Drivers of digital technologies-driven circular economy in the Nigerian construction Industry: A PLS-SEM Approach

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REVIEWERS' COMMENTS AND AUTHORS' RESPONSE

The authors deeply wish to extend thanks to the editors and referees for their constructive comments and suggestions. The paper has now been improved as a result of addressing this positive feedback. Each comment has either been addressed or defended as appropriate (refer below) and a final file resubmitted for your consideration (see **coloured** texts and sentences) within MS Word.

Once again, thank you.

Reviewers Comments to Author	Authors Response to Reviewers Comments
REVIEWER No. 1	
Recommendation: Minor Revision	Thank you. What appeared to be an error/mismatch is not an error. See detail rebuttal below/relevant section of paper.
Comments: The paper reads well and presents an interesting topic.	Thank you. This means a lot to us
Additional Questions:	
1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes	Thank you.
2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes	Thank you.
3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: There seems to be an error in the Research Hypotheses section. Please look at H1 to	Thank you for your comment here. There is no mismatch or error between the developed hypotheses and the supporting passages in the referred pages (14 & 15) of revision R2.

H5, it would seem that the sub-titles do not match the passages e.g. H1 Is subtitled Technological drivers... but the passage is on Economic and Business drivers (pgs 14 and 15).	Please, see (**subsection 3.1 Research hypotheses)** of revision R3 for details and colour codes for each of the hypotheses (H1 to H5) and supporting passages. 1) The 2nd paragraph in (**subsection 3.1),** is for 'Technological drivers' and H1. 2) The 3rd paragraph in (**subsection 3.1),** is for 'Economic and Business drivers' and H2. 3) **Etc.,**
4. Results: Are results presented clearly and analysed appropriately? Do the conclusions adequately tie together the other elements of the paper?: Yes	Thank you.
5. Implications for research, practice and/or society: Does the paper identify clearly any implications for research, practice and/or society? Does the paper bridge the gap between theory and practice? How can the research be used in practice (economic and commercial impact), in teaching, to influence public policy, in research (contributing to the body of knowledge)? What is the impact upon society (influencing public attitudes, affecting quality of life)? Are these implications consistent with the findings and conclusions of the paper?: Yes	Thank you.
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Recommendation: Accept	Thank you. This means a lot to us
Comments: The authors have addressed all of my comments. I have no further comments.	Thank you. This means a lot to us

Additional Questions:	
1. Originality: Does the paper contain new and significant information adequate to justify publication?: Yes.	Thank you.
2. Relationship to Literature: Does the paper demonstrate an adequate understanding of the relevant literature in the field and cite an appropriate range of literature sources? Is any significant work ignored?: Yes.	Thank you.
3. Methodology: Is the paper's argument built on an appropriate base of theory, concepts, or other ideas? Has the research or equivalent intellectual work on which the paper is based been well designed? Are the methods employed appropriate?: Yes.	Thank you.
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Abstract

Purpose – The predominance of linear economy practices has contributed to inefficiencies, poor productivity, poor health and safety issues, and cost and time overruns, impacting the volume of construction and demolition waste generated in the construction. Digital technologies (DTs) enable the speedy transition to circular economy (CE) practices to overcome the waste and inefficiencies associated with the linear production system and bring about the sustainability of the built environment. This study investigated the drivers of the digitalisation of CE transition in construction, with a focus on the Nigerian construction industry.

Design/methodology/approach – A quantitative approach was adopted, and a structured questionnaire was conveniently used to gather relevant data from construction professionals. The collected data were analysed using the relative importance index (RII) Kruskal-Wallis H test and partial least square-structural equation modelling (PLS-SEM).

Findings – The RII revealed that the assessed factors are important driving forces of digital technologies-enabled CE adoption in construction, and the leading five drivers are Optimise product recycling, Conversion of waste to valuable energy, regulations and legislation on technology usage, Laws and regulations prohibiting poor waste handling, and availability of data and improved information exchange. Based on the SEM outputs, the factors influencing the adoption and implementation of digital technologies in CE transition are organisational drivers, economic and business drivers, environmental drivers, social and cultural drivers, technological drivers, and government and institutional drivers.

Practical implications - Construction stakeholders and decision-makers will use this study as input in making decisions that impact the tripods of sustainability (i.e., environment, society and economy). Future studies can utilise the findings of this study as a base to underpin theoretical assumptions and hypotheses.

Originality/value –There is a dearth of quantitative studies on the drivers of technology-led CE transition in construction in Nigeria. This study pioneers research in this area and provides a comprehensive understanding of the drivers of the technology-led CE transition in the Nigerian construction industry.

Keywords: Digital technologies, Drivers, Circular economy, Sustainability, Waste reduction, Nigerian Construction industry.

1. Introduction

Waste from construction activities has remained a grievous problem confronting the global construction industry. It is the result of high materials consumption relative to low materials recycling (Brandãoz et al., 2021) and the predominance of the linear production model. The industry consumes at least 30% of nature's raw materials, 25% of nature’s water resources, 40% of global energy and 12% of Earth's land (Bilal et al., 2020; Adadre et al., 2022). It equally causes environmental degradation as up to 3 billion tonnes of waste from construction and demolition activities are generated yearly (Akhtar & Sarmah, 2018). The high volume of waste associated with the linear production model contributes to the poor sustainability performance of the construction sector, and the continuous call for the adoption of more sustainable production techniques and methodologies in construction (Pomponi & Moncaster, 2017).

The adoption of the circular economy (CE) concept is rapidly growing in many economic sectors, including the construction industry. The exigency to transition from the linear model to CE in the construction sector has since begun in industrialised nations of the USA, UK, France, Netherlands, Denmark and others (Ellen MacArthur Foundation, 2014), and this is because of the role it plays in the fight against climate change. CE is being promoted as a sustainable approach and a panacea to poor resource consumption and utilisation, as well as the problems of the high volume of waste in the construction sector (Shooshtarian et al., 2022) and high resource consumption from nature. CE is a sustainable alternative that transforms the linear system of take-make-use-dispose to a cyclical model of materials recycling and reuse, which grossly minimises waste in landfills. CE adds value to construction and demolition waste by giving it the opportunity to be reused in new construction projects (Smitha & Thomas, 2021). This practice makes the environment safe and improves organisations' productivity, profits and competitiveness (Annata, 2022). A sustainable enabler of CE transition is digital technologies, and this has been echoed in several studies (Rodrigo et al., 2024; Chauhan et al., 2022; Rejeb et al., 2022).

Research has shown that digitalisation influences and speeds up the transition from a linear economy to a CE production model and the sustainability of businesses (Han et al., 2023). An appreciable number of business environments are experiencing transformation and the disruptive effects of the dynamics of technological evolution and sustainable circular production model (Patil et al., 2023). DTs-integrated CE allows businesses to advance the functions of tracking, predictive analytics and monitoring of products and processes across the entire production chain/life cycle (Singh, 2024). DTs such as machine learning, artificial intelligence (AI), big data analytics, blockchain, and Internet of Things (IoT), among others, enable circular business model (CBM) in construction by aiding construction and demolition waste generation forecasting, identification and classification of waste, and waste management (Rodrigo et al., 2024). Digitalisation fosters CE transition, resource optimisation, enhanced productivity and performance, data management and proactive cycling and waste management (Eze et al., 2024a), which helps to optimise resource usage and improve transparency and sustainability practices in the construction industry.

While the use of modern technologies and production methodologies has grown in mature nations, the developing countries of which Nigeria is a part lag as innovative tools and techniques adoption are still at the embryonic stage (Ebekozien & Aigbavboa, 2021). The construction industry lags other industries (e.g., finance, health, aviation) in the adoption of technological innovation. The construction industries of the UK, USA, Canada, and Japan, among others, are ahead of those of developing countries like Nigeria. This is because of awareness issues, lack of standards, lack of experts and cost factors, which made smooth digitalisation adoption in the industry difficult (Aliu & Oke, 2023).

