

LEVERAGING DIGITAL TECHNOLOGIES FOR SUSTAINABLE AND HUMAN-CENTRIC WASTE MANAGEMENT: A REVIEW OF CURRENT PRACTICES AND FUTURE PERSPECTIVES

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ABSTRACT

PURPOSE

As global waste generation continues to surge, the need for sustainable and human-centered waste management strategies has become more critical. Hence, this paper explores the transformative role of digital technologies in supporting sustainable and human-centered waste management practices within the context of Construction 5.0 (C5.0).

DESIGN / METHODOLOGY / APPROACH

A systematic review approach was utilised in achieving the aim of the study. The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses standards. A comprehensive literature search was carried out across different electronic databases to find germane peer-reviewed studies published between 2013 and 2023.

FINDINGS

The findings from the SRA divulged that by enabling real-time monitoring, predictive analysis, and transparent decision-making, digital technologies enhance operational efficiency, reduce environmental impact, and empower communities to participate actively in waste reduction. Furthermore, contractors' awareness, waste management-related policy, legislation and regulation, and the use of Building Information Modelling are critical components of Sustainable and Human-Centric Waste Management Practices for waste monitoring.

RESEARCH LIMITATIONS / IMPLICATIONS

This study focuses on secondary data related to waste management practices in the construction industry. Emerging technologies not covered in the study may present additional opportunities and challenges that must be studied.

PRACTICAL IMPLICATIONS

The article emphasizes a human-centered approach, arguing that digital tools must be integrated with inclusive policies and behavioral interventions to provide equal access and long-term sustainability in the context of Construction 5.0 (C5.0).

ORIGINAL / VALUE OF THE PAPER

This study contributes to the discourse on Sustainable and Human-Centric waste management practices by presenting a roadmap for leveraging digital innovation to foster resilient, inclusive, and environmentally responsible waste management systems.

Keywords: *Construction 5.0, Digital Technology, Human-Centric Approach, Sustainable Development, Waste Management Practices.*

INTRODUCTION

The rapid growth of urban populations and industrial activities such as the manufacturing of building materials and construction, has resulted in a significant upsurge in waste generation, posing serious challenges to environmental sustainability and public health. For this reason, the construction industry, a key driver of the global economy, is facing growing pressure to adopt more sustainable and human-centered waste management practices^[1]. Consequently, the industry is moving toward innovative solutions as a result of the increasing need to address environmental issues, resource efficiency, and worker safety^[51,52]. Construction 5.0 (C5.0), which amalgamates emerging digital technologies and ecological principles, proffers a sustainable solution to these difficulties^[2]. This paradigm shift is in consonance with the United Nations' Sustainable Development Goals (SDGs) for 2030, particularly goals 12, 13, and 3, which emphasize natural resource optimisation, reduced environmental impact, and improved worker well-being, respectively^[53].

The implementation of digital technologies such as the Internet of Things (IoT), Building Information Modelling (BIM), artificial intelligence (AI), blockchain, and data analytics to improve sustainable and human-centered waste management practices in the construction industry presents several difficulties^[54]. For instance, integrating advanced technologies such as Building Information Modeling (BIM) into established procedures often necessitates significant investment and expertise^[55]. Data management is another challenge, as diverse formats and standards impede seamless information interchange^[3]. Furthermore, staff adaptation and training are vital, closing the skills gap and overcoming resistance to technological change are required to maximize the benefits of these technologies^[56]. Financial constraints, regulatory difficulties, and the requirement for scalable solutions all exacerbate adoption attempts^[4]. Overcoming these difficulties requires cross-sector collaboration to establish strong policies that promote both environmental sustainability and worker well-being in construction waste management procedures^[4,5]. Furthermore, materials such as concrete, bricks, soil, rocks, lumber, cement, drywall, insulation, plumbing fixtures, electrical equipment, asphalt roofing materials, corrugated cardboard, and glass make up construction waste^[31].

