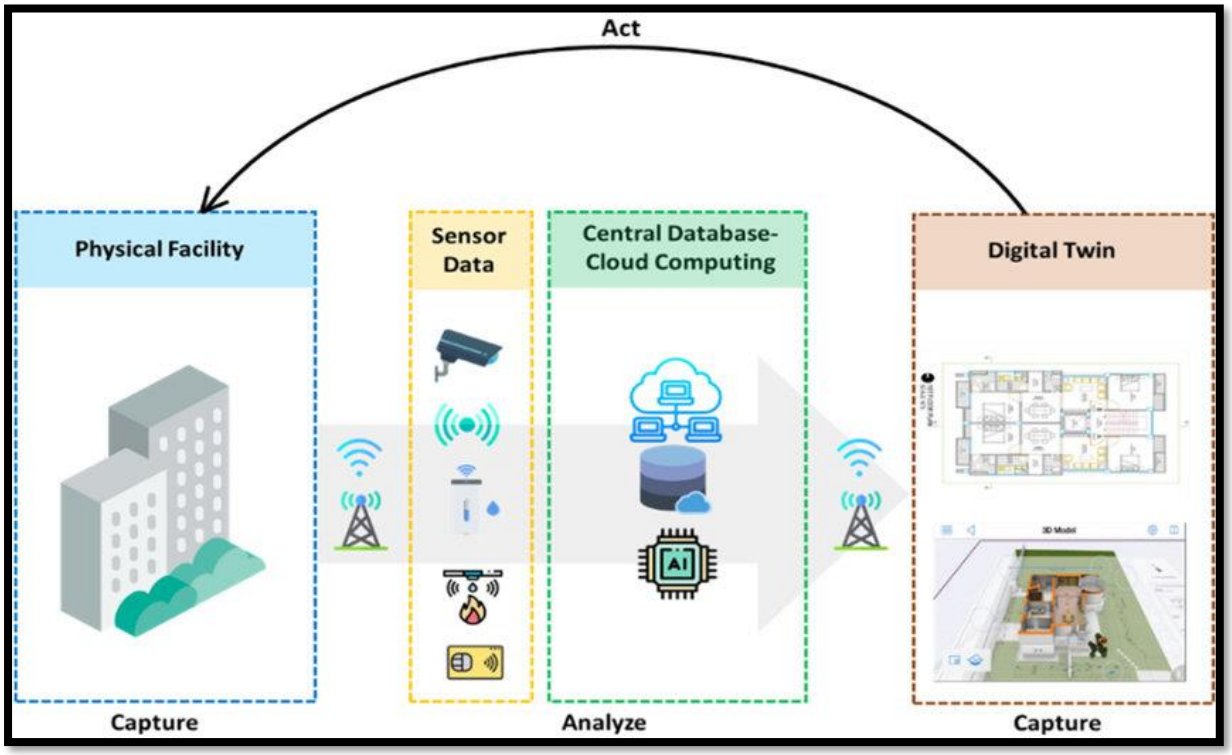

Figure 1: Digital twin construction framework

(Source: El Jazzar *et al.* 2020)

Fig. 1 provides a theoretical framework for the digital twin integration in construction practices that aims at circular economy. The framework presents the various components together which in turn makes green accounting to facilitate this strategy.

- **Act:** Here the process leads us to guessing that there are multiple events which are related to the physical life cycle of the structure. At this stage different stages can encompass such as designing, building, maintaining, refurbishing, demolition and so on.
- **Physical Facility:** This factor, which may be the building or the infrastructure itself, is the element which may require construction. The digital twin of this real-world facility will be a one replica of it with all data and information at hand.
- **Sensor Data:** The sensors inside the building or deployed nearby the construction area help to gather the actual data from the time points. This data may include parameters like the property life cycle ecological footprint, energy consumption, environmental conditions or number of inhabitants in the area.

- **Central Database- Cloud Computing**: The gathered sensor data could probably be sent to a central database that is deployed on cloud computing infrastructure which is an internet-based hosting service. Cloud computing has advantages such as virtualization that makes it possible to scale the systems necessitated, accessibility that is easy, real time data process capabilities among others.
- **Digital Twin:** This is the basis of the framework. The digital twin is a virtual image of the actual listed facility that is regularly updated with latest information from the central database through the minute. It not only connects information about the design, materials, construction history, as well as the performance of the facility, but also it integrates it.

The framework likely depicts how these elements interact:

1. Works that get carried out in the real world (repair, maintenance and such) lead to knowledge creation.
2. Sensors collect the data from physical facilities into the feed into a system.
3. The system acquires the burdens and sends the data to the central server (cloud).
4. Digital twin gets updates with recent data due to its high rate of communication.

