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GREEN TECHNOLOGY AND DIGITAL TRANSFORMATION AS STRATEGIC DRIVERS OF GREEN ECONOMY TRANSITION IN THE CONSTRUCTION INDUSTRY: ENVIRONMENTAL, ECONOMIC, MANAGERIAL AND BUSINESS IMPLICATIONS.

ABSTRACT

Inefficient utilization of resources, high operational costs, high dependence on human labour, low productivity and profitability, unabated delays and reworks, high carbon emissions and huge waste generation with significant negative environmental impacts, have been the major criticisms levelled against the construction industry. Intense pressure has therefore risen for the construction industry to adopt transformative methods that integrate technological innovations and sustainability principles that would transit the industry towards the green economy model by improving resource efficiencies, productivity, profitability, and circularity, and as well reduce carbon footprints and environmental degradations that contribute to global warming. This study, employing Systematic Literature Review (SLR) as the research method, examines the Environmental, Economic, Managerial, and Business implications of the integration of Green Technology (GT) and Digital Transformation (DT) as strategic drivers of the construction industry's transition towards green economy model. Whereas the independent adoptions of both GT and DT in the construction industry as parallel technological trends have been widely studied, their potentials to create strategic value chain in the industry when jointly adopted have not been given appropriate attention by scholars. This study addresses this gap by scanning and synthesizing relevant knowledge and information across the globe, from Peer-reviewed Journals, Conference Proceedings, Authoritative Industry Reports etcetera, published between 2010 and 2025 to investigate how GT such as Energy-efficient materials, Renewable energy systems, Waste minimization & recycling technologies, and Low-carbon construction methods combine with DT tools such as Building Information Modelling (BIM), Digital Twins, 3D Printing, Internet of Things (IoT), and Blockchain to enhance environmental performance, economic and operational efficiency, and lifecycle management of construction projects. The findings reveal that the joint synergistic adoption of GT and DT in the construction industry significantly propel it towards green economy model and drastically reduces waste generation, environmental degradation and carbon emissions; optimizes resource utilization, improves project delivery, productivity and profitability; supports strategic decision-making and cost control mechanisms that are data driven; and enhances leadership capability, skills development, innovation capacity, resilience and competitiveness. Additionally, the study also identifies adequate policy frameworks, technological infrastructure, stakeholder collaboration, upskilling, quality leadership and the possession of requisite skills by the staff as key enablers for the green economy transition in the construction industry while high initial costs, poor stakeholders' buy-in, limited technical infrastructure and expertise are the barriers. The study concludes that the integration of GT and DT offers a robust pathway for achieving sustainability objectives and advancing the construction industry's transition towards a resilient and inclusive green economy model.

1.1 Background/ Introduction

The human developmental activities over the years have been unsustainable largely due to mindless pursuit of wealth without adequate consideration for human health and wellbeing of both the present and future generations, and in fact the entire ecosystems. As a result of such activities which have led to high carbon footprint, global warming, environmental degradation, resource depletion, poverty and other socio-economic problems, the quality of life is steeply deteriorating globally. In order to save humanity and our planet's ecosystems, there is need to embrace new innovations in science and technology and carryout human activities more sustainably by transiting towards green economy model. The construction industry is one of the sectors of the economy that contributes significantly to global economic growth, infrastructure development, and employment generation but has continued to adopt conventional unsustainable development model unlike the manufacturing industry that has largely embraced green and digital tools in its operations. And because construction industry's activities are characterized by high energy and material consumption, and high dependence on fossil fuels which invariably result in high operational costs, high carbon emissions, high solid waste generation, and environmental degradation, the industry has unarguably become a candidate for green economy transition due to its significant contributions to global economic growth. Digital transformation (DT) and Green technology (GT) are two interrelated strategic enablers whose joint adoption are capable of addressing the various challenges in the construction industry; thus this study focuses on the Environmental, Economic, Managerial and Business implications of their joint adoption as Strategic Drivers of Green Economy Transition in the Industry.

1.2 Statement of the problem

According to the United Nations Environment Programme (UNEP 2022) Global Status Report, the construction industry globally accounts for approximately 36% of energy consumption and 37% of energy-related carbon dioxide (CO_2) emissions, positioning it as a priority sector for green economy transition. Despite the awareness of the growing negative impacts of climate change, most activities in the construction industry have been driven largely by fossil fuel–based energy systems and intensive resource extraction, with most major players prioritizing economic growth and profit maximization above all other factors leading to severe environmental externalities, including rising greenhouse gas emissions, air and water pollution, land degradation, and climate-related disasters (IPCC, 2022).

1.3 Aim and Objectives

The main aim of this study is to examine how GT and DT jointly function as strategic drivers of green economy transition in the construction industry and their implications: environmental, economic, managerial, and business.

The Specific Objectives are to:

RO1 Identify basic GT and DT tools that can be jointly adopted in the construction industry to support green economy transition.

RO2 Evaluate the extent to which the joint adoptions of GT and DT in the construction industry improve environmental sustainability: reduce energy consumption, carbon emissions and waste generation.

RO3 Evaluate the economic implications of integrating GT and DT in construction projects, with respect to efficiency, productivity, and long-term economic sustainability.

RO4 Assess the managerial implications of integrating GT and DT in construction industry in the spheres of decision-making, organizational capability, and change management.

RO5 Evaluate the business implications of the joint adoption of GT and DT in the construction industry with respect to competitiveness, innovation capacity, and market performance.

1.4 Research Questions

In line with the above stated objectives, this study is guided by the following research questions:

RQ1 Which GT and DT tools are jointly adopted in the construction industry to support green economy transition?

RQ2 How does the joint adoption of GT and DT in the construction industry contribute to environmental sustainability?

RQ3 What are the economic implications of integrating GT and DT in construction projects for construction firms and other stakeholders?

RQ4 What skills, managerial capabilities and institutional frameworks are required to support the joint adoption of GT and DT in the construction industry?

RQ5 How does the joint adoption of GT and DT in the construction industry impact on construction firms' competitiveness, innovation, and market performance?

1.5 Significance of the Study

The traditional construction model is characterized by high labour intensity, high levels of risks, inefficiency, wastefulness, high carbon emissions, environmental degradation, low productivity, high level of mistrust among stakeholders, corruption, delays in meeting deadlines resulting in schedule and cost overruns, substandard infrastructural development due to poor coordination and collaboration among industry stakeholders, and comparatively poor returns on investment. There is therefore the need to embrace GT and DT which are key enablers that support the transition of the construction industry towards green economy. This study will transform construction industry's processes, systematically address its numerous problems, and consequently help to reduce carbon emissions and lower environmental pollution, improve energy efficiency, minimize waste, lower operational costs, improve overall efficiency, enhance productivity, improve project planning and workflows, drastically reduce corruption, improve trust and transparency, boost stakeholders collaboration, encourage innovation and enhance competitiveness,.