In response to these issues, there is a growing interest in terms of integrating sustainable and human-centric waste management to enhance the effectiveness, efficiency, and inclusivity of waste management practices. Sustainability in construction goes beyond energy efficiency and green building materials to include holistic resource management strategies such as construction waste reduction, recycling, and reuse^[6,7]. Effective construction waste management not only decreases environmental impact, but also improves resource efficiency, lowers project costs, and facilitates regulatory compliance^[8,9]. A successful construction project requires an effective construction materials waste management process^[10]. It reflects the recognition that effective management is crucial to achieving several key construction project performance indicators, including time, cost, quality, waste, and safety^[10]. However, country's productivity is negatively affected by construction waste due to its environmental effects, costs, and time^[11]. The suitable techniques are nonetheless indicated by the actual situation, as a result, the options for managing construction waste are not all-inclusive^[12]. Against this backdrop, the problem to be addressed can be summarised as follows: there is limited integration and effective use of digital technologies to engender data-driven waste management decisions in line with construction projects, thereby contributing to avoidable material loss, poor coordination among stakeholders, and missed opportunities for circularity adoption. Although digital technologies take the centre stage as the core intervention of this study, nonetheless, environmental and human-centric approach serve as guiding constraints and evaluation systems for assessing their effectiveness in construction waste management. In connection with the foregoing problem statement the following research question was pursued:

How can digital technologies be effectively integrated to enhance sustainable and human-centric waste management practices in the construction industry?

Waste minimisation challenges in general building projects are frequently noted by researchers and industry practitioners^[57]. According to^[57], traditional waste management systems, which are frequently plagued by inefficiencies, limited data transparency, and reactive approaches, are increasingly inadequate to address the complexity and scope of modern waste-related issues^[57]. Consequently, this paper explores the transformative role of digital technologies in supporting sustainable and human-centered waste management practices within the context of Construction 5.0 (C5.0). The study relied predominantly on secondary data by conducting a systematic literature review of recent industry and academic sources. By adopting a systematic literature review, the study identified interventions that may proffer solutions to the upsurge of waste generation in the construction industry. The interventions are conceptualised into four elements such as education and training, awareness creation, governance systems, and the adoption of digital technology for monitoring waste.

LITERATURE REVIEW

OVERVIEW OF CONSTRUCTION 5.0 AND ITS RELEVANCE TO SUSTAINABILITY

Construction 5.0 is the construction industry's next evolutionary phase, incorporating advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Building Information Modeling (BIM), and robotics to improve efficiency, safety, and sustainability in construction processes^[27,7]. Unlike its predecessor, Industry 4.0, which was largely focused on automation and data interchange, construction 5.0 prioritizes a human-centric approach, ensuring that technological developments complement and augment human talents rather than replace them^[13,14]. Hence, the paradigm change intends to enhance working conditions, encourage creativity, and promote continuous learning among employees, resulting in a more inventive and resilient construction industry^[15].

In terms of sustainability, Construction 5.0 (C5.0) is closely aligned with the United Nations' 17 Sustainable Development Goals (SDGs) for 2030, which promote environmental preservation, resource efficiency, and social responsibility^[16]. The combination of C5.0 tools such as IoT and AI enables real-time monitoring of construction sites, maximising resource utilisation, eliminating waste, and limiting environmental effect^[158]. Previous research on Construction 5.0 has mostly focused on the application of technologies to enhance productivity, with increasing attention on environmental sustainability outcomes such as waste reduction^[15]. However, the gap in empirical research investigating the human-centric of Construction 5.0, particularly its implementation challenges, and relevance to construction waste in developing countries contexts such as South Africa^[19]. In addition, BIM and digital twins enable exact planning and resource allocation, whilst robotics improves productivity and safety by taking over dangerous activities^[27]. Additionally, smart technologies enhance energy efficiency and regulatory compliance, ensuring that construction activities are both environmentally responsible and legally sound^[17].

SUSTAINABLE CONSTRUCTION

Sustainable construction is a comprehensive procedure that aims to restore and sustain the interaction between the natural and built environment, and to build communities that uphold fairness and human dignity^[18]. The construction sector creates a variety of physical facilities, such as dams, roads, bridges, residential and commercial buildings, factories, and recreational areas, which have an impact on society, the environment, and the economy^[19]. It requires the building team to use construction techniques that eliminate adverse environmental impacts including pollution and carbon dioxide emissions^[20,21]. Sustainable construction ensures the preservation of the environment as well as major development-related concerns, such as resource efficiency, constant social and economic growth, and the eradication of poverty^[22].