Such a feature enables the system to bring in data updating in real-time as it will update all the variables that it supports to also reflect the evolving state of the digital twin. Based on the data, it can be optimised to save resources, minimise the generation of wastes and push the agenda of circular economy principles throughout the lifespan of the building.

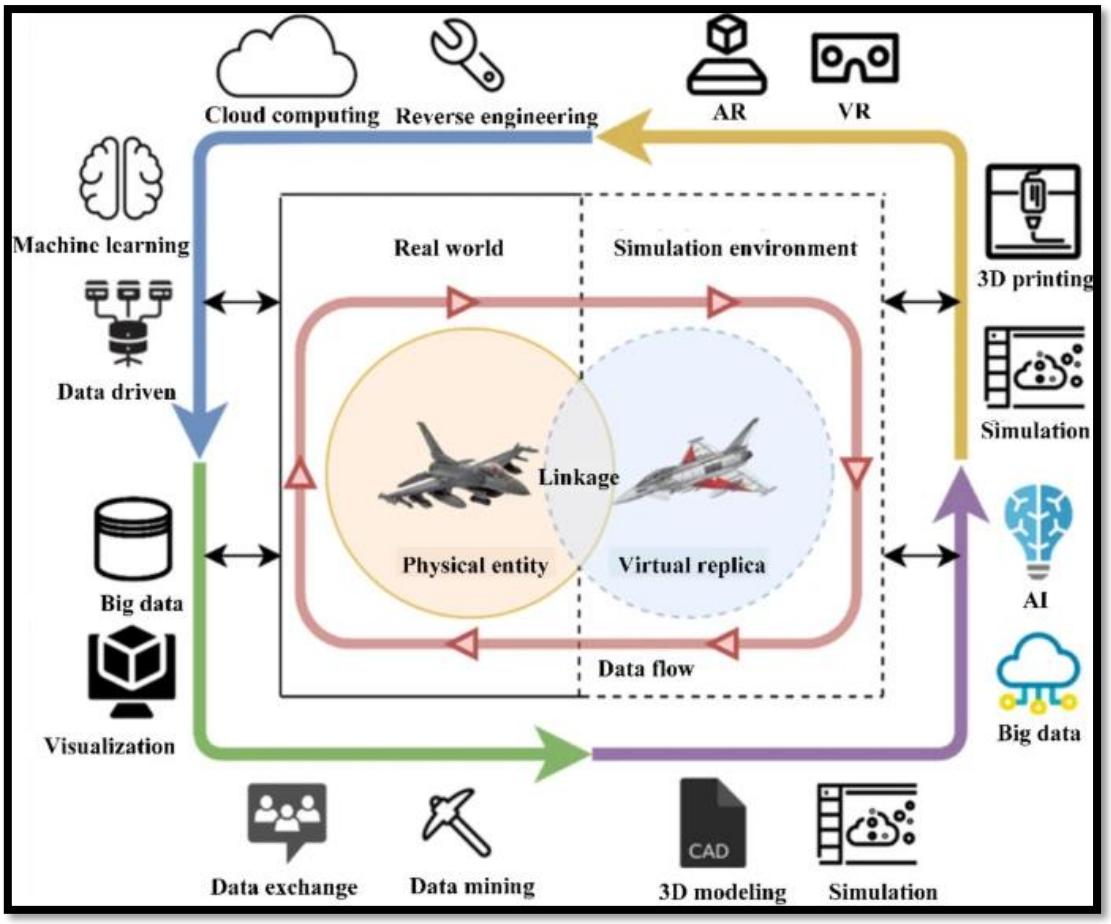

Figure 2: Application of Digital twin construction

(Source: Yao *et al.,* 2023)

Figure 2 presents different possible implementations of the digital twin technology in the building industry, which gives evidence of mastery in a circular economy. Maybe so, it is quite possible to interpret it as a representation of a chosen link where the digital twin links to the physical world throughout the lifetime of a building.

Bridging the Physical and Digital:

The principal symbol will illustrate the real world with all elements of the life cycle of the construction project including design phase, construction phase, operation phase and later on, deconstruction phase. Tied to the authenticity is a virtual surrounding. This is the spot where the virtual reality, or the digital copy, exists. It is the equivalent of the physical component. A digital twin is a dynamic model that is always live-updated with real-time data that are mostly incoming from the actual world.

Data Flow and Optimization:

It may very well be that Snapshot 2 is an example of arrows pointing to information flow between the real world and the digital representation. The sites' physical construction parts or building itself contain sensors that collect data about various elements. The data therefore could include aspects such as: material health, energy use, environmental factors or occupancy statistics in the operational stage. The sensor data is sent to the digital twin by means of transfer through a cloud-based system, where further data processing takes place.