1.6 The Conceptual Framework

The construction industry's journey towards green economy started piecemeal and in silos. GT and DT adoption progressed as if they were mutually exclusive. This unintegrated approach brought incremental improvements in the industry; however the systemic transformation needed for a green economy transition could not materialize. It therefore becomes obvious that for a successful transition of the construction industry towards green economy, GT and DT must be seen to be mutually inclusive and interdependent and therefore jointly adopted alongside capacity development and structural changes in the industry. GT and DT are joint interdependent strategic drivers that synergistically revolutionize the construction industry and mutually accelerate it to the Green Economy Transition model as conceptualized in Figure 1.

The framework contends that neither GT nor DT can independently produce fully the desired green economy outcomes; rather, it is their integration and bidirectional synergistic relationship that generate multidimensional implications across environmental, economic, managerial, and business domains as shown in Figure 2. The Framework presents GT and DT as strategic enablers that synergistically and dramatically move the construction industry from a linear, wasteful process to a circular, intelligent ecosystem rather than mere isolated technological interventions.

The framework explains the architecture, mechanics, and outcomes of this interdependence as follow:

- ❖ Green technology innovations such as low-carbon and recycled materials, renewable energy systems and waste reduction technologies directly improve environmental performance.
- ❖ Digital transformation tools such as Building Information Modelling (BIM), Digital twins, Artificial Intelligence (AI), Internet of Things (IoT), Data analytics, Robotics and Blockchain enhance efficiency, transparency, and lifecycle optimization.
- ❖ The integration of both GT and DT tools create synergistic effects that accelerate and sustain green economy transition.
- ❖ The transition produces multidimensional environmental, economic, managerial, and business sustainable outcomes.

FIGURE 1: GT and DT are joint interdependent strategic drivers to the Green Economy Transition model

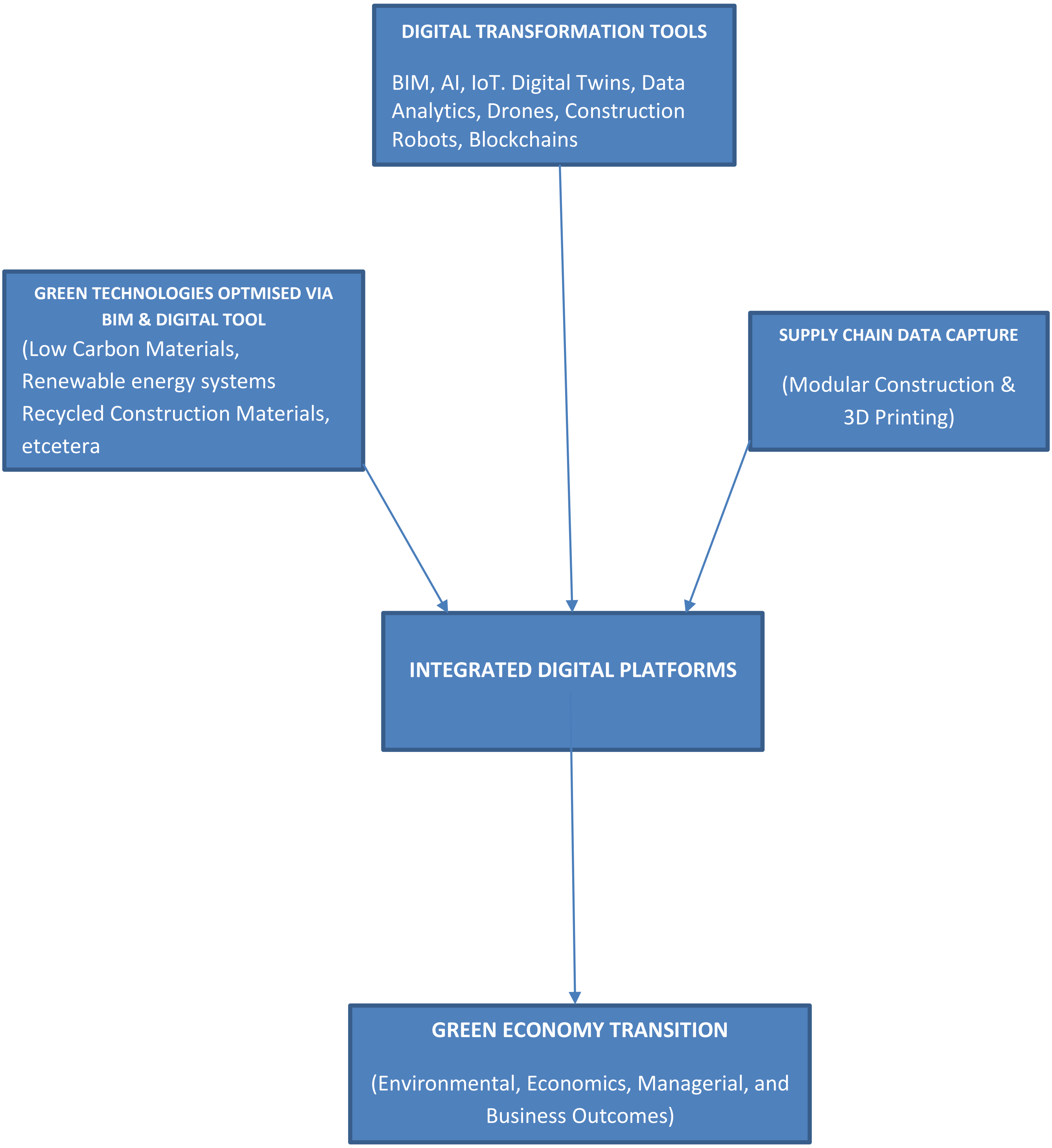
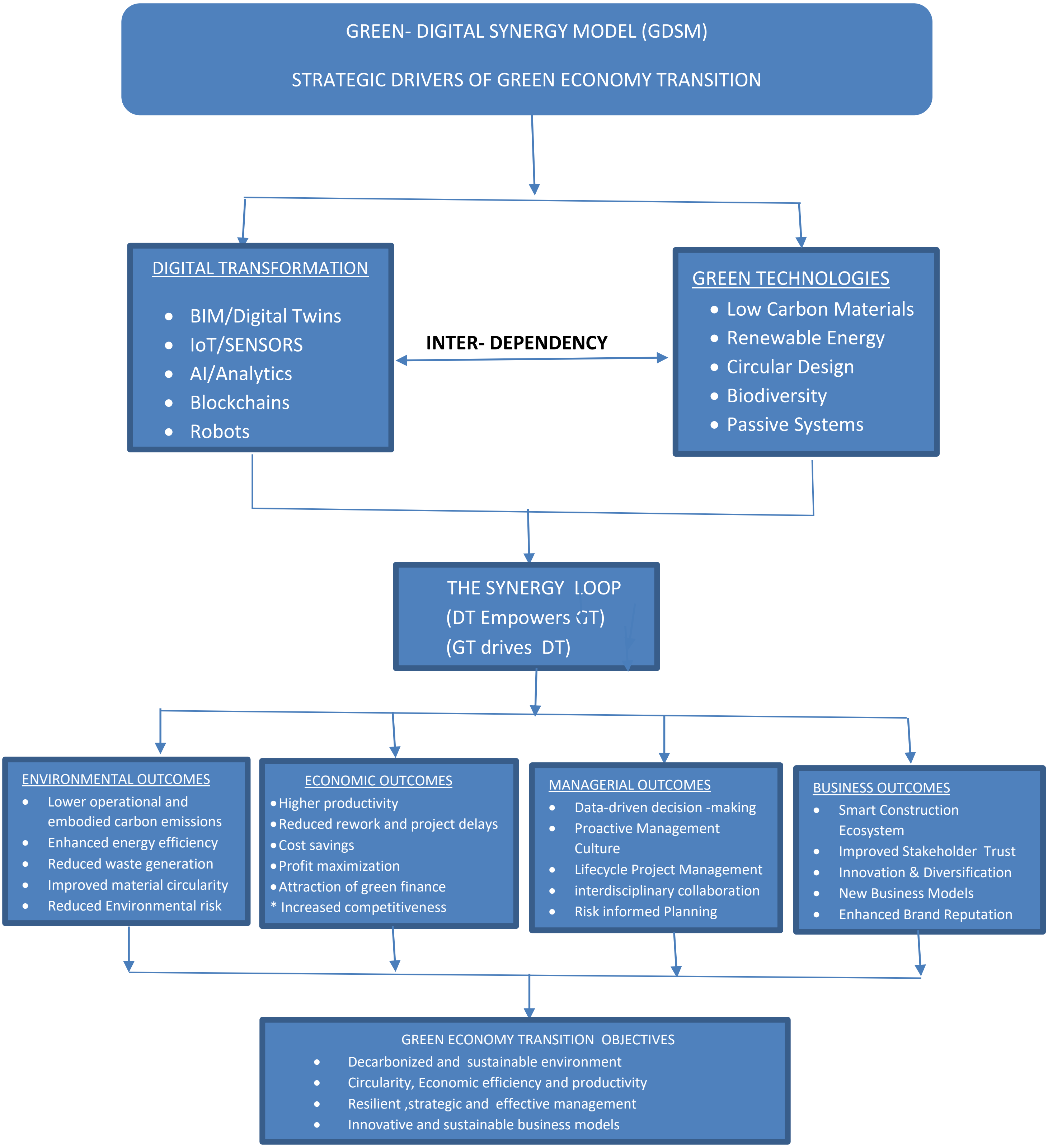