REGULATORY COMPLIANCE

Construction 5.0 promotes proactive compliance with changing environmental policies in addition to guaranteeing adherence to current regulations^[23,24]. For example, accurate modeling and simulation of building projects made possible by digital twins and BIM enables comprehensive environmental impact evaluations and better planning to reduce adverse environmental effects^[25,26]. Technology resources aid in the application of sustainable practices, which are frequently required by law and include recycling, trash reduction, and energy efficiency^[27,28]. Moreover, comprehensive reporting capabilities offered by advanced data analytics facilitate construction enterprises' ability to prove compliance to stakeholders and regulatory bodies^[29]. In addition to helping to prevent legal ramifications, this proactive approach to regulatory compliance fosters a culture of sustainability and establishes construction firms as ethical and progressive players in the market^[30].

KEY CHALLENGES PREVENTING THE INTEGRATING TECHNOLOGIES IN SUSTAINABLE AND HUMAN-CENTRIC WASTE MANAGEMENT PRACTICES IN C5.0

Contractors have several challenges when it comes to sustainable and human-centric construction waste management methods in C5.0 projects^[59,49]. The first and most important step is to increase awareness and educate all project stakeholders on the value of sustainable practices^[31]. Akhund et al.^[60] add that this includes not just instilling knowledge about environmental benefits but also ensuring that employees and subcontractors understand how their activities can help to reduce waste and promote recycling on-site. Overcoming established habits and cultivating a sustainable culture frequently need ongoing teaching and reinforcement throughout the project's life cycle^[31].

Financial issues are still another major obstacle. Although adopting sustainable practices might result in long-term financial advantages by lowering waste disposal costs and increasing resource efficiency, the initial expenses may be too high^[32]. Moreover, contractors have to strike a compromise between the upfront costs associated with sustainable technologies like eco-friendly materials or trash sorting equipment and the long-term cost and image benefits these investments may yield^[49]. Strategic planning and meticulous budgeting are necessary to manage these financial dynamics and guarantee the economic viability of sustainability efforts^[32]. The sheer amount and diversity of solid waste are one of the most significant obstacles in its management^[34]. Construction sites generate a large amount of garbage, and properly sorting, recycling, or disposing of these materials necessitates strong infrastructure and logistics planning^[33]. However, skills shortages and resistance to change affect the implementation of human-centric waste management practices, as the workforce lacks competencies that are required to interact effectively with intelligent systems, raising more concerns about job security, and reducing the interest on adoption of technology driven waste management^[32]. Therefore, contractors fail to develop efficient waste management systems that include on-site segregation of materials, dedicated storage locations, and agreements with recycling facilities to divert as much waste as possible from landfills^[34].

A systematic literature review (SLR) approach was employed to achieve the aim of the study. The rationale for conducting the SLR is two-fold. The lack of a structured and unifying view regarding the available approaches and methodologies to be adopted in supporting sustainable and human-centered waste management practices within the context of Construction 5.0 (C5.0) was the main trigger for undertaking this systematic review. Furthermore, waste management practices in the construction industry across different sub-regions are quite a complicated and broad research area given that peculiarities such as culture and adaptation to technological advancement may differ. The SLR aided in identifying technologies that can support sustainable and human-centered waste management practices within the scope of Construction 5.0. Current practices adopted in the construction industry are ineffective since the issue of construction waste persists. The SLR provides for clear deductions because it includes all relevant, sound research with varied techniques^[35]. This provides a comprehensive picture of the evidence for managing construction waste in the literature, assisting the review in integrating technologies that promote sustainable and human-centered waste management practices within the framework of the Construction 5.0 target. The following sections delve into the details of the five-step review procedure that was used.

STEP 1: PROBLEM IDENTIFICATION

The South African construction industry has expanded greatly in recent years, supporting the nation's economic development^[36]. Nonetheless, this expansion has also led to a notable rise in waste generated by contractors, creating problems for the environment, human health, and the economy. A large portion of the waste produced by contractors is caused by activities in the construction industry^[37]. Waste occurs on construction sites because of ineffective resource management, material overordering, and inappropriate handling and storage techniques^[38]. These actions result in higher expenses, detrimental effects on the environment, and lost chances for recycling and waste reduction^[39]. However, the issue is made worse by the absence of comprehensive waste management laws that target contractors particularly^[40]. The specific difficulties presented by contractors' waste are not sufficiently addressed by the general waste management standards that are in existence. Construction waste is further compounded by the inappropriate disposal of resources including steel, concrete, wood, and other building debris^[41]. There are several factors contributing to construction waste in South Africa, which include among others: waste management practices used in the construction sector, poor waste management laws, low levels of awareness and education, and inadequate infrastructure^[42,43]. Despite technological breakthroughs that provide solutions such as reuse and thermal treatment, their actual execution is riddled with challenges^[37]. Hence this study seeks to identify the most effective waste management practices in line with evolving sustainability rules and endorsing responsible practices to attain SDG 12.