Nigeria is a rapidly growing country with huge population expansion and housing and infrastructure needs (Aboginije et al., 2021). This transformation has put enormous pressure on Earth's resources, which has led to excessive extraction and use of natural resources in building and developmental projects. The huge waste associated with these activities causes environmental imbalance due to poor waste management (Ojo et al., 2021) and recycling challenges. While the Government has made efforts to establish the "Nigeria Circular Economy Working Group (NCEWG)" to encourage sustainable production and consumption in the construction industry, the knowledge of CE concepts and the sustainability impact of DTs is still limited among stakeholders, which has impacted the transition of the sector and the slow rate of adoption of efficient and sustainable Techniques and methodologies (Bello et al., 2023).

2. Research gap and relevance

Technology-led CE transition adoption is still in its infancy, and studies integrating DTs and CE transition are limited as well as a rapidly growing field of research as evident in the number of review studies linking technologies with CE transition. For instance, a review of Internet of Things (IoTs) and CE in businesses and management literature (Rejeb et al., 2022), Review of studies on leveraging DTs for promoting CE practices and life cycle analysis (Hariyani et al., 2024), Review of driver and barriers to Smart technologies for CE (Traunt et al., 2024), Drivers of Big data analytics in food supply chain for CE transition (Kazancoglu et al., 2021), the impact of DTs in CE in the construction industry (Rodrigo et al., 2024), and others (Elghaish et al., 2023; Setaki & van Timmeren, 2022; Chauhan et al., 2022; Liu et al., 2021; Lu et al., 2022). While these studies made significant contributions to the synergy of DTs and CE, they are mostly review-based and/or conceptual. Although a few of these studies touched on the drivers of technologies-driven CE, their focus was not on construction (Kazancoglu et al., 2021). Thus, this gap in the construction management literature; in particular, a quantitative assessment of the driver of DT adoption in CE needs to be filled.

Technology-driven CE studies focusing on the Nigerian construction industry are scarce and an underexplored area in construction management literature. Specifically, there is an absence of a study on the drivers of DTs that aid CE transition in Nigeria. This critical literature gap calls for this present study, whose aim is to critically investigate, using the structural equation modelling (SEM) technique, the drivers of digital technologies adoption in the circular economy transition in Nigeria's construction industry. SEM is a robust statistical technique that assesses complex relationships among diverse factors (Hair et al., 2019). Moreover, studies linking DTs and CE have yet to employ partial least square structural equation modelling (PLS-SEM). This study will use quantitative methods - relative importance index (RII), Kruskal-Wallis H test, and SEM- to help bridge the literature gaps on the drivers of DT implementation in CE transition efforts in the Nigerian construction industry. It will also support the sustainability and innovation diffusion in the sector, which could lead to higher technology adoption and the practices of the CE among the industry players for the sustainability of the sector and in pursuit of sustainable development goals (SDG).

3. Drivers of Digital technologies-driven circular economy

Technology support systems for CE can be driven by the need for construction businesses to enhance resource efficiency (Chi et al., 2023; Singh, 2024). A resource-efficient economy is achieved through production process optimisation, reduction in waste generation and enhancement of materials recycling (Singh, 2024). CE harnesses blockchain, IoT and AI technologies to enhance the sustainability of the materials selection process, automate the sorting of construction wastes and improve construction supply chain efficiency for better resource conservation and pollution minimisation. There is a need to revolutionise construction materials and component design in projects (Wang et al., 2023; Sánchez-García et al., 2024). AI aids the design of products that are easily recycled and reliable, which helps to transform the consumption and production patterns of the industry. Thus, products designed for circularity are influenced by data-driven insights, which make them more economical and environmentally sustainable (Chauhan et al., 2022). Construction waste conversion to valuable energy sources is made possible by technology adoption and this is in line with the circularity principles (Singh, 2024).

Innovation awareness and approval by stakeholders are key drivers of such innovation in the construction industry. Research shows that social awareness and approval of a technique or technology are important drivers of technology-led CE transition (Čábelková et al., 2021). Increasing awareness can facilitate the adoption of reverse logistics processes in construction (Elghaish et al., 2023). Top management support is another leading driver of technology innovation adoption in construction (Tetteh et al., 2024; Truant et al., 2024). DTs-driven CE cannot survive without management support. In addition to management support, the Management team's capability and expertise in the integration of DTs and CE principles is important in the quest for sustainability. The management team should be knowledgeable about information and data management and the subject of CE (Ferenhof et al., 2019). Government incentives and support are another critical driver of the technology-led CE transition in construction (Kazancoglu et al., 2021). The adoption of DTs in CE transition efforts is also influenced by the quest for operational efficiency and supply chain integration. Government incentives, operational efficiency and collaboration, are the critical drivers of big data analysis adoption CE transition (Kazancoglu et al., 2021). Construction supply chain visibility is a factor for DT adoption in the CE transition as it increases the real-time control of production resources (Kamble et al., 2020).

Another factor is the quest for openness, transparency and accountability in circular construction transactions. Blockchain technology allows for the traceability of materials and products within the construction supply chain, and this helps to promote transparency and accountability in circular construction production systems (Singh, 2024). The origin of building materials, products and equipment and their life cycle information can be tracked by clients, and this empowers them to make informed purchase decisions with consideration of circular economic principles. This client/consumer empowerment approach can cause construction firms to adopt a technology-driven CE business approach to remain competitive. Clients take part in decisions regarding the procurement of sustainable buildings. Firms can select sustainable construction materials that match clients' requirements through mass personalisation brought by the disruptive effect of the linear business model by the adoption of AI and big data (Chauhan et al., 2022). The competitiveness of a business, increased market share, and cost reduction are among the leading drivers of DT adoption in production (Chaffey, 2014).

Maximisation of the value of physical products through added services to improve the competitive advantage of firms is critical. Technology-driven CE support servitisation for value addition to clients leads to better client satisfaction (Bag & Pretorius, 2020). IoT allows for product-service integration, which impacts CE transition (Rejeb et al., 2022), particularly for subcontractors and building materials vendors. Technology-driven CE opens new economic opportunities and creates jobs for technology enthusiasts among construction experts. The growth in the demand for technology experts could expand the job market for data analytics and artificial intelligence professionals (Singh, 2024) for the construction industry. Digital platforms provide avenues for collaboration and sharing of knowledge relating to circular business objectives. The need to create an ecosystem of experts dedicated to promoting the ideals of sustainability in construction is one of the driving forces for technology-led CE adoption. Digitalisation-led CE allows for ecosystem collaboration, which provides a significant opportunity for product data to be shared with recyclers internationally and, thus, help suppliers of disassembled parts showcase or sell their products. This enhances recyclability and waste minimisation (Irie & Yamada, 2020). Digital platforms facilitate the exchange of materials among companies in the economy. The digital platforms create a market where construction organisations can sell or donate excess building materials or products, to encourage the reusability of materials and components and the reduction of waste. Thus, DTs enable materials exchange objectives in the construction industry (Singh, 2024).

In the CE model, technologies can complement labourers' skills and capabilities by improving decisions that impact circular construction objectives (Mboli et al., 2020). Big data aids the accumulation of diverse datasets that improve circular-based decision-making (Chauhan et al., 2022). 3D printing technology aids the practice of 'on-demand manufacturing'. This practice brings the construction materials manufacturers closer to the building sites, which helps to reduce the carbon footprint that is associated with transporting building materials over long distances (Singh, 2024). Remanufacturing is another role modern transformative technologies adoption in CE can bring. The availability of product data can make the implementation of remanufacturing possible to reduce waste and enhance recycling (Okorie et al., 2018). DT adoption in CE makes reverse logic possible as construction waste gathering, treatment and transportation for remanufacturing are facilitated (Akkad & B'anyai, 2021). According to Wilson et al. (2021), AI is a critical factor for optimal reverse logic operation, and this is supported by Schlüter et al. (2021), who submitted that AI adoption in CE can enhance materials identification, inspection and segregation for reverse logic operation.