An existing digital mock-up would act as the central hub. The digital twin would, therefore, be an integrated combination of the building's real-time data and information on its design, materials, and construction history. Through constantly studying this information, there is a way that the digital counterpart can be employed to perfect various steps in the construction sector. In this way, the requirements in the circular economy will be fulfilled.

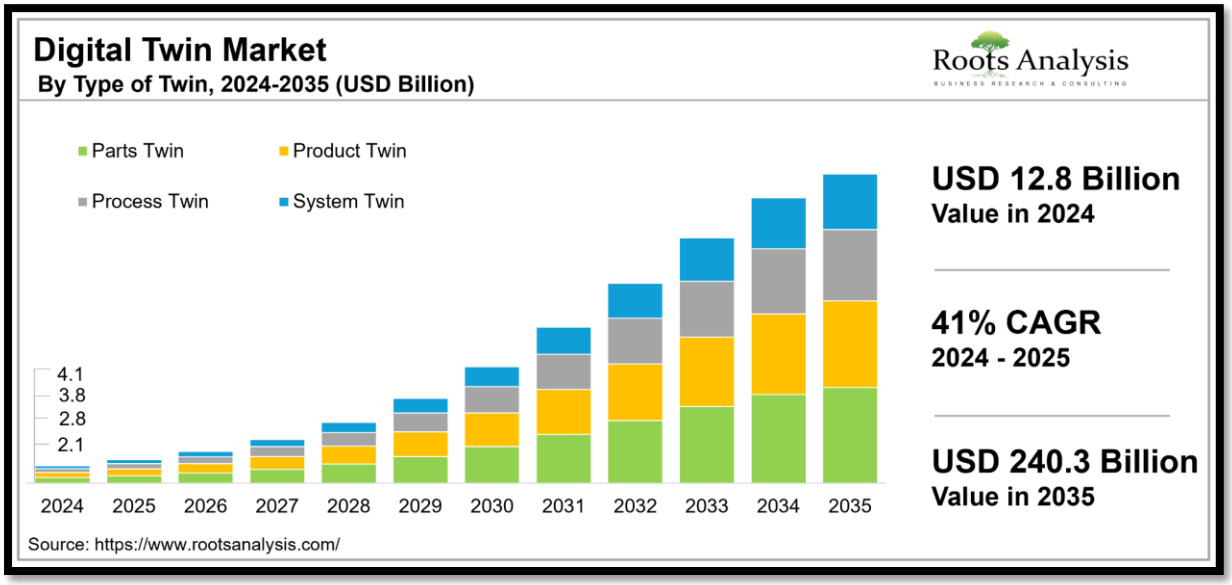

Figure 3: Market size of digital twin

(Source: Root Analysis, 2024)

As displayed in the graph "Digital Twin Market by Type of Twin, 2024-2035 ($US Billion)", the prognosis of utilisation of the digital twin technology is shown in the construction industry in the USA by the means of representing different types of digital twin. The x-axis is in years, and it covers the period from 2024 to 2035. It is worth noting that the y-axis is the market size in terms of the US dollars (per billion).

It is predicted by the figure that the US construction market construction industry will however see a growth in the market size of digital twin for the next decade. There is an expected figure

of US this year 2024 which equals to US this year 2035 there is an expected figure of US. This signals an annual compound growth rate (CAGR) of 41% for the period 2024 - 2025.

The data is further broken down into two categories of digital twins: kinds of twins in genus (e.g. cereal plant species) and types of twins in process/system twins (e.g. seedling plant seed). Process and system twins, being the parts which are not as directly linked to the production line, are marked to have fast growth, reaching $3.8 billion in 2024 only and expected to experience an incredible growth of $21.8 billion by 2035.