STEP 2: LITERATURE SEARCH

The literature reviewed in this study specifically focuses on integrating technologies can promote sustainable and human-centric waste management practices within the framework of Construction 5.0. An online search was conducted using Google Scholar. The selection criteria regarding the choice of literature reviewed were guided by the: data source, year the data was published; keywords, and subject area, as shown in Table 1

Table 1: Selection criteria for articles

Inclusion criteria	
Data source	Journal articles
	Conference proceedings
Year	2013 — 2023
Keywords	"Construction 5.0" OR " Human -centric" OR "Construction sustainability" OR "sustainable development"
	"Construction waste" Planning of workOR "Waste Management practices"
Subject area	Engineering
	Environment
	Society
	Earth

STEP 3: DATA EVALUATION BASED ON THE INCLUSION AND EXCLUSION CRITERIA

The review and selection of relevant publications were aided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guiding principle (Simpeh et al., 2021) comprising the four steps of identification, screening, eligibility, and inclusion (Figure 1). The literature search was conducted via the Cape Peninsula University of Technology's digital library. Databases such as SCOPUS and Web of Science were consulted to aid in sourcing germane and up to date publications of academic literature. As indicated in Table 1, Keywords and Boolean operators related to "construction 5.0", "construction sustainability", "construction waste", "digital technologies," "sustainable development", "sustainable waste management", "human-centric approaches" and "waste management practices" were used to refine the search. It is worth noting that preference was given, but also not limited to, articles that were published within the last ten years, as a literature review of current trends was more appropriate for this paper. Furthermore, papers were screened in two stages: first, the title and abstract were screened, followed by a full-text review using predetermined inclusion and exclusion criteria. According to^[45], sources using comparable research procedures can use exclusion and inclusion criteria to establish quality scores, which can then be incorporated into the design. However, different research procedures may only be fairly compared when specific outliers indicate that the methodological shortcomings of the source may be to blame for the discrepancy in the results. It would be important to assess the caliber of studies that draw on theoretical and empirical sources, just as it would be for historical research. The number of publications identified through meta search was 348. Subsequently, the search criterion was refined by obliterating the duplicated ones. Furthermore, the abstract of each manuscript was carefully scrutinised to establish if it could be considered for inclusion in the next step. It is evident from Figure 1 that publications removed based on the abstract analysis were 176 whereas 128 were eligible for the next screening. The penultimate step was the full-text screening through a content review to determine which publications should be included in the systematic literature review. Notably, only 35 publications met the inclusion criteria. It is important to highlight that the literature reviewed in this study only analyses manuscripts obtained using the foregoing selection criteria. The flow chart depicting the inclusion and exclusion criteria is presented in Figure 1.