In a smart packaging strategy, QR codes are included in the packaging of construction materials and products to provide information about the use and recycling methods. This makes clients and builder consumers partake in recycling (Singh, 2024; Boz et al., 2020). Thus, technology is adopted in CE to optimise product recycling (Singh, 2024). Technologies improve the life of products such as air conditioning units and other equipment through predictive maintenance capacities, thus, improving clients' experiences and waste reduction from the client's end (Singh, 2024). The overall production, processing and waste recovery opportunities of the firms can be enhanced via the supply chain visibility that technology brings to CE practices (Chauhan et al., 2022). Information management and technology driver help firms control their stock and materials, improve forecasting, faster product distribution, and sustainable operations (Bamel & Bamel, 2020). Client requirements, leadership, regulations and legislation, environmental sustainability and market demands are the drivers of innovation for sustainable construction (Nguyen, 2023). Digital twins' adoption is driven by factors such as efficient project management and monitoring, predictive maintenance, data collection and visualisation of real-time data for better decision-making and reduced operational cost (Jahangir et al., 2024).

The literature review led to the identification of forty potential drivers of DTs aided CE in construction, and these were categorised and summarised in Table 1 below.

Table 1. Drivers of Digital technology-driven CE in construction

Code	Main Category	Drivers	Source(s)
TED01	Technological drivers	Availability of support infrastructure technologies and equipment	Wuni (2023); Nguyen (2023)
TED02		Availability of data and improved information exchange	Wuni (2023)
TED03		Conversion of waste to valuable energy	Singh (2024)
TED04		Revolutionise the design of materials and components	Singh (2024); Chauhan et al. (2022)
TED05		Optimise product recycling.	Traunt et al. (2024); Singh (2024)
TED06		On-demand manufacturing	Singh (2024)
TED07		Predictive maintenance and improved product life	Chauhan et al. (2022); Jahangir et al. (2024); Singh (2024)
TED08		Improved supply chain and integration	Chauhan et al. (2022); Kazancoglu et al. (2021)
TED09		Quality management	Traunt et al. (2024); Chauhan et al. (2022)
TED10		Products remanufacturing and reverse logic.	Okorie et al. (2018); Traunt et al. (2024); Akkad and B´anyai (2021); Wilson et al. (2021); Schlüter et al. (2021); Rejeb et al. (2022); Elghaish et al. (2023); Wuni (2023)
TED11		Efficient project management and monitoring	Jahangir et al. (2024);
TED12		Transformational process innovation for cleaner production	Wuni (2023)
EBD01	Economic and Business Drivers	New market opportunities for businesses	Bello et al. (2023) Wuni (2023)
EBD02		Improve revenue and business expansion.	Bello et al. (2023) Wuni (2023)
EBD03		Better competitive advantage and market share	Chaffey (2014); Traunt et al. (2024);
EBD04		Support servitisation	Bag and Pretorius (2020); Rejeb et al. (2022)
EBD05		Empowering consumers/clients	Singh (2024)
EBD06		Reduce operational cost	Chaffey (2014); Jahangir et al. (2024); Traunt et al. (2024)
EBD07		Materials exchange objectives	Singh (2024)
EBD08		Promoting Transparency and Accountability	Traunt et al. (2024); Singh (2024)
EBD09		Client requirements and market demand	Nguyen (2023)
END01	Environmental Drivers	Enhance resource management and efficiency	Traunt et al. (2024); Chauhan et al. (2022); Singh (2024)
END02		Support product recovery	Rejeb et al. (2022); Traunt et al. (2024);
END03		Waste segregation	Schlüter et al. (2021)
END04		Environmental sustainability	Nguyen (2023); Traunt et al. (2024);
END05		Minimise dependence on Earth's raw materials	Bello et al. (2023) Wuni (2023)
CSD01	Social & Cultural Drivers	Social responsibilities	Wuni (2023); Giorgi et al. (2022)
CSD02		Improved community health and wellbeing	Bello et al. (2023) Wuni (2023); Giorgi et al. (2022)
CSD03		Stakeholders' awareness and approval	Čábelková et al. (2021)
CSD04		Job creation and growth in technology experts	Singh (2024); Wuni (2023); Bello et al. (2023)
GRD01	Government and institutional drivers	Government incentives	Kazancoglu et al. (2021); Chauhan et al. (2022);Traunt et al. (2024)
GRD02		Financial support and incentives to use secondary materials	Wuni (2023)
GRD03		Law and regulations prohibiting poor waste handling	Wuni (2023)
GRD04		Regulations and legislation on technology usage	Nguyen (2023); Traunt et al. (2024);
OGD01	Organisational Drivers	Information management and technology	Bamel and Bamel (2020)
OGD02		Operational efficiency	Kazancoglu et al. (2021); Chauhan et al. (2022)
OGD03		Top management support	Kazancoglu et al. (2021); Chauhan et al. (2022); Nguyen (2023)
OGD04		Resource management	Traunt et al. (2024); Chauhan et al. (2022); Giorgi et al. (2022)
OGD05		Complement labour efforts on the circular decision-making process	Mboli et al. (2020); Chauhan et al. (2022); Jahangir et al. (2024); Traunt et al. (2024);
OGD06		Improved Collaboration and knowledge exchange	Traunt et al. (2024); Singh (2024)

3.1 Research hypotheses

Literature shows that technologies influence circular economy transition and sustainability. The categorised factors were also found to have the potential to drive and influence the digitisation of CE efforts in the construction industry, and based on these, six hypotheses were formulated to guide this study.

The study by Yuan and Pan (2023) revealed that DT application bolsters the circular economy capability of corporations. DT adoption influences improvement in CE transformation (speed up change from linear value chains to circular value chains), which impacts improvement in performance and product efficiency for reduced waste and resource optimisation (Wuni, 2023; Vimal et al., 2023). Technological factors help to beam more light on CE concepts, as they play significant roles in the growth and development of CE concepts (Vimal et al., 2023). The availability of appropriate tools and technologies can significantly impact the decision to adopt CE in construction. Supportive infrastructure, technologies and equipment and data availability, can provide many solutions including re-engineering business processes for better strategic circular business model implementation and a sustainable CE practice in the construction industry (Huang et al., 2022; Wuni, 2023). Therefore, technological factors can positively influence the adoption of technology-led CE concepts in construction. Based on this, the hypothesis (H1)is formulated.

H1: Technological drivers have a significant and positive influence on the implementation of technology in CE

The need to promote economic and business performance can significantly influence the adoption of social and eco-friendly practices (Dey et al., 2022). The use of technology in CE practices can generate jobs and create opportunities for new business development as well as growth and expansion of existing ones. Innovation and the emergence of new business models are bolstered by technology integration into sustainable practices for economic development (Singh, 2024). Economic and business motives influence technology-led CE business model practices in construction, which reduce cost, improve efficiency, profitability, better competitive edge and sustainability (Wuni, 2023; Nguyen, 2023), thus, H2 is formulated.

H2: Economic and Business Drivers have a significant and positive influence on the implementation of technology in CE

Environmental factors play a crucial role in technology and production innovations, and such are essential to an organisation's production plans. The adverse effect of the traditional construction approach on climate change, pollution, biodiversity, resource scarcity and ecosystems, can induce construction stakeholders and organisations to CE (Wuni, 2023), and technologies are critical to ensure smooth CE implementations (Singh, 2024). These environmental considerations can positively influence a technology-driven CE in construction.

H3: Environmental Drivers have a significant and positive influence on the implementation of technology in CE

Social dimensions drive the adoption of smart technologies in the construction industry, which has a social impact on the larger community (Zhou et al., 2023). The need for social impact on society can significantly influence the adoption of technologies and circular economy (Rodríguez-Espíndola et al., 2022; Patwa et al., 2021). The study by Valencia et al. (2023) showed that CE adoption and sustainability practices are impacted by social needs. Cultural factors can effectively influence how Industry 4,0 technologies are utilised to drive CE practices in an economic sector (Tiwari et al., 2024). Based on these, the fourth hypothesis is developed.

H4: Social and cultural Drivers have a significant and positive influence on the implementation of technology in CE

Government and institutional drivers are essential policies stipulated and/or applied by governments at all levels to facilitate CE transition among business organisations in the construction industry. Legislation and policies regarding the use of circular/ recyclable materials and products as well as the technologies to adopt, to CE and waste management (Adabre et al., 2022). Government policies are critical to innovation adoption in the construction industry (Hazarika and Zhang, 2019; Arowoiya et al., 2023). Based on this knowledge, the fifth hypothesis was developed.