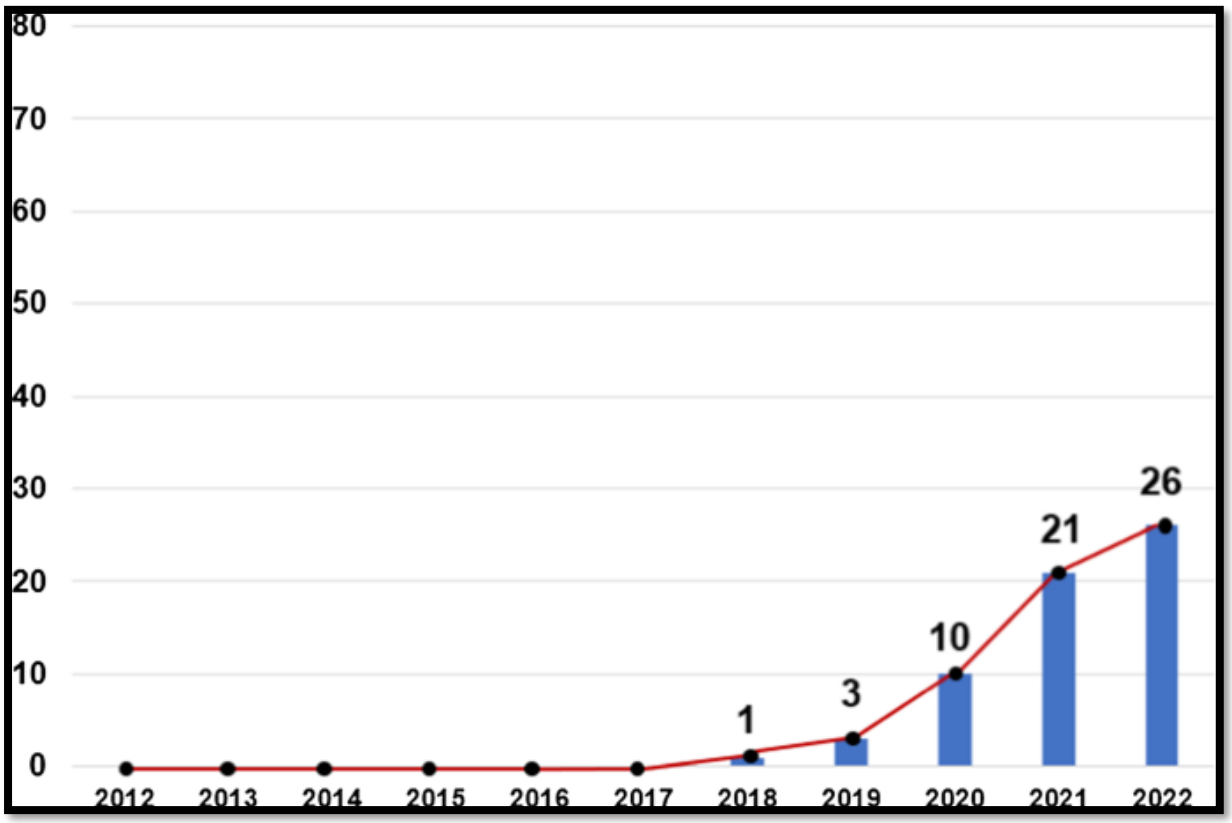

Figure 4: Digital twin for product versus project lifecycles

(Source: Abanda *et al.,* 2024)

The chart: "The Digital Twin in Product Versus Project Lifecycles" expressed numerically providing the numbers per industry in the USA during the period 2012-2022. The x-axis refers to the time ranges, which are years beginning from 2012 to 2022. There is a y-axis that has got tick marks but no given unit on the whole number of digital twins.

Each point, one representing the cost and the other the unit performed, is plotted on a graph of which there are two lines. The axis comparisons represent the digital twin examples in product life cycles with the blue line and the examples used in project lifecycles with the orange line. The data gives evidence in favour of a constant rise in the two types of digital twins used simultaneously in product as well as project life cycles since it covers a decade.

It looks like the use of digital twins for products is rising at a steeper angle as compared to the project. Accordingly, the linear expression that depicts the progress of the product life cycle starts from 1 in 2012 and climaxes at 21 in 2022. The year-to-year growth of the project life cycle graph spans from 3 to 26, represented in 2012 and 2022, respectively.

While it is significant to recognize that the lack of data units shown on the y-axis and the fact that specific numerical values are not specified for every year makes it harder to draw a more precise conclusion, it is still possible to discern some patterns. Nevertheless, the overall tendency looks like acceleration of the adoption of digital twins in both product and project life cycles within the United States over the last ten years.

Questionnaire

1. Age

- 26-30
- 31-35
- 36-40
- 41 and above

2. Gender

- Male
- Female
- Other

3. Condition surveys and construction risk assessments can be enhanced with the use of digital twins in the construction sector.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

4. By leveraging digital advancements to create an economic structure, technology may support the Circular Economy.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

5. Building information modelling (BIM) is the digital technology in construction that is frequently reported on.

- Strongly agree
- Agree
- Neutral
- Disagree

- Strongly disagree

6. The digital twin for the circular economy is different from the digital twin used in building for various reasons.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

7. From concept to construction, digital twin systems and associated sensor networks help to manage material flows and enhance material passports.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

8. Reducing waste and raising a constructed asset's salvage value is a key goal of the circular economy.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

9. Estimating the salvage value of constructed assets using a life cycle performance framework based on BIM.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree

10. With the use of digital technology, Integrated Digital Delivery (IDD) simplifies the various phases of a building project.

- Strongly agree
- Agree
- Neutral
- Disagree
- Strongly disagree