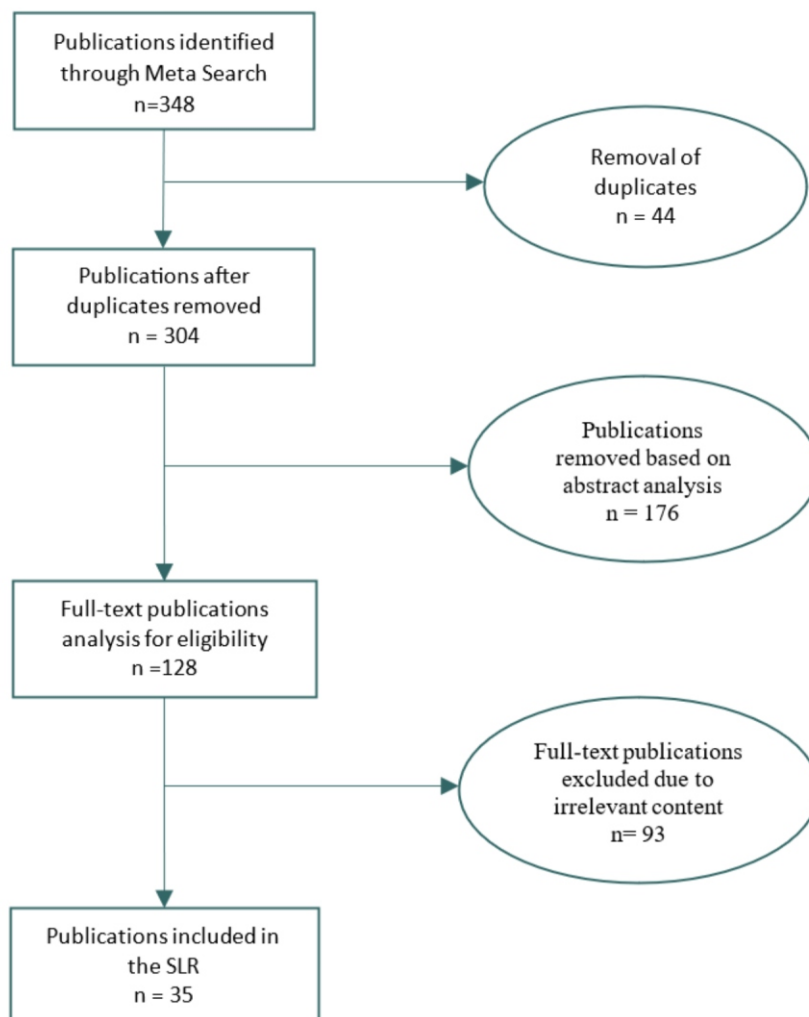


Figure 1: PRISMA flowchart of the study

STEP 4: DATA ANALYSIS

It is necessary to classify, arrange, organise, and summarize the data in a research review before performing the data analysis. The objective of the data analysis stage in an integrative review is an objective and complete interpretation of the data and synthesis of the evidence^[46]. To categorize the data that has been retrieved into groups that allow for the discovery of trends, themes, distinctions, and linkages, a method of constant comparison is utilized in this review. To begin with, the retrieved data is compared item by item to group and code-related data. Furthering the analysis and synthesis of the data, the coded categories are then contrasted. Using data from sources using a variety of research approaches is appropriate for this approach to data analysis in an integrated review^[44]. The relevant articles were found, and then a descriptive analysis was done to characterize the chosen articles using frequency and percentage approaches. The variables utilized in the descriptive analysis give an overview of the year of publication, the publication type, the country or region of publication, and the research approach and method adopted in the study.

STAGE 1: DE-CONTEXTUALISATION

This stage includes selecting an analysis unit and making sense of the data instead of actual linguistic units, this content analysis used themes as its unit of analysis (e.g., words, sentences, or paragraphs). Themes serve to express a thought or idea through a single word, phrase, sentence, or even the entirety of a written piece^[47]. Therefore, if a theme represents a single topic and any size of text, a code can be assigned to that theme^[48]. The coding process in this study used the theme of waste management practices as the unit of analysis. Table 2 shows decontextualize the language adopted to identify the articles based on the descriptive analysis, an initial standard list of coding groups was produced. The code list was used to refer to a Microsoft Excel document in which all the data from the chosen articles was manually extracted.

Table 2: Initial article code list

Code	Code list
Year	Year of publication of article
Author(s)	List of authors
Article title	Title of article
Journal or conference	Journals or conferences where article has been published
Country	Country or region where data was collected
Research approach	Research approach used in the study
Research method	Research methods used to collect data
Construction waste management	Identify sustainable construction waste management Technology to enhance human collaboration

Stage 2: Re-contextualisation

Stage 2 refers to the process of open coding by condensing the various descriptions of the unit of analysis under the major theme of identifying innovative waste management practices. The extracted meanings are initially re-contextualized by categorising them under the primary themes with explicit codes or sub-themes based on how similar they are to each other. The codes of subthemes can easily be collected throughout this stage, and so freely generate categories^[47].

Stages 3: Categorisation and Compilation

In Stage 3, categorisation entails grouping the sub-themes into categories and then compiling the results. Similar or dissimilar sub-themes are combined into bigger sub-themes throughout the categorisation process to create the grouping lists of sub-themes in Stage 2. Then, each sub-theme was given a name based on the terms in that category that were particular to its content. To keep track of the number of studies for each sub-theme, the information was then entered into a new Excel spreadsheet.