H5: Government and institutional drivers have a significant and positive influence on the implementation of technology in CE

The process of transitioning to CE in the construction industry is a complex one, that requires strong organisation and institutional reforms in addition to significant technologies investment and capacity building (Wuni, 2023). Processes within the CE can be automated and optimised by technology adoption (Sánchez-García et al., 2024), therefore, construction organisations must be committed to repositioning their businesses for better efficiency and performance through a technology-led CE practice. These confirm the criticality of organisation in driving sustainable practices in the construction industry.

H6: Organisational Drivers have a significant and positive influence on the implementation of technology in CE

4. Research Methodology

This study adopted a quantitative research approach, in which a structured questionnaire survey was used for data collection from built environment experts (Engineers, Architects, Builders, and Quantity Surveyors) in Lagos state, Nigeria. The questionnaire is suitable for the collection of unbiased numerical data and enables statistical analysis to be executed to establish trends and patterns as well as relationships and dependencies between variables (Oke et al., 2024). The premise for choosing Lagos State for this study is because the industry experts in the area have an appreciable level of experience and knowledge about modern, transformative production methodologies and techniques over other regions (Eze et al., 2024a). The study questionnaire was developed after a detailed review of relevant literature. From the literature review, 40 drivers of DT adoption in CE were selected and categorised into 6 main categories of drivers, which were used to design the questionnaire. The adopted questionnaire was designed to have two sections. The first section gathered data about the profile of the respondents. The second section gathered data on the drivers of DT adoption in CE transition in construction organisations. The respondents were required to rate the factors based on their level of importance in driving the digitalisation of the CE production model in the industry on a 5-point Likert scale, where (1= lowest rating scale; 5= highest rating scale). The initial draft of the research instrument was subjected to experts' validation to confirm the categorised main drivers and the factors. Following this, pilot testing was conducted to assess its completeness and suitability to gather the data it was meant for. Following the pilot survey of 7 industry experts and 5 academics with experience and knowledge of DTs, CE and sustainability in construction, the final questionnaire was revised and used for data collection. Google Forms was used to design the questionnaire so that data collection could happen remotely and in real-time.

A sample size of 372 was obtained from the experts' population of 5330 (Aliu et al., 2024), using the Yamane equation, at a 5% error margin. Yamane equation use is common among construction management studies. The participants were recruited based on these criteria: (1) they must have a minimum of 5 years of practice experience in construction, (2) knowledge of CE concepts and digital technologies, (3) must ply their trades within the study area and must be willing to take part in the survey. Based on these, the convenience sampling approach was used in the administration of the questionnaire by the researchers. This sampling approach does not place restrictions on any qualified experts who meet the sample selection criteria (Etikan et al., 2016), and it is widely used in construction management literature. After a survey period of 16 weeks, 194 responses were received, out of which 7 were discarded for incomplete responses. This leaves 187 usable data, which is equivalent to a 50.27% response rate, and which is well above the suggested 20-30% for surveys using questionnaires (Moser & Kalton, 1999).

The gathered data were analysed using descriptive statistical tools and partial least square structural equation modelling (PLS-SEM). The data normality assumption was confirmed using the Shapiro-Wilk test, which is suitable for sample sizes below 2000 (Ghasem & Zahediasl, 2012). The result showed the data are non-parametric. Frequency and percentage were used to analyse the respondents' profile information. The relative importance index (RII) technique was used to rank the drivers as perceived by the study respondents. The Kruskal-Wallis's test was used to determine if there is potential variation in the respondent's rating of the variables since they are from different organisations and experiences backgrounds. PLS-SEM was used to determine the association and dependencies that exist within variables and the constructs. The presence of a hypothesis and a pre-established conceptual model makes it necessary to use PLS-SEM (Hussain et al., 2016) to confirm the relationships and contribution of the drivers to the implementation of Digitalisation of CE practices. SEM provides a vigorous and detailed statistical method that permits a sophisticated examination of the fundamental relationship between assessed variables (Hair et al., 2019). The PLS-SEM was conducted using SmartPlS version 4.

Factor categorisation validation survey

Following the design of the questionnaire as described earlier, experts' validation was carried out to confirm the suitability of the identified drivers in each category. Twenty-three experts from the industry and academia were invited to participate in the validation of the factors influencing DTs-aided CE transition in construction. In the end, only twelve of them responded and subsequently validated the categorised drivers extracted from the literature review. They were required to place a 'Yes' or 'No' against each of the factors under the category they had been placed. The results of the expert validation confirm the suitability of the factors under their classified groups.

5. Results

5.1: Profiles of Survey Participants

The analysis of the profession of the respondents showed a fair representation of the key experts in the construction industry. 33.16% of the respondents were engineers by profession, quantity surveyors constituted 24.06% of the participants, architects constituted 22.99%, and builders constituted 19.79%. Their years of experience showed that the majority (39.04%) of survey participants have about 11-15years of experience, and this is closely followed by those with 5-10 years of experience (25.13%), then 16-20years of experience (20.86%) and 14.97% have 21years and above experience. The academic/educational qualification revealed that a larger proportion (41.71%) of the respondents have bachelor's degrees, 37.97% hold master's degrees, those with higher national diplomas constitute 11.23% of the participants, and 9.09% hold a Doctorate.

The background information of the respondents revealed that they possess the requisite educational qualifications and professional experiences to provide reliable responses to meet the study purpose.

5.2 RII techniques of Drivers of DTs-driven CE transition in construction

The ranking of the assessed variables and the respondents' agreement evaluation are contained in (appendix Table S1). The results show that the top 10 drivers of DTs-led CE implementation in construction are: Optimise product recycling (TED05) (RII =0.846), Conversion of waste to valuable energy (TED03) (RII =0.832), regulations and legislation on technology usage (GRD04) (RII =0.824), Law and regulations prohibiting poor waste handling (GRD03) (RII =0.822), availability of data and improved information exchange (TED02) (RII =0.820), predictive maintenance and improved product life (TED07) (RII =0.820), revolutionise the design of materials and components (TED04) (RII =0.818), government incentives (GRD01) (RII =0.814), enhance resource management and efficiency (END01) (RII =0.812) and Operational efficiency (OGD02) (RII =0.812).

Overall, irrespective of the relative ranking of the variables, they are significant drivers of the digitalisation of CE transition in the construction industry. This is based on the number of drivers with RII values within 0.60-0.80 (high importance) = 21 drivers and 19 of the assessed variables have RII values within the range of 0.80 -1.00 (very high importance).

The Kruskal Wallis H test showed that 4(10%) of the 40 assessed drivers have a p-value of less than 0.05, indicating that the participants' view differs significantly on these variables. The divergence of opinions occurred in the Conversion of waste to valuable energy (TED03)(p-value=0.002), Quality Management (TED09) (p-value=0.001), Products remanufacturing and reverse logic (TED10) (p-value =0.034), and Materials exchange objectives (EBD07) (p-value=0.002). This divergence in the perception of these variables could be attributed to the uneven digital uptake and sustainability practices in the organisations of the sampled experts, as well as the knowledge and awareness of the roles of DTs in CE transition efforts.

5.3 PLS-SEM of drivers of DTs-enabled CE transition in construction

5.3.1 Measurement model

The measurement model was assessed by examining the internal reliability and convergent and discriminant validities (Hair et al., 2006). The construct reliability was confirmed using various criteria like Cronbach's alpha (α), Dijkstra-Henseler's rho (*p*A), composite reliability (CR) and Average Variance Extracted (AVE). The established cut-off for these measures from previous studies is α=0.7, *p*A=0.7, CR=0.7, and AVE=0.5 (Hair et al., 2019; Hulland, 1999). While items with an outer loading of 0.7 or more are generally acceptable, for exploratory study, items with outer loadings of 0.5 or 0.4 and above can be considered reliable, as submitted by (Hulland, 1999). The measurement model test was run and iterated until the construct reliability and convergent validity were satisfied, as indicated in Table 2. (See also Appendix Figures S1 and S2), for the initial and final measurement model assessment.

Multicollinearity was examined using the variance inflation factor (VIF). The Multicollinearity measure the presence or otherwise of common method bias (CMB) in the gathered data.

Column 10 of Table 4 shows that all the constructs as well as the measured items, have VIF lower than the 3.3 recommended threshold (Kock, 2015). This confirms the absence of CMB in the data. With no measurement validity concerns, the structural model was assessed.