FIGURE 2: VISUAL ARCHITECTURE SHOWING THE SYNERGY AND INTERDEPENDENCE OF DT & GT AS KEY DRIVERS



1.7 Scope of the Study

The study focuses on the environmental, economic, managerial, and business implications of the joint adoption of GT and DT as strategic drivers of green economy transition in the construction industry. It adopts a global perspective, scanning for adequate and relevant information and evidence across the globe, from both developed and developing economies. This study however is largely conceptual and analytical in nature, and does not involve empirical data collection.

2.0 Literature Review

The construction industry for a long time has been very slow in accepting and adopting new trends in technological developments unlike other sectors of the economy that embraced automation in their activities decades ago. Although the construction industry plays crucial roles in global economy, the activities within its domain contribute to high carbon footprints and other forms of environmental degradations which globally affect human health and wellbeing as well as the entire ecosystems. The unpalatable effects of climate change and the need to develop more sustainably, coupled with pressure from governments and non-governmental organizations, is steeply pushing the construction industry stakeholders to adopt strategies that utilize GT and DT in their activities. Incidentally, many of the construction industry players viewed these strategic enablers from narrow perspectives; adopting them piecemeal and in isolation. This approach has not produced the much desired outcomes. The successful shift of the construction industry from its tradition methods to more robust and sustainable methods towards green economy transition therefore requires integrated adoption of GT and DT tools as well as necessary administrative and technical changes.

2.1 Concept of Green Economy

For a very long time human developmental activities prioritized economic gains over other considerations despite the hazardous effects of most of these activities on man and his environment. The high carbon footprints, resource depletion and inefficient utilization of resources, wastages, biodiversity loss, environmental degradation and other forms of pollution became unacceptably high globally, thus threatening human health and wellbeing. According to World Bank Report (2020), traditional economic systems, heavily dependent on fossil fuels and linear production models, have contributed significantly to greenhouse gas emissions and ecological damage. The concept of the green economy therefore emerged following continuous discourse on how to mitigate unsustainable human activities in various sectors of the economy that have resulted in the dramatic change in global climate. The United Nations Environment Programme defines a green economy as one that results in “improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities” (UNEP, 2011). Green economy represents an evolution of sustainable development by placing stronger emphasis on economic instruments, innovation, and structural transformation (Loiseau et al., 2016). In developing counties, the green economy is also viewed as a pathway for addressing poverty, unemployment, and infrastructure deficits while protecting environmental resources (World Bank, 2021).

2.2 Green Economy Transition in the Construction Industry

This simply refers to the construction industry's operational shift from the traditional resource-intensive construction practices towards low-carbon, resource-efficient, digital innovations, sustainable governance frameworks and socially inclusive construction practices. This operational shift ensures drastic reduction in emissions and wastes, environmental sustainability, improved productivity and profitability, promote long-term economic resilience, and enhanced stakeholders' inclusiveness and social wellbeing (UNEP, 2011; Ghobakhloo, 2020; Lu et al., 2017; OECD, 2017). Traditional construction methods are characterized by high material consumption, reliance on fossil fuel based energy systems, high labour intensity, inefficiency, high carbon emissions, waste generation, and environmental degradation which conflict with green economy objectives (IPCC, 2022). Accordingly, transforming the construction industry practices is very crucial for green economy transition and achievement of global sustainability targets, including climate change mitigation and the Sustainable Development Goals (SDGs) (IEA, 2019).

The European Commission's Transition Pathway for the Construction Industry, released in March 2023, outlined actionable framework for the sector's green and digital transformation, setting targets focusing on accelerating sustainable renovation, enhancing digital adoption, improving skills, and boosting resilience across the EU construction ecosystem by 2030. The EU knowing that the construction industry is its second-largest ecosystem, anchored a green economy blueprint centred on joint adoption of GT and DT, and set the 2030 timeline for the sector to become more sustainable, digital, and resilient in order to deliver energy-efficient infrastructure, low-carbon footprints, sustainable construction processes, and circular material flows (European Commission, 2023). As the world is rattled by the current realities of climate change globally, green construction practices using appropriate technologies to move the construction industry towards a green economy model should be embraced and sustained for man's good health and wellbeing now and in the future, and for sustenance of our planet's ecosystems.