Step 4: Interpretation of results

Step 4 is related to the interpretation of results and subsequently presents the analyses and conclusions drawn from the integrative review's data analysis.

DESCRIPTIVE RESULTS

After evaluating the secondary data to establish if they met the inclusion criteria, 35 papers were selected to be categorised and coded. Of the publications that were selected, it is apparent from Figure 2 that conference papers constituted nine (9) items, whereas journal articles accounted for twenty-six (26) articles. Conference papers were selectively included in this study to capture recent developments, emerging themes, and evolving technologies related to construction waste management domain that are not yet extensively reported in journal publications.

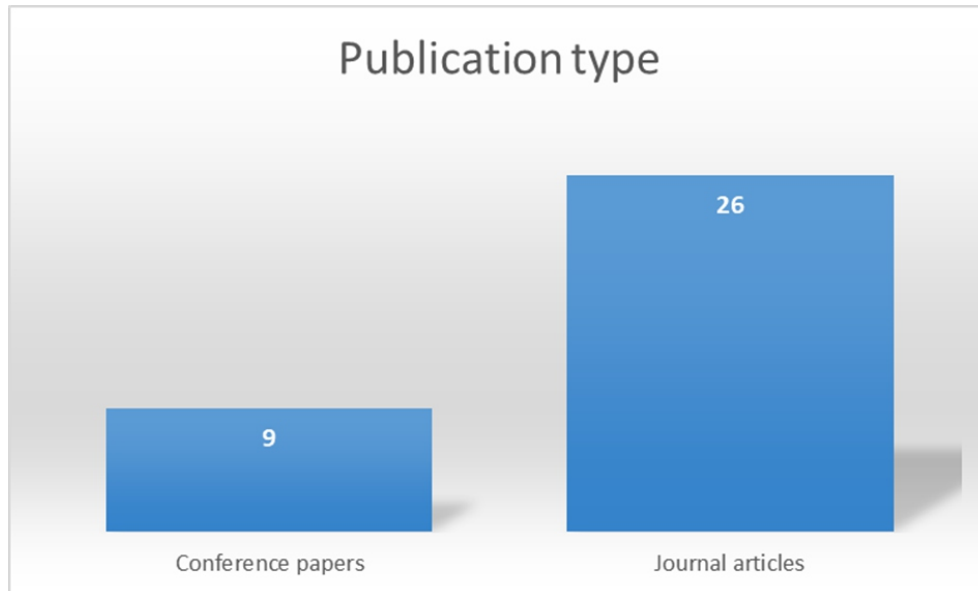


Figure 2: Type of publication

Table 3 depicts the number of selected papers published annually, with an unpredictable development pattern beginning in 2013 and ranging from one (1) to six (6) articles released each year. Since the majority of the papers were published in 2022, there has been an increase in interest in waste management research, with 17.14 percent of articles published in 2020. The publishing of the second-highest number of articles related to this study represents 11.43 percent of all articles published in 2023

Table 3: Number of publications per year

Year	No.	Percentage (%)
2013	1	2.86
2014	3	8.57
2015	3	8.57
2016	2	5.71
2017	1	2.86
2018	3	8.57
2019	4	11.43
2020	5	14.29
2021	3	8.57
2022	6	17.14
2023	4	11.43
Total	35	100.00

RESEARCH APPROACH AND METHOD

IA critical analysis of the publications revealed that all of the research were empirical and used qualitative, quantitative, and mixed-methods approaches. Figure 3 shows that a total of 35 articles with their respective frequencies indicated in parentheses were examined. Evidently, 46% of articles used a questionnaire survey to conduct quantitative research, 40% used interviews and case studies to conduct qualitative research, and 14% used a mixed-methods research approach that included both questionnaire surveys and interviews. Thus, there is potential to increase the use of mixed-method techniques, which would improve the validity of the research study.



Figure 3: Research approach of articles

ANALYSIS OF RESULTS

The integration of technologies to promote sustainable and human-centric waste management practices within the framework of Construction 5.0. described by the authors listed in Table 6 are shown in Table 5 below. Based on the descriptive statistics, the strategies are ranked in a hierarchical order. Evidently, awareness creation with a percentile score of 28.0% is ranked first. Additionally, Table 5 divulges that 24.0% of publications corroborate that waste-related policy, legislation, and regulation are important for promoting waste management practices in C5.0 and ranked second. Promoting sustainable and human-centric waste management practices via the 'Adoption of Building Information Modelling (BIM) to monitor waste' is ranked third and supported by 20.0% of articles. Furthermore, the analysis reveals that 18.0% of articles were resolute that educating the workforce is significant in terms of enhancing waste management practices in C5.0.