Multiple methods were employed to assess the discriminant validity of SEM. This study utilised the Fornell-Larcker criterion and heterotrait-monotrait (HTMT) criterion (Fornell & Larcker, 1981; Hair et al.,2017). Literature shows that HTMT is the most recent and preferred method of measuring the discriminant validity of structural models (Hair et al., 2019). The HTMT assumes that for a clear separation between two factors (constructs) to exist in SEM, a value of at most 0.85 should be obtained (Henseler et al., 2016). The results in Table 2 also confirmed the discriminant validity of HTMT. Also, the Fornell-Larcker criterion for discriminant validity was satisfied. The Fornell-Larcker criterion holds that the square root of the AVEs for all the construction should be greater than their resultant correlation coefficient (Fornell & Larcker, 1981); see bolded diagonal values.

Table 2: Convergent validity and Discriminant validity Test

Convergent validity result									
Constructs	Initial Loading				Final Loading				VIF
	α	***ρA***	**CR**	**AVE**	**α**	***ρA***	**CR**	**AVE**	
Social & cultural Drivers	0.740	0.772	0.838	0.568	0.740	0.772	0.838	0.568	2.126
Economic & Business Drivers	0.870	0.875	0.896	0.490	0.866	0.870	0.894	0.513	1.195
Environmental Drivers	0.802	0.833	0.865	0.570	0.833	0.834	0.889	0.668	1.686
Government & Institutional Drivers	0.780	0.789	0.859	0.604	0.780	0.790	0.859	0.604	2.164
Organisational Drivers	0.844	0.848	0.885	0.564	0.844	0.848	0.885	0.564	1.863
Technological Drivers	0.729	0.777	0.797	0.270	0.766	0.770	0.840	0.514	1.186
Discriminant validity results									
	Culture & Social Drivers	Economic & Business Drivers	Environmental Drivers	Government & Institutional Drivers	Organisational Drivers	Technological Drivers			
Heterotrait-Monotrait ratio (HTMT) Matrix									
Social & cultural Drivers									
Economic & Business Drivers	0.222								
Environmental Drivers	0.697	0.354							
Government & Institutional Drivers	0.77	0.122	0.249						
Organisational Drivers	0.536	0.208	0.385	0.753					
Technological Drivers	0.337	0.192	0.177	0.355	0.427				
Fornell-Larcker Criterion									
Social & Cultural Drivers	**0.754**								
Economic & Business Drivers	0.132	**0.717**							
Environmental Drivers	0.562	0.323	**0.817**						
Government & Institutional Drivers	0.562	-0.051	0.205	**0.777**					
Organisational Drivers	0.429	0.181	0.327	0.612	**0.751**				
Technological Drivers	0.272	0.147	0.147	0.288	0.357	**0.717**			

5.3.2 Path analysis (Bootstrapping) & Model validation (CVPAT) analysis

The bootstrapping approach was used to establish the structural relationship that exists between the constructs and the implementation of DTs in the CE transition. It is the most accepted technique for establishing the strength and significance of the path coefficient in SEM (Kline, 2023). Bootstrapping was carried out with 5000 subsamples as advocated by (Wong, 2013), and the results show the standardised path coefficient (β), t-statistics, confidence intervals and p-values (Table 7). The results in Table 3 reveal that all the hypotheses were supported, as the t-value, p-value and CI all met the criteria for significance. This implies that the factors are significant drivers of Technology-led CE in construction. While the six factors are significant drivers of DTs-driven CE in Nigeria's construction industry, Organisational Drivers have the strongest influence (36.7%). This is closely followed by the Economic and Business Drivers (30.8%) and Environmental Drivers (23%), then Culture and social Drivers (22.5%), Technological Drivers(21%) and lastly, the Government and institutional Drivers (19.7%).

The model was validated using the cross-validated predictive ability test (CVPAT) analysis. The CVPAT is the most recent approach to theoretically verify models (Sharma et al., 2023). This technique was developed by (Liengaard et al., 2021), and it is utilised to determine if the proposed model can outperform a naïve baseline, which is a core predictive validity component of the models (Shmueli, *et al.*, 2016). The predictive validity of the models is ascertained when the average loss is significantly below naïve indicator averages used as a benchmark. If this condition fails, the models should be abandoned (Shmueli *et al.*, 2016). Evidently, the model has a strong predictive validity (Table 3). In addition, the hypothesised model showed an acceptable level of approximate model fit, and this is based on the value of the standardized root means square residual (SRMR), which is 0.16. The acceptable threshold for the model fit criteria is 1.0 or less (Bagozzi and Yi, 2012; Henseler et al., 2014).

Table 3: Path analysis (Bootstrapping) results & CVPAT Analysis

Path analysis (Bootstrapping) results								
Hypothetical path	**β**	**M**	**SD**	**T**	**LCI 2.5%**	**UCI 97.5%**	**P values**	**Remark**
H1: Technological Drivers -> Implementation of DTs in CE Transition	0.21	0.203	0.047	4.48	0.106	0.29	0.000*	Supported
H2: Economic & Business Drivers -> Implementation of DTs in CE Transition	0.308	0.295	0.118	2.598	0.06	0.519	0.009*	Supported
H3: Environmental Drivers -> Implementation of DTs in CE Transition	0.23	0.224	0.044	5.199	0.121	0.299	0.000*	Supported
H4: Social & culture Drivers -> Implementation of DTs in CE Transition	0.225	0.218	0.027	8.325	0.166	0.272	0.000*	Supported
H5: Government & Institutional Drivers -> Implementation of DTs in CE Transition	0.197	0.193	0.049	4.065	0.085	0.277	0.000*	Supported
H6: Organisational Drivers -> Implementation of DTs in CE Transition	0.367	0.356	0.05	7.395	0.254	0.446	0.000*	Supported
CVPAT LV summary								
	PLS loss	**IA loss**	**ALD**	**t value**	**p-value**			
Implementation of DTs in CE Transition	0.818	0.976	-0.158	7.047	0.000			
Overall	0.818	0.976	-0.158	7.047	0.000			

β=Original sample; M=Sample mean; SD= standard deviation; T= t- statistics; LCI= Lower confidence interval; UCI= Upper confidence interval; *p-value = significant; ALD=average loss difference

5.3 Discussion

The RII technique revealed that the assessed factors are important and significant driving forces of digital technologies-enabled CE adoption in construction, and the leading drivers are: Optimise product recycling, Conversion of waste to valuable energy, regulations and legislation on technology usage, Laws and regulations prohibiting poor waste handling, availability of data and improved information exchange, predictive maintenance and improved product life, revolutionise the design of materials and components, government incentives, enhance resource management and efficiency and Operational efficiency. These findings are supported by literature (Traunt et al., 2024; Singh, 2024; Wuni, 2023; Chauhan et al., 2022; Kazancoglu et al., 2021). In addition, the Kruskal Wallis test further showed that the participants (construction professionals in Nigeria) acknowledged the importance of the variables as their views converged on 90% of the assessed variables.

Technological drivers are at the core of bolstering CE transition in construction; this is echoed in the construction experts' responses, which showed these factors positively and significantly influence the implementation of DTs in CE practice in the industry. Thus, hypothesis (H1) is supported. Technologies adoption improves supply chain visibility and the integration of circularity activities (Kazancoglu et al., 2021). The need to improve quality management in CE and optimise the recycling of materials and products is essential for driving technology-led CE in construction (Traunt et al., 2024). Technological integration manufacturing of construction materials and components is faster, and this makes on-demand production possible to reduce waste and warehousing costs due to over-production (Singh, 2024). Machine learning algorithms permit predictive maintenance which improves the product upkeep and repair. This proactive maintenance approach can help elongate materials and product life, thus reducing waste and improving circularity (Jahangir et al., 2024).