2.3 Green Technology (GT) in the Construction Industry

The concept of GT in the construction industry evolved from the need to innovate new technologies that can address the shortcomings of the conventional systems in the industry and thus reduce negative environmental impacts, conserve natural resources, increase resource efficiency, minimize wastes, improve productivity, and enable sustainable development in the long run through lifecycle thinking (Zuo & Zhao, 2014). GT encompasses innovations such as Energy-efficient materials, Renewable energy systems, Waste minimization & recycling technologies, and Low-carbon construction methods which when applied to construction industry processes lower carbon emissions, minimizing waste, conserving energy and water, and become strategic enablers towards Green Economy transition (OECD, 2017; UNEP, 2011). The current push in the adoption of GT in the construction industry alongside other technological innovations is however driven by a combination of regulatory, economic, technological, and organizational factors which include stricter environmental regulations, rising energy costs, client demand for sustainable infrastructural facilities, and alignment with international climate commitments (Darko & Chan, 2017; European Commission, 2023).

i Modular Construction

Modular construction is an aspect of GT which involves the production of modules, components or entire sections of a structure in a controlled factory environment before taking those components to the construction site for assembling. This method reduces construction time because of some overlapping construction processes off-site and onsite, reduces material wastes, and improves quality and productivity. The application of Modular Construction in the Construction Industry can therefore reduce project delivery time by up to 50%, improve cost and productivity performance, and significantly lower waste, energy use, and carbon emissions compared to conventional construction (Lawson et al., 2014; Kamali & Hewage, 2017).

ii Smart and Sustainable Construction Materials

These are aspects of GT that play critical roles in the green economy transition of the construction industry. Such materials which include geopolymer concretes, recycled aggregates, low-carbon cement, engineered timber, and bio-based composites considerably reduce lifecycle environmental impacts while supporting resource efficiency and green economy principles (Cabeza et al., 2014; Ghisellini et al., 2016; Pomponi & Moncaster, 2017). By lowering carbon emissions, minimizing construction waste, and improving building energy performance, sustainable materials enable construction firms to align economic growth and profitability with responsible environmental conservation (Scrivener et al., 2018). As regulatory pressures from governmental and nongovernmental organizations intensify following the devastating effects of climate change globally, the adoption of sustainable construction materials increasingly functions as a strategic enabler of construction industry green transformation initiative rather than a supplementary environmental program (Akadiri et al., 2012).

2.4 Digital Transformation (DT) in the Construction Industry

DT is the strategic integration of digital technologies into economic and social systems to improve efficiency, stimulate innovation, and enhance connectivity among stakeholders (Vial, 2019, Bharadwaj et al., 2013). DT in construction entails the transition from fragmented, paper-based practices to integrated, data-driven, and automated lifecycle processes (Sawhney et al., 2020). Thus, DT in construction represents a systemic change in how construction projects are conceived, designed, delivered, and operated, reshaping collaboration, governance, and decision-making structures (Westerman et al., 2014; Brennen & Kreiss, 2016; OECD, 2019). DT therefore extends beyond mere technological adoption; it represents a strategic restructuring of processes, capabilities, and institutional arrangements that drives innovation, enhances system-wide efficiency, and supports sustainable and interconnected development across economic and social domains (Vial, 2019; Verhoef et al., 2021).

The DT tools in the construction industry include Building Information Modelling (BIM), Digital Twins, 3D Printing, Construction Robots, Drones, Geographic Information Systems (GIS), Artificial Intelligence (AI), Big Data, Blockchain and Internet of Things (IoT) applications which enable real-time monitoring, predictive analytics, and system optimization (OECD, 2019). They allow project teams to collaborate seamlessly, share real-time updates, and address potential issues before they escalate, fostering a more integrated approach to project management. These digital technologies streamline tasks, reduce manual tasks, minimize errors, shorten project duration, and reduce rework and improve cost control through automated budgeting and data-driven insights (Eastman et al., 2018; Bryde et al., 2013).

(a) Building Information Modelling

BIM is a collaborative digital process in Architecture, Engineering, and Construction that uses intelligent, data-rich 3D models to manage a project's entire lifecycle, from planning and design through construction, operation, and maintenance, thereby enhancing coordination, cost control, and overall efficiency among stakeholders thereby improving productivity, reducing errors and rework, and enabling more sustainable and efficient project delivery (Sawhney et al., 2020; Azhar, 2011; Eastman et al., 2011). BIM as a digital software tool has therefore revolutionized collaboration among construction industry professionals and other stakeholders in the design and management of construction projects by proving a digital platform that enables all stakeholders to collaboratively work together and seamlessly exchange information and optimize project outcomes. It allows project stakeholders to visualize design alternatives, detect clashes, reduces design errors, rework, schedule and cost overruns, optimize construction sequencing, and improve cost, time, and quality performance, and supports informed decision-making across the design, construction, operation, and facility management phases, thereby (Chong et al., 2017; Azhar, 2011; Eastman et al., 2011).

(b) Smart Sensors and Internet of Things

The construction industry is labour intensive; one of the most risky and accident prone sectors of the economy due to various reasons. Apart from productivity and profitability gains, digital technologies such as IoT and smart sensors are increasingly deployed on construction sites to enhance safety, monitor operations, reduce delays, and track environmental data, thereby minimizing reliance on manual processes and associated challenges (World Economic Forum, 2016; Li et al., 2019). With the aid of IoTs and smart sensors, project teams can quickly identify issues, take informed decisions based on real time scenarios of live site conditions and salvage any bad case before it gets worse.

(c) Artificial Intelligence (AI)

AI is a broad field concerned with developing systems capable of intelligent behaviour, combining multiple techniques that enable machines to perceive, learn, reason, and interact with their environment in ways that resemble human cognitive functions (Haenlein & Kaplan, 2019). In the construction industry, AI is rapidly transforming its activities; it automates tasks, analyses data and optimizes resource allocation to enhance decision making, efficiency, safety, sustainability, and project performance across the project lifecycle. AI undertakes data-intensive tasks, uncovers hidden risks, and automates repetitive practices, enabling human experts to focus on strategic decision-making, complex problem-solving, and skilled trade activities (Pan & Zhang, 2021).