Table 5: Waste management strategies

Theme	ID	Frequency	Percentage	Rank
Waste related policy, legislation, and regulation	1, 3, 6, 7, 8, 15, 16, 17, 20, 25, 30, 34	12	24.0	2
Awareness	2, 3, 4, 5, 8, 11, 13, 15, 17, 18, 20, 29, 30, 35	14	28.0	1
Adoption of Building information Modelling (BIM) to monitor waste	9, 11, 12, 20, 21, 23, 24, 25, 28, 32	10	20.0	3
Educate Workforce	4, 5, 8, 14, 18, 19, 22, 23, 26	9	18.0	4
Training	4, 11, 14, 17, 30	5	10.0	5
Total		50	100.0	

Table 6: A list of authors identified the successful and sustainable waste management practices to reduce construction waste

Author	ID
Gemechu Beyene Mekonnen, Leticia Sarmiento dos Muchangos , Lisa Ito and Akihiro Tokai (2022)	1
Saheed O. Ajayi, Lukumon O. Oyedele, Olugbenga O. Akinade, Muhammad Bilal, Hakeem A. Owolabi, Hafiz A. Alaka and Kabir O. Kadiri (2017)	2
Mazen M. Omer, Rahimi A. Rahman and Saud Almutairi (2022)	3
Saheed O. Ajayi, Lukumon O. Oyedele, Muhammad Bilal, Olugbenga O. Akinade , Hafiz A. Alaka, Hakeem A. Owolabi and Kabir O. Kadiri (2015)	4
Beatriz C. Guerra, Fernanda Leite and Kasey M. Faust (2020)	5
Ademilade Aboginije, Clinton Aigbavboa and Wellington Thwala (2021)	6
Soo Yong Kim, Minh V. Nguyen and Van Truong Luu (2020)	7
Mohamed Hussein Hassan, Abdifitah Yusuf Mohamed, Ahmed Mohamud Ibrahim, Zakariye Abdullahi Roble and Ali Tighnavard Balasbaneh (2022)	8
Ibrahim Idris, Abdulkadir Sani and Alkali Ibrahim Abubakar (2015)	9
Seyed Hamidreza Ghaffar, Matthew Burman and Nuhu Braimah (2020)	10
Shitaw Tafesse, Yidnekachew Esayas Girma and Eliyas Dessalegn (2022)	11
Dongchen Han, Mohsen Kalantari and Abbas Rajabifard (2021)	12
José-Luis Gálvez-Martos, David Styles, Harald Schoenbergerd and Barbara Zeschmar -Lahl (2018)	13
Havva Aksel and İkbāl Cetiner (2020)	14
Noraziah Wahia, Corina Josephb, Rudy Tawiec and Roseline Ikau (2015)	15
Ajayi S.O, Oyedele L.O, Bilal M, Akinade O.O, Alaka, H.A and Owolabi, H.A (2017)	16
Erold Pasajol DIMACULANGAN (2023)	17
Llatas C and Osmani M (2016)	18
Jiayuan Wang, Zhengdao Li and Vivian W.Y. Tam (2015)	19
Shitaw Tafesse (2021)	20
Musa Mohammed, Nasir Shafiq, Ali Elmansoury, Al -Baraa Abdulrahman Al -Mekhlafi, Ehab Farouk Rached, Noor Amila Zawawi, Abdulrahman Haruna, Aminu Darda Rafindadi and Muhammad Bello Ibrahim (2021)	21
Mario Ramos, Graca Martinho, Joaquim Pina (2023)	22
Abioye A. Oyenuga and Rao Bhamidiarri (2015)	23
Mbadugha, L C, Aghaegbuna O U Ozumba and Winston M W Shakantu (2021)	24
Muhammad Fikri Hasmori, Ahmad Faizul Md Zin, Sasitharan Nagapan, Rafikullah Deraman, Norhaslinda Abas, Riduan Yunus and Mustafa Klufallah (2020)	25
Solomon Adjei, Nii Ankrah, Issaka