The study revealed that economic and business forces play a significant and positive role in the digitalisation of CE by construction-based organisations. CE practice in construction is still a growing area and therefore presents genuine business development opportunities. Investment in technologies to drive CE can lead to new business formation, revenue improvement and expansion of construction businesses (Wuni, 2023). The economic and business motive for DTs-led CE in construction can emanate from the need to expand the market share and competitiveness of construction organisations and minimise production and operation costs in CE transition activities (Traunt et al., 2024). Servitisation improves customer experiences through value addition and satisfaction, which helps businesses reduce time losses and improve savings and revenue drive (Bag & Pretorius, 2020). In addition, Technology-led CE is driven by the need to improve transparency and accountability in circular construction transactions, enhance objectivity in materials exchange, and boost clients/customer powers and inputs in circular business decisions (Singh, 2024).

Environmental protection and sustainability can be achieved through a conscious strategy focused on the reduction of waste generation and waste build-up in landfills. Therefore, environmental sustainability attainment is one of the important forces behind Technology adoption in CE in construction. Technology aids the recovery of products from buildings during demolition or deconstruction (Rejeb et al., 2022) and improves waste segregation and utilisation of fewer raw materials from nature (Wuni, et al., 2023). These enhance waste management effectiveness and prevention of environmental destruction. Social and cultural considerations are important considerations in technology-led CE practices for the sustainability of the construction industry in Nigeria, and this is well understood by the experts who participated in the survey as hypothesis (H4) was supported. The sustainability market in Nigeria is still unsaturated, thus, CE practices can create jobs for the locals, stimulate the growth of technology experts and contribute to community health and wellbeing (Giorgi et al., 2022; Wuni, 2023).

Government and Institutional drivers have a significant and positive influence on the implementation of technology in CE, which impacts the sustainability of the built environment. Governments and their agencies must make implementable laws and regulations, and support and incentive systems that will favour a technology-led CE in the construction industry (Traunt et al., 2024). Such regulations and legislation must prescribe how secondary building materials should be handled and how waste should not be handled (Wuni, 2023). The significance of Government and institutional forces in the digitalisation of CE transition in construction is evident in the supported (H5) observed in this study. Organisational Drivers have a significant and positive influence on the implementation of technology in CE, and this is supported by literature (Kazancoglu et al., 2021; Chauhan et al., 2022). The leadership and management of construction businesses are at the centre of driving innovative techniques and methodologies through digitalisation. Therefore, their support or its absence could make or mar CE transition efforts of the construction industry (Nguyen, 2023).

6. Implications of the study

This study holds significant implications that encompass practical, managerial and theoretical aspects, which present an advantageous guide for stakeholders in the construction business in Nigeria and, by extension, other developing countries with similar construction market development. From a practical aspect, the study highlights the strong impact of digitalisation on the circular business production model transition in the Nigerian construction industry (NCI). It indicates that Nigerian construction stakeholders need to place emphasis on diverse factors to drive sustainable technology-led CE practices in the sector. While organisational, 'economic and business drivers showed a stronger influence on the digitalisation of CE, the environmental, cultural and social drivers as well as technological, 'Government and institutional drivers, have a substantial influence on the adoption of DTs in CE transitions. Stakeholders in the NCI would leverage this report to put these drivers in place to ensure a smooth DT-driven CE transition implementation for sustainability.

The managerial implication has to do with the influence this study could have on professionals and policymakers. These stakeholders could use this report as input in the decision-making process towards the choice of DTs to adopt and the choice of project delivery approach and materials to integrate into buildings and other infrastructures production in Nigeria and, by extension, other developing nations with similar production characteristics. Decisions that impact the tripods of sustainability (i.e., environment, society and economy) are dependent on policymakers in the sector.

From the theoretical perspective, this research makes a significant impact and contribution to knowledge and understanding of the technology-led drivers of CE implementation in Nigeria. In addition to filling a critical literature gap, it also serves as a fundamental foundation for future research in the domain and the long-term implications for the sustainability of the built environment via the integration of DTs and CE practices for the economy, environment, and societies.

7. Conclusions and recommendations

This study, via a quantitative approach, examined the potential drivers of digitalisation of CE transition in construction, with a focus on Nigeria. The study utilised the PLS-SEM to analyse data gathered from construction professionals, which led to some critical findings upon which a conclusion was drawn. Based on SEM, the key drivers influencing the adoption and implementation of digital technologies in CE transition are organisational drivers, economic and business drivers, environmental drivers, cultural and social drivers, technological drivers, and government and institutional drivers. These findings reinforced the criticality of these factors in the actualisation of the digitalisation of CE practices in the Nigerian construction industry. This is evident in the survey participants' perceptions, which converged on 90% of the assessed factors, and the positive and significant statistical relationships of the key factors on the implementation of DTs-led CE practices in the country. Also, a high level of agreement was observed in the participant's rating of the factors, which means that intervention and strategies to boost DT integration in CE practices could have universal acceptance and applicability by the diverse professional groups in the sector, and this could make the implementation process smooth.

This study contributes to knowledge and ongoing discussion on sustainability driven by technology innovation adoption and other innovative methodologies and techniques, like the CE concepts, in the construction industry. It also supports the discourse on driving CE practices and sustainability with digital technologies, which have been adjudged to transform and distort the traditional linear way of production in different economic sectors. Finally, as clearly stated in previous sections, this study has implications for practitioners and decision-makers, managers in the industry and for theory to aid research and knowledge expansion in academia.

While this study made significant contributions to knowledge and practices, the generalisation of the findings is limited by the geographical boundary, sample size and use of questionnaire. Future studies build upon the findings reported herein by leveraging the qualitative approach and expanding the sample size and boundaries in a mixed research approach to gain a deeper comprehension of the drivers influencing the digitalisation of CE transition in construction. Future studies could also ascertain the significance of the drivers in bringing accelerated impact on the transition to technology-led CE in the construction industry. Future studies can also expand on the findings reported herein by assessing the correlation between the main drivers. The fuzzy set logic can also be used to precisely confirm what has been reported in this study. The findings in this study can also serve as the foundation for future studies to establish determinants of the adoption of specific modern technology in driving the CE transition of the construction industry in Nigeria or other developing countries of the world could be examined. These will provide data for comparison.

References

Aboginije, A., Aigbavboa, C. & Thwala, W. (2021). A holistic assessment of construction and demolition waste management in the Nigerian construction projects. Sustainability, 13(11), p. 6241.

Adabre, M. A., Chan, A. P. C., Darko, A., & Hosseini, M. R. (2022). Facilitating a transition to a circular economy in construction projects: intermediate theoretical models based on the theory of planned behaviour. *Building Research & Information*, *51*(1), 85–104.

Akhtar, A., & Sarmah, A. K. (2018). Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. Journal of Cleaner Production, 186, 262–281. https://doi.org/10.1016/j. jclepro.2018.03.085

Akkad, M.Z. & Bányai, T. (2021). Applying Sustainable Logistics in Industry 4.0 Era. In: Jármai, K., Voith, K. (eds) Vehicle and Automotive Engineering 3. VAE 2020. Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-15-9529-5_19

Aliu, J. & Oke, A.E. (2023).Construction in the digital age: exploring the benefits of digital technologies", Built Environment Project and Asset Management, 13(3), 412-429, doi:10.1108/BEPAM-11-2022-0186.

Aliu, J., Oke, A.E. & Ehiosun, L.U. (2024). Distributed ledger technology integration in Nigerian construction industry: key drivers. International Journal of Building Pathology and Adaptation, https://doi.org/10.1108/IJBPA-02-2024-0044

Annata (2022).Leveraging technology towards a circular economy. available at: https://annata.net/leveraging-technology-towards-a-circular-economy/ [accessed 10 June 2023].

Arowoiya, V.A., Oke, A.E., Ojo, L.D., and Adelusi, A.O. (2023). Driving Factors for the Adoption of Digital Twin Technology Implementation for ConstructionProject Performance in Nigeria. Journal of Construction Engineering and Management, 150(1), 1-12. https://doi.org/10.1061/JCEMD4.COENG-13659

Bag, S. & Pretorius, J.H.C. (2020). Relationships between industry 4.0, sustainable manufacturing and circular economy: proposal of a research framework. International Journal of Organizational Analysis,30(4),864-898. doi: 10.1108/IJOA-04-2020-2120.

Bagozzi, R.P., and Yi, Y. (2012.) Specification evaluation, and interpretation of structural equation models. Journal of Academy of Marketing Science, 40, 8–34.