(d) Data Analytics

Data analytics refers to the systematic processing and analysis of large volumes of structured and unstructured data to generate actionable insights that support informed decision-making and performance optimization. In the construction industry, data analytics plays a critical role across the project lifecycle, from planning and design to construction and facility operation, by improving efficiency, productivity, and sustainability outcomes (Sacks et al., 2020; Bilal et al., 2016). Data Analytics is actually the fulcrum on which many AI applications revolve; it examines raw data to find patterns and draw conclusions about what has happened or is happening while AI thinks through the analysed data and make actionable decisions.

(e) Digital Twins

Digital twins are dynamic virtual replicas (mirrors) of physical assets in digital mediums that facilitate the interaction between humans and replicas through the use of real time data from IoTs sensors, BIM etcetera, to visualize objects in three dimensions allowing users to virtually analyse, simulate and predict behaviour and make informed decisions (Fuller et al., 2020; Kritzinger et al., 2018). In the construction industry sector, digital twins enable the simulation, monitoring, and optimization of buildings and infrastructure across their entire lifecycle, from design and construction to operation and maintenance (Boje et al., 2020). During construction, digital twins help track project progress, identify clashes where design elements conflict or fail to integrate properly, and improve construction sequencing by optimizing the order of tasks to ensure smooth workflows and minimize delays (Lu et al., 2020; Sacks et al., 2018).

(f) Construction Robots

Robots are mechanized, programmable devices designed to perform tasks that are complex, repetitive, risky, or require precision and consistency either autonomously or via remote control (Bekey, 2012). In the construction industry, the commonly used robots include quadruped robots, bricklaying robots, robotic arms for prefabrication, autonomous earth-moving equipment, and other robotic systems for specific tasks. They perform construction activities ranging from excavation, lifting of heavy objects, bricklaying, welding, plastering, drilling, assembling, and 3D printing. By executing tasks with high accuracy and consistency, construction robots enhance productivity, reduce human error and rework, improve safety, and address labour shortages.

(g) Drones

Drones, also known as Unmanned Aircraft System (UAS) or Unmanned Aerial Vehicles (UAVs), are flying systems that are autonomous or controlled remotely to perform desired tasks real time (Colomina & Molina, 2014; Nex & Remondino, 2014). To be able to function effectively, drones are usually equipped with cameras, sensors, and applicable communication technologies that enable aerial data collection, monitoring, and analysis with no pilot or crew on-board. In the construction industry, when drones are integrated with IoT networks they are used for real-time site surveys, inspections, and progress tracking since they transmit real-time data, thus helping the project team to detect issues early and make informed decisions that drive operational efficiencies and lower costs.

(h) 3D Printing

3D Printing, also referred to as Additive Manufacturing, is a digitally driven construction technology that fabricates components of buildings or structures layer by layer, enabling faster, more sustainable and automated delivery of projects. The process of layer-by-layer fabrication of the components of the intended structure directly from digital models ensures that 3D printing minimizes material waste, reduces formwork requirements, lowers labour intensity, enhances design flexibility, shortens construction time, supports the use of alternative low-carbon and recycled materials and thus advances green economy objectives through reduced resource consumption. 3D printing can reduce on-site construction waste by up to 60% since materials are precisely deposited layer-by-layer where needed thereby avoiding overproduction and optimizing resource use. (Panda et al., 2022; Buswell et al., 2018;. Lim et al., 2012)

(i) Blockchain

Blockchain is a tamper-proof decentralized shared digital ledger that records transactions in blocks linked chronologically and secured by cryptography technology that enables secure, transparent, and traceable transactions among multiple stakeholders without the need for centralized intermediaries like a bank. In the construction industry, Blockchain is increasingly recognized as an enabling technology for the green economy transition in the construction industry as it enhances transparency, accountability, and efficiency across the project lifecycle (Saberi et al., 2019). Blockchain oils transparency and traceability in the supply chain for materials as it allows stakeholders to track the origin, certification, and environmental footprint of construction materials, supports resource efficiency and waste reduction by enabling accurate material tracking, automated inventory management, and verification of reuse and recycling processes (Kouhizadeh et al., 2021; Perera et al., 2020).

2.5 Integration of GT and DT in the Construction Industry

This refers to the coordinated joint adoption of GT with DT to enhance sustainability, efficiency, and innovation across the project lifecycle (Ghobakhloo, 2020; Lu et al., 2017). The green economy transition of the construction industry requires the strategic integration of GT and DT as they reciprocally reinforce one another, and collectively reshape industry structures, business models, and sustainability outcomes. This integration underpins a systemic restructuring of the construction industry towards a low-carbon, resource-efficient, socially responsible, and digitally enabled green economy (European Commission, 2019; UNEP, 2011). The more robust the integration between GT and DT tools, the faster and more resilient the transition towards a low-carbon, resource-efficient, and economically competitive construction sector (Sepasgozar et al., 2022; Zuo & Zhao, 2014; UNEP, 2011).

For instance when Modular construction is integrated with BIM, Blockchain, and 3D printing, material waste and emissions are drastically reduced, workflows are properly streamlined and construction time compressed, collaboration and immutable tracking of materials are also enhanced, (Wu et al., 2021; Ding et al., 2020; Bosch-Sijtsema et al., 2019; Kamali & Hewage, 2017). Generally, GT and DT are synergistically mutually reinforcing processes whose integrated adoptions accelerate Green Economy transition of the construction industry.

2.6 Implications of Green Economy Transition in the Construction Industry

(a) Environmental

The environmental implications of the joint adoption of GT and DT in the construction industry include: reduced carbon emissions, improved resource efficiency, improved material circularity, and enhanced environmental sustainability outcomes (Ofori et al., 2024). For instance, the use of geopolymer concretes alongside DT tools in construction of buildings and other infrastructures can reduce carbon dioxide (CO_2) emissions by up to 80% compared to ordinary Portland cement, depending on material composition and energy sources (Habert et al., 2020).

(b) Economic

Cost reduction, productivity improvement, good returns on investment (ROI), long-term revenue growth, and market competitiveness are some of the economic benefits of the joint adoption of GT and DT in the construction industry. Through the use of robotics, automation and other DT tools, repetitive jobs done by employees are reduced, thus reducing overall project costs and construction time (Kamaruddin et al., 2016). The joint adoption of GT and DT also dramatically reduces the nagging construction industry's problems of delivering projects above budget, beyond the expected time, and below agreed specifications (Delgado et al., 2019; Oke et al., 2018). Construction companies that integrate GT and DT into their business operational strategies can differentiate themselves through innovation, sustainable investments, and competitiveness (Zhang & Song, 2025). Such integration enhances a company's capacity to adapt to economic uncertainties, market dynamics, and regulatory changes by improving decision-making and resource planning capabilities (Li et al., 2022).