Bamel, N. & Bamel, U. (2020). Big data analytics based enablers of supply chain capabilities and firm competitiveness: a fuzzy-TISM approach. Journal of Enterprise Information Management, *Journal of Enterprise Information Management*, 34(1), 559-577. https://doi.org/10.1108/JEIM-02-2020-0080

Bello, A.O., Isa, R.B., Afolabi, O.P., Arogundade, S. & Khan, A.A. (2023). Drivers for the implementation of circular economy in the Nigerian AECO industry: a structural equation modelling approach. Journal of Engineering, Design and Technology, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/JEDT-09-2023-0434

Bilal, M., Khan, K. I. A., Thaheem, M. J., & Nasir, A. R. (2020). Current state and barriers to the circular economy in the building sector: Towards a mitigation framework. Journal of Cleaner Production, 276, 123250. https://doi.org/10. 1016/j.jclepro.2020.123250

Boz, Z., Korhonen, V., and Sand, C.K. (2020). Consumer Considerations for the Implementation of Sustainable Packaging: A Review. Sustainability, 12(6), 1-34. https://doi.org/10.3390/su12062192

Brandãoz, R., Edwards, D.J., Hosseini, M.R., Silva Melo, A.C. & Macêdo, A.N. (2021). Reverse supply chain conceptual model for construction and demolition waste. Waste Management & Research, 39(11):1341-1355.

Čábelková, I., Strielkowski, W., Streimikiene, D., Cavallaro, F., & Streimikis, J. (2021). The social acceptance of nuclear fusion for decision making towards carbon free circular economy: evidence from Czech Republic. Technological Forecasting and Social Change, 163,120477. Doi:10.1016/j. techfore.2020.120477.

Chaffey, D. (2014). Digital business and e-commerce management: strategy, implementation and practice. Pearson Education.

Chauhan, C., Parida, V., & Dhir, A (2022). Linking circular economy and digitalisation technologies: A systematic literature review of past achievements and future promises. Technological Forecasting & Social Change, 177, 1-18. https://doi.org/10.1016/j.techfore.2022.121508

Chi, Z., Liu, Z., Wang, F., and Osmani, M. (2023). Driving Circular Economy through Digital Technologies: Current Research Status and Future Directions. Sustainability, 15(24), 1-28. https://doi.org/10.3390/su152416608

Del Giudice, M., Chierici, R., Mazzucchelli, A., & Fiano, F. (2020). Supply chain management in the era of circular economy: the moderating effect of big data. *The International Journal of Logistics Management*, 32(2), 337-356. https://doi.org/10.1108/IJLM-03-2020-0119

Dey, P.K., Malesios, C., Chowdhury, S., Saha, K., Budhwar, P. and De, D. (2022). Adoption of circular economy practices in small and medium-sized enterprises: Evidence from Europe. International Journal of Production Economics, 248,1-19. https://doi.org/10.1016/j.ijpe.2022.108496

Ebekozien, A. & Aigbavboa, C. (2021). COVID-19 recovery for the Nigerian construction sites: the role of the fourth industrial revolution technologies. Sustainable Cities and Society, 69, 102803; https://doi.org/10.1016/j.scs.2021.102803

Elghaish, F., Hosseini, M.R., Kocaturk, T., Arashpour, M. & Ledari, M.B. (2023). Digitalised circular construction supply chain: an integrated BIM-Blockchain solution. Automation in Construction, 148, 104746, doi: 10.1016/j.autcon.2023.104746.

Ellen MacArthur Foundation (2014). Towards the Circular Economy: Accelerating the Scale-Up across Global Supply Chains, MacArthur Foundation, Geneva.

Etikan, I., Musa, S.A. & Alkassim, R.S. (2016). Comparison of convenience sampling and purposive sampling. American Journal of Theoretical and Applied Statistics, 5(1),1-4

Eze, E.C., Aghimien, D.O., Aigbavboa, C.O. and Sofolahan, O. (2024b). Building information modelling adoption for construction waste reduction in the construction industry of a developing country. Engineering, Construction and Architectural Management, 31(6), 2205-2223. doi: 10.1108/ECAM-03-2022-0241.

Eze, E.C., Sofolahan, O., Ugulu, R.A. & Ameyaw, E.E. (2024a). Bolstering circular economy in construction through digitalisation. Construction Innovation, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/CI-10-2023-0245

Ferenhof, H.A., Bonamigo, A., Da Cunha, A., Tezza, R. & Forcellini, F.A. (2019). Relationship between barriers and key factors of dairy production in Santa Catarina, Brazil. British Food Journal, 121(2), 304-319

Fornell, C. & Larcker, D.F. (1981). Evaluating structural equation models with unobservable variables and measurement error", Journal of Marketing Research, 18(1), 39-50, doi:10.2307/3151312.

Ghasem, A. & Zahediasl, S. (2012). Normality test for statistical analysis: A guide for non-statisticians. International Journal Endocrinol Metab., 10(2), 486-489

Giorgi, S., Lavagna, M., Wang, K., Osmani, M., Liu, G. & Campioli, A (2022).Drivers and barriers towards circular economy in the building sector: Stakeholder interviews and analysis of five European countries policies and practices. Journal of Cleaner Production, 336,1-16.

Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. & Tatham, R.L. (2006). Multivariate Data Analysis, 7th-ed., Sage publications, London, Vol. 6.

Hair, J.F., Hult, G.T., Ringle, C. & Sarstedt, M. (2017). A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM), Sage

Hair, J.F., Risher, J.J., Sarstedt, M. & Ringle, C.M. (2019). When to use and how to report the results of PLS-SEM. European Business Review, 31(1), 2-24. https://doi.org/10.1108/EBR-11-2018-0203

Han, Y., Shevchenko, T., Yannou, B., Ranjbari, M., Shams Esfandabadi, Z.; Saidani, M.; Bouillass, G.; Bliumska-Danko, K.; Li, G. (2023). Exploring How Digital Technologies Enable a Circular Economy of Products. Sustainability, 15(3), 2067. https://doi.org/10.3390/su15032067

Hariyani, D., Hariyani, P., Mishra, S. & Sharma, M.K. (2024). Leveraging digital technologies for advancing circular economy practices and enhancing life cycle analysis: A systematic literature review. Waste Management Bulletin, 2(3), 69–83

Hazarika, N., and Zhang, X. (2019). Factors that drive and sustain eco-innovation in the construction industry: The case of Hong Kong." Journal of Cleaner Production, 238 (11): 117816. https://doi.org/10.1016/j.jclepro.2019.117816.

Henseler, J., Dijkstra, T. K., Sarstedt, M., Ringle, C. M., Diamantopoulos, A., Straub, D. W., Ketchen, D. J., Hair, J. F., Hult, G. T. M., & Calantone, R. J. (2014). Common Beliefs and Reality About PLS: Comments on Rönkkö and Evermann (2013). Organizational Research Methods, 17(2), 182-209.

Henseler, J., Hubona, G. & Ray, P.A. (2016). Using PLS path modeling in new technology research: updated guidelines. *Industrial Management & Data Systems*, 116(1), 2-20.

Hulland, J. (1999). Use of partial least squares (PLS) in strategic management research: A review of four recent studies. Strategic Management Journal, 20(2), 195-204.

Hussain, M., Khan, M. & Al-Aomar, R. (2016). A framework for supply chain sustainability in service industry with Confirmatory Factor Analysis. Renewable and Sustainable Energy Reviews, 55,1301-1312, doi: 10.1016/j.rser.2015.07.097

Jahangir,M.F., Schultz, C.P.L. & Kamari, A. (2024). A review of drivers and barriers of Digital Twin adoption in building project development processes. Journal of Information Technology in Construction (ITcon), 29, 141-178, DOI:10.36680/j.itcon.2024.008

Kamble, S., Gunasekaran, A. & Gawankar, S. (2020). Achieving sustainable performance in a datadriven agriculture supply chain: a review for research and applications. International Journal of Production Economics, 219, 179-194.

Kline, R.B. (2023). Principles and Practice of Structural Equation Modeling, Guilford publications, New York, NY.