(c) Managerial

The joint adoption of GT and DT in the industry has made it easier for information and data to be seamlessly shared real time, transparency and trust to be built through adequate communications and collaboration leading to improve coordination, better monitoring and control, improved stakeholders' buy in, and data-driven decision-making across the project lifecycle thus enhancing both operational efficiency and sustainability outcomes (Yaman & Abd Ghadas, 2022). The integration of GT and DT necessitates significant managerial and organizational change requiring competencies in digital literacy, up-skilling, and interdisciplinary collaboration and commitment to learn and relearn across board.

(d) Business

In the construction industry, the joint adoption of GT and DT fosters innovation, enhances resource and cost efficiencies, thus securing long term competitive advantage and sustained market share through the development of new business models. Accordingly, the integrated adoption of GT and DT empowers construction companies to develop innovative business models, enhance brand reputation, and access to emerging green finance opportunities (Liu et al., 2022; Taghizadeh-Hesary & Yoshino, 2019). Such business model innovations enable construction companies to shift from product-based offerings towards service-oriented and performance-driven models that generate long-term value (Zhou et al., 2023). BIM, Digital Twins, and other digital tools enable construction companies to redesign traditional project delivery methods while entrenching sustainability objectives. For instance modular and prefabricated constructions, when supported by digital twin and automation, enhance energy efficiency, reduce material waste, and improve overall sustainability objectives (Gallo et al., 2021).

2.7 Barriers to GT and DT adoption in the Construction Industry

Notwithstanding the numerous positive outcomes of the joint adoption of GT and DT in the Construction Industry, the study identifies some financial, technical, and social barriers which many construction companies face in the adoption. The Financial barriers include high initial investment costs, operational/running costs, and capacity development costs. The Technical barriers on the other hand include skills gap/shortages, data connectivity issues, and cyber security risks associated with data breaches. The social barriers include: resistance to change, inadequate digital literacy among some industry stakeholders, and insufficient digital technological infrastructure support especially in developing countries. Consequently, despite their transformative potentials, the adoption of GT and DT in the construction industry faces many challenges globally, especially in developing countries (World Bank, 2020).

2.8 Research Gap

Despite growing literature on DT and GT as essential areas of interest in the construction industry, limited studies provide comprehensive analysis of their integrated adoption in advancing green economy transition in the industry. There remains a need for this context-specific study, particularly in developing economies.

3.0 RESEARCH METHODOLOGY

3.1 Research Design

This study adopts Systematic Literature Review (SLR) as the research method to investigate the implications of the integrated adoption of GT and DT in the green economy transition of the construction industry. Appropriate interconnected research questions that will lead to relevant searches on the subject matter were designed.

3.2 Eligibility Criteria

The study adopts a global perspective and scans for relevant information and evidence across the globe, from both developed and developing economies but developed an inclusion and exclusion criteria to remain focused. Peer-reviewed journals, Conference Proceedings, Authoritative Industry Reports that address the integration of GT and DT, and published between 2010 and 2025 are considered eligible for the search while those that dwell on Material Science without digital application were excluded.

3.3 Information Sources

Different Search Engines and Databases such as Google Scholar, Scopus, CORE, IEEE Xplore, ScienceDirect and Science.gov were employed to fish out documents and Articles with relevant information. Search Strings involving keywords such as construction industry, green economy, green technology, digital transformation, BIM, Blockchain, IoT, sustainability, carbon emission, climate change, etcetera were used to mine information. Reports of International Agencies and Organizations relevant to the study also provided useful materials.

3.4 Data Extraction, Analysis, and Synthesis

Data extracted from Articles/Papers used for this study included: Bibliographic Information (Author(s), Year of publication, Country/region of study, Journal/source etc), Study Characteristics (Research aim/objectives, Study design Sample size and sector focus), Technology Variables (Green technologies and Digital technologies), Sustainability and Green Economy Outcomes (Carbon emission reduction, Resource efficiency, Energy efficiency improvements, Waste reduction, Innovation and competitiveness, Innovation and competitiveness, Enhanced Productivity and Profitability, Risk reduction and safety improvement, and Governance transparency), Key Findings', Recommendations and Conclusion.

The data extracted are analysed to systematically identify, examine, and evaluate trends, patterns, relationships, and methodological differences across studies in order to break down and interpret evidence from each study and transform the extracted raw data into interpretable results. The findings from the analysed data are brought together in order to interpret them and draw conclusions about the evidences obtained from multiple studies to generate coherent insights, identify patterns, compare findings, and develop integrated comprehensive higher-level conclusions that address the research questions and align with the research objectives.

Table 1: SUMMARY OF SOME INCLUDED STUDIES

Author(s) & Year	**Country / Region**	**Title of Article/Paper**	**Green / Digital Technology or Tools Employed**	**Integration Focus or Desired Goals**	**Sustainability / Green Economy Outcomes or Objectives**	**Research Questions Addressed**	**Study Type**
World Bank, 2021	Global	From crisis to green, resilient, and inclusive recovery	Governance and policy instruments	Green, Resilience & Inclusive Development	Reduced material wastes, Environmental sustainability, Resource efficiency and productivity, Innovation & Diversification	RQ2, RQ3 RQ4 RQ5	Policy
UNEP, 2022	Global	2022 Global Status Report for Buildings and Construction	Governance and policy instruments	Zero-Emissions, Efficient and Resilient Buildings and Construction Sector	Decarbonization (Zero-Emissions), Resource & Energy Efficiency, Efficient Technologies adoption (GT & DT), Upskilling, Productivity and resilience	RQ1, RQ2, RQ3 RQ4	Policy
OECD, 2017	Global	Green growth indicators	Governance and policy instruments	Green Growth and sustainable Development	Environmental Sustainability & Lower Carbon Footprint, Resource Efficiency & improved productivity	RQ2, RQ3 RQ4	Policy
European Union, 2023	EU	Pathways of the Construction Ecosystem	Governance and policy instruments	Green and Digital Transition	Economic & Environmental sustainability, Energy & Water conservation, Upskilling, digital, productive, & resilient,	RQ1, RQ2, RQ3 RQ4 RQ5	Policy
Kamali & Hewage, 2017	Canada	Life cycle performance of modular buildings	BIM, Modular construction	Environmental sustainability and Circularity	Environmental sustainability & Circularity, Resource efficiency, Reduction in delays, wastes, emissions, and costs.	RQ1, RQ2, RQ3 RQ4	Review
Scrivener et al, 2018	Switzerla nd	Eco Efficient Cement	Low Carbon Cement	Decarbonization	Environmental sustenance, Energy Efficiency, lower Carbon emissions	RQ1, RQ2,	Review

Lu et al., 2020	China	Digital twin-driven smart manufacturing	BIM, Digital twins, IoT	Cyber–physical integration	Proactive Decision making, Operational & Resource efficiency, Reduced delays, wastes & emissions; Improved safety, Productivity, profitability, & Economic resilience , Collaboration, innovation &diversification	RQ1, RQ2, RQ3 RQ4, RQ5	Review
Pomponi & Moncaster , 2017	UK	Circular Economy for the Built Environment	BIM, Digital Twins, circular design tools	Digital support for circular construction	Resource efficiency & productivity; Waste & Carbon Reduction, Collaboration, innovation, & diversification, Lifecycle Tracking, and improved circularity	RQ1 RQ2, RQ3, RQ4, RQ5	Conceptual
Boje et al., 2020	Sweden	Towards a Semantic Digital Twin	Digital twins, IoT	Real-time performance monitoring	Energy & Resource Efficiency, Carbon Reduction, Predictive Maintenance, Safety & Productivity, Proactive Lifecycle Management & Improved Data Interoperability	RQ1, RQ2, RQ3, RQ4	Case study / Simulation
Zuo & Zhao, 2014	Australia	Green Building Research Review	Green Materials	Environmental Performance and sustainability	Green growth, Energy efficiency; lower carbon emissions; social wellbeing	RQ1, RQ2,	Review
UNEP, 2011	Global	Towards a Green Economy	Governance and policy instruments	Green Economy Framework	Economic Resilience; Social Inclusion; Environmental Protection, Enhanced Efficiency & Productivity	RQ2, RQ3, RQ4	Policy
Delgado & Oyedele, 2021	UK	Robotics and Automated Systems in Construction	Robotics and Automated Systems (Digital Twins, BIM, IoT)	Enhanced automation in Construction for Productivity & efficiency	Operational & Resource efficiency, Inclusivity & Stakeholders' buy-in, Improved safety, Productivity, profitability, & Economic resilience , Collaboration, innovation &diversification	RQ1, RQ2, RQ3, RQ4	Mixed (Review & Case Study)

Sepasgozar et al., 2022	Australia	Digital Transformation of Construction	BIM, IoT, AI	Integrated Green Construction Workflows	Operational & Resource Efficiency, Reduced delays, wastes & emissions; Improved Safety, productivity, & profitability; Economic resilience and competitiveness	RQ1, RQ2, RQ3, RQ4	Mixed
Perera et al., 2020	UK	Blockchain-enabled smart contracts	Blockchain, IoT	Automated compliance & Supply Chain Transparency	Green Procurement, Risk Mitigation & Reduction; Transparency, Trust & Accountability	RQ1, RQ2, RQ3, RQ4	Conceptual
Zhang et al., 2019	China	Robotics in green construction	Robotics, automation	Automated construction processes	Reduced Labor Risk, delays, & Rework Remote Monitoring, Control & Collaboration Improved Efficiency, Speed, Productivity, Profitability & Output Quality,	RQ1, RQ2, RQ3, RQ4	Empirical
Saberi et al., 2019	Germany	Blockchain & Sustainable Supply Chains	Blockchain, Smart Contracts	Green Supply Chain Transparency	Transparency; Trust Enhancement, Reduced Environmental Risk & Compliance With Green Standards	RQ1, RQ3	Review
Darko et al, 2017	Global	Drivers for Green Building Adoption	Green Technology	Environmental Sustainability	Energy efficiency; Carbon reduction; Economic competitiveness	RQ1, RQ2, RQ5	Review
Gallo et al, 2021	Spain	Digital Twin–Enabled Prefabricated Construction	Digital Twin & Prefabrication	Improved Sustainability and Performance	Improves construction sequencing, Minimises delays, emissions and wastes, Improves safety	RQ1, RQ2, RQ4	Review
Pan et al, 2021	China	Roles of AI in Construction Engineering and Management	AI and IoT	Automation in Construction,	Predictive Maintenance & Data based Decision making , Operational & Resource Efficiency, Reduced delays, wastes, risks & emissions.	RQ1, RQ2, RQ3, RQ4	Review

4.0 Findings Aligned with Research Objectives (RO1-RO5) and Questions (RQ1-RQ5)

In alignment with RO1 and RQ1, the GT that support Green Economy transition in the Construction Industry include low-carbon and recycled construction materials, renewable energy systems, modular and prefabricated construction, passive design technologies etcetera while the DT that support Green Economy transition in the Construction Industry include BIM, Digital Twins, 3D Printing, AI, Drones, IoT Sensors, Robots, Blockchain, etcetera. The primary objective of GT is to reduce environmental impact while promoting sustainable growth while that of DT is to enhance data-driven decision-making, efficiency, transparency, and lifecycle optimization.

The SLR reveals that when GT and DT are jointly adopted in the construction industry, they create multi-layer network systems that transform traditional linear construction processes into intelligent, sustainable and circular lifecycles from design and construction to operation. The study therefore identifies the fact that the successful transition of the construction industry from its conventional linear model to green economy model depends greatly on the integrated adoption of both GT and DT tools in its operations rather than deploying them in silos.

With respect to RO2 and RQ2, the joint adoption produces multi-dimensional environmental impacts that lead to reduction in Carbon emissions, waste generation, and enhanced real-time energy optimization. When BIM and other DT tools such as Digital Twins, drones, robotics, 3D printing, and IoT sensors are simultaneously deployed with GT, they provide the platform needed to visualize virtually and simulate performances before construction processes begin, thus giving stakeholders in the industry the opportunity to address identified areas of concern and enforce sustainability standards that drastically reduce or eliminate carbon emissions and other forms of environmental pollution. During the construction phases, they enable a data-driven and automated construction ecosystem that improves general resource efficiency, biodiversity, and reduces environmental impacts.

Regarding Carbon emissions reduction, BIM-enabled Life Cycle Assessment (LCA) reduces embodied and operational carbon. On waste reduction, IoT-enabled tracking of construction processes ensures that there is resource efficiency, proper material scheduling and utilization. Regarding Energy Efficiency, Smart Building Systems enable real-time energy optimization while Digital twins allow continuous performance tuning.

With regards to RO3 and RQ3, there are usually high upfront/initial costs for construction firms adopting GT and DT, but the resultant lower lifecycle costs deliver high operational savings and returns on investment. The SLR reveals that integrating GT and DT in construction projects create strategic value chain, generating both economic returns and operational efficiencies for construction firms and other stakeholders. Joint adoption of GT and DT streamlines workflows, reduces rework, enhance coordination, shortens project duration, lower project delivery and lifecycle costs, mitigates risks, boosts productivity, profitability, and make firms achieve other stronger economic and financial performances.