Kock, N. (2015). Common method bias in PLS-SEM: a full collinearity assessment approach. International Journal of e-Collaboration, 11(4), pp. 1-10

Liengaard, B.D., Sharma, P.N., Hult, G.T.M., Jensen, M.B., Sarstedt, M., Hair, J.F. & Ringle, C.M. (2021). Prediction: coveted, yet forsaken? Introducing a cross-validated predictive ability test in partial least squares path modelling. Decision Sciences, 52(2), 362-392.

Liu, Z., Liu, J., & Osmani, M. (2021). Integration of Digital Economy and Circular Economy: Current Status and Future Directions. Sustainability, *13*(13), 7217; https://doi.org/10.3390/su13137217

Lu,H., Zhao, G., & Liu, S. (2022). Integrating circular economy and Industry 4.0 for sustainable supply chain management: a dynamic capability view, Production Planning & Control, 35(2), 170–186. https://doi.org/10.1080/09537287.2022.2063198

Mboli, J.S., Thakker, D.K., & Mishra, J.L., (2020). An Internet of Things-enabled decision support system for circular economy business model. Software: Practice and Experience, 52(3), 772-787.

Moser, C.A., & Kalton, G. (1999). Survey Methods in Social Investigation, second ed., Gower Publishing Company, Aldershot, 1999.

Nguyen, M.V. (2023). Drivers of innovation towards sustainable construction: A study in a developing country. Journal of Building Engineering, 80, 1-18.

Ojo, L.D., Oladinrin, O.T. & Obi, L. (2021). Critical barriers to environmental management system implementation in the Nigerian construction industry. Environmental Management, 68(2),147-159.

Oke, A.E., Aliu, J., Fadamiro, P., Jamir Singh, P.S., Samsurijan, M.S. & Yahaya, M. (2024). Robotics and automation for sustainable construction: microscoping the barriers to implementation. Smart and Sustainable Built Environment, 13(3),625-643. https://doi.org/10.1108/SASBE-12-2022-0275

Okereke, R.A., Pepple, D.I., and Eze, E.C. (2022). Design and Pre-Contract Delay and Its Impact on Construction Project Delivery in Nigeria. Construction and Human Settlements Management Journal,2(1),1-20.

Pasqualotto, C., Callegaro-De-Menezes, D., and Schutte, C.S.L. (2023). An Overview and Categorization of the Drivers and Barriers to the Adoption of the Circular Economy: A Systematic Literature Review. Sustainability 2023, 15(13), 1-24. https://doi.org/10.3390/su151310532

Patil, A., Dwivedi, A., Moktadir, M.A. & Lakshay (2023). Big data-Industry 4.0 readiness factors for sustainable supply chain management: Towards circularity. Computers & Industrial Engineering, 178, 1-10.

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, 725-735.

Pomponi, F. & Moncaster, A. (2017). Circular economy for the built environment: a research Framework. Journal of Cleaner Production, Vol. 143, pp. 710-718.

Rejeb, A., Suhaiza, Z., Rejeb, K., Seuring, S. & Treiblmaier, H. (2022). The Internet of Things and the circular economy: a systematic literature review and research agenda. Journal of Cleaner Production, 350, 131439, doi: 10.1016/j.jclepro.2022.131439

Rodrigo, N., Omrany, H., Chang, R. & Zuo, J. (2024). Leveraging digital technologies for circular economy in construction industry: a way forward. Smart and Sustainable Built Environment, 13(1), 85-116. https://doi.org/10.1108/SASBE-05-2023-0111

Rodríguez-Espíndola, O., Cuevas-Romo,A., Chowdhury, S., Díaz-Acevedo, N., Albores, P., Despoudi, S., Malesios, C. and Dey, P. (2022). The role of circular economy principles and sustainable-oriented innovation to enhance social, economic and environmental performance: Evidence from Mexican SMEs. International Journal of Production Economics, 248,1-18.

Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara,B., and Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. Environmental Technology & Innovation, 33,1-23.

Sánchez-García, E., Martínez-Falcó, J., Marco-Lajara, B., and Manresa-Marhuenda, E. (2024). Revolutionizing the circular economy through new technologies: A new era of sustainable progress. Environmental Technology & Innovation,33,1-23.

Schlüter, M., Lickert, H., Schweitzer, K., Bilge, P., Briese, C., Dietrich, F., & Krüger, J. (2021). AI-enhanced identification, inspection and sorting for reverse logistics in remanufacturing. Procedia CIRP, 98(2021),300-305.Doi: 10.1016/j.procir.2021.01.107.

Setaki, F. & van Timmeren, A. (2022). Disruptive technologies for a circular building industry. Building and Environment, 223, 109394, doi: 10.1016/j.buildenv.2022.109394.

Sharma, P.N., Liengaard, B.D., Hair, J.F., Sarstedt, M. & Ringle, C.M. (2023). Predictive model assessment and selection in composite-based modeling using PLS-SEM: extensions and guidelines for using CVPAT", European Journal of Marketing, 57(6), 1662-1677. https://doi.org/10.1108/EJM-08-2020-0636

Shmueli, G., Ray, S., Estrada, J.M.V. & Chatla, S.B. (2016). The elephant in the room: Predictive performance of PLS models. Journal of Business Research, 69(10), 4552-64. https://doi.org/10.1016/j.jbusres.2016.03.049

Shooshtarian, S., Hosseini, M.R., Kocaturk, T., Arnel, T. & Garofano, N.T. (2022). Circular economy in the Australian AEC industry: investigation of barriers and enablers. Building Research & Information, 51(1), 56-68.

Singh, R. (2024). Role of Technology in Circular Economy. Available at: https://www.finextra.com/blogposting/25642/role-of-technology-in-circular-economy [April 8, 2024]

Smitha, J.S. & Thomas, A. (2021). Integrated model and index for circular economy in the built environment in the Indian context. Construction Economics and Building, 21(3), 198-220

Tetteh, P.A., Addy, M.N., Acheampong, A., Akomea-Frimpong, I., Ayidana, E. and Ghansah, F.A. (2024), "Critical drivers for the adoption of wearable sensing technologies (WSTs) for construction safety monitoring in Ghana: a fuzzy synthetic analysis", Construction Innovation. https://doi.org/10.1108/CI-04-2023-0071

Tiwari, G., Kumar, R.R., Raj, A., and Foropon , C.R.H. (2024). Antecedents and consequents of circular economy adoption: A meta-Analytic Investigation. Journal of Environmental Management, 367,1-13.

Truant, E., Giordino, D., Borlatto, E. & Bhatia, M. (2024). Drivers and barriers of smart technologies for circular economy: Leveraging smart circular economy implementation to nurture companies' performance. Technological Forecasting & Social Change, 198, 1-16.

Valencia, M., Bocken, N., Loaiza, C. and Jaeger, S. D. (2023). The social contribution of the circular economy. Journal of Cleaner Production, 408,1-15.

Vimal, K.E. K., Sivakumar, K., Kandasamy, J., Venkat, V., & Mani, R. S. (2023). Barriers to the adoption of digital technologies in a functional circular economy network. Operations Management Research,16, 1541-1561.

Wang,X.Q., Chen,P., Chow,C.L., and Lau, D. (2023). Artificial-intelligence-led revolution of construction materials: From molecules to Industry 4.0. Matter,6(6), 1831-1859.

Wilson, M., Paschen, J., & Pitt, L., (2021). The circular economy meets artificial intelligence (AI): understanding the opportunities of AI for reverse logistics. *Management of Environmental Quality*, 33(1), 9-25.

Wong, K.K. (2013). Partial least squares structural equation modeling (PLS-SEM) techniques using SmartPLS. Marketing Bulletin, vol 24. Technical Note 1. pp 1–32

Wuni, I.Y. (2023). Drivers of circular economy adoption in the construction industry: a systematic review and conceptual model. Building Research & Information, 51(7), 816-833. DOI: 10.1080/09613218.2023.2211689

Yuan, S. and Pan, X. (2023). The effects of digital technology application and supply chain management on corporate circular economy: A dynamic capability view. Journal of Environmental Management, 341,1-13.

Zhou, Z., Su, Y., Zheng, Z. and Wang, Y. (2023). Analysis of the Drivers of Highway Construction Companies Adopting Smart Construction Technology. Sustainability 2023, 15(1), 1-20.