Considering RO4 and RQ4, the SLR reveals pointedly that the success of the joint adoption of GT and DT in the construction industry is highly dependent on the availability of hybrid professionals and staff with the requisite skills and digital competences, strong management with strategic capabilities, and institutional frameworks to synergistically integrate them and transit construction from traditional linear model to green economy model. To effectively deploy and efficiently integrate DT and GT to achieve sustainability outcomes, construction companies require an array of staff with technical skills and competences in BIM dimensions (3D–7D lifecycle Modelling), IoT Systems Integration and Sensor Data Interpretation, Data Analytics and AI skills (for analytical and decision-making), Digital Twin development and simulation capabilities, Automation and Robotics operation, etcetera.

The joint deployment also necessitates a transformation that involves fundamental reconfiguration of organizational capabilities, leadership practices, and performance measurement systems require Managerial Capabilities needed for the successful joint adoption such as Change Management, Strategic, Operational, Innovation and Learning, Collaboration, and cross-functional integration capabilities. They are crucial in such transformation for managing resistance to new technologies and aligning organizational culture with sustainability objectives.

The SLR indicates that robust Institutional Frameworks significantly support the joint adoption of GT and DT in the construction industry as they enable the diffusion and scalability of GT and DT in the industry. Without them, adoption remains fragmented, limited and slow. Regulations, Codes, and other strong governance structures therefore act as primary catalysts to drive adoption, especially in early adoption stages. The implementation of Green Building Codes, Sustainability Regulations, and mandatory BIM adoption policies, etcetera in some countries is already boosting GT and DT adoption. The success of the joint deployment of GT and DT in the construction industry therefore depends greatly on the alignment of human capabilities, organizational strategy, and institutional support systems.

On RO5 and RQ5, the SLR reveals that the business implications of the joint adoption of GT and DT in the construction industry essentially centre on business model innovations, competitive positioning, and ecosystem transformations which affect how construction firms create, deliver, and capture value. In the sphere of business model innovations, the integration of GT and DT in the industry generates major transformations which shift construction firms from Project-Based-Linear-Revenue Models to Continuous Value-Creation and Performance-Based Services Models that generate lifecycle revenue. Thus, instead of the traditional one-off, project-based revenue models hitherto operated by construction firms, the integration of GT and DT has enabled a transition towards broad lifecycle-based business models where firms generate value across the various project phases by strategically tailoring their services throughout the project lifecycle and offering integrated products and services systems which ensure flexible revenue streams and resilience. With regards to competitive positioning, construction firms that integrate GT and DT can distinguish themselves and create brand reputation by offering services that give them comparative advantages and competitive edge over others within their sphere of operation.

5.0 Discussion

The joint deployment of GT and DT as strategic drivers of construction industry's green economy transition is characterized by complex interdependencies and transformative capabilities with multi-dimensional impacts across mutually reinforcing environmental, economic, managerial, and business domains. The integration is therefore a socio-technical challenge which connects human, organizational, cultural, and technical elements that require deeper integration, not just a technical one as being misunderstood by some industry players and construction firms.

The strategic value of the integration is not additive but multiplicative as the true gains come from GT and DT working synergistically together in a closed loop where GT generates solutions and DT validates them with real-world data, and that feedback continuously improves both systems. These two forces act as interdependent enablers: DT provides the data, transparency, and efficiency needed to implement GT effectively. Without DT, GT remains fragmented and costly; and without GT, DT lacks environmental purpose.

The major findings across environmental, economic, managerial, and business domains indicate that DT acts as an enabler, potentiator, and optimizer of GT by providing foundational tools necessary to accelerate the impact and scale of GT ensuring maximum efficiency, minimal waste and reduction of carbon emissions. GT on the other hand achieve higher efficiency and reduced waste when integrated with DT. The study therefore identifies the fact that the successful transition of the construction industry from its conventional linear model to green economy model depends greatly on the integrated adoption of both GT and DT tools in its operations rather than deploying them in silos.

Thus, with respect to environmental sustainability, the integration of GT and DT in the construction industry allows for simulation, precise material quantification and planning, remote monitoring and control, which enhance resource efficiency, reduce waste generation, environmental degradation, and carbon emissions. On the economic sphere, the joint adoption enhances productivity, cost efficiency and profitability, reduces delays, rework, and material wastage, and delivers good returns on investment (ROI), enhances competitiveness, long-term revenue growth and economic resilience. As regards the managerial standpoint, the integration of GT with DT in the construction industry avails industry stakeholders with digital platforms that provide real time and historical data/information which enhance planning, collaboration, coordination, performance tracking, sustainability benchmarking, and development of proactive innovative management culture.

Under the domain of business, the integration of GT and DT in the construction industry is dramatically transforming and reshaping its landscape as new business models such as service contracts, management contracts, lease/concession, operations and maintenance, design-build-finance-operate, etcetera are evolving. The joint deployment of GT and DT therefore offers many opportunities to industry stakeholders to diversify their product base, strengthen brand reputation, boost stakeholder trust, ensure regulatory compliance, and compete more favourably.

The joint adoption of GT and DT ensures that the traditionally fragmented Firm-Centric construction industry ecosystem is transformed to Networked collaborative dynamic ecosystem where value is generated through interconnected industry stakeholders over digital platforms rather than one isolated firm. However, high initial costs, capacity gaps and inadequate digital literacy, lack of interoperability, poor stakeholders' buy-in, poor change management capability, inadequate technological infrastructure, etcetera, are some of the barriers that impede GT and DT adoption in the construction industry, especially in developing nations.

Conclusion

The SLR reveals that though GT and DT are key drivers of green economy transition in the construction industry, their isolated adoption do not yield the full desired positive outcomes. The study shows that green economy transition in the construction industry can only be successfully achieved through a unified combination of GT and DT entrenched in the industry's organizational project delivery processes and strategies. This study therefore establishes that GT and DT are key strategic drivers of green economy transition in the construction industry and that their combined adoption radically improves environmental quality, economic efficiency and productivity, managerial capabilities, and business sustainability. The study also reveals that the quality of the leadership and the possession of requisite skills by the staff of the industry are necessary ingredients in the green economy transition in the construction industry. The study however discloses that despite all these lofty sustainability outcomes barriers such as investment and operational costs, poor network connectivity, cyber breaches, inadequate technical/digital literacy, poor stakeholders' buy-in, and key infrastructural deficits slow down the adoption, especially in developing economies. The study contributes to theory, practice, and policy and provides a robust platform for future empirical research. Future research could build on this work by incorporating empirical case studies or quantitative analysis to further validate the findings.

Recommendation

This study recommends that a unified green economy transition blueprint for the construction industry that would involve the wholesome integration of GT and DT tools should be institutionalized at both national and regional levels across the globe to advance further the United Nations' initiatives on sustainable developments and climate actions. Construction firms should on the other hand embrace GT and DT as a single, unified business transformation scheme rather than adopting them in silos as if they are mutually exclusive

Keywords

Green Technology, Digital Transformation, Green Economy, Construction Industry.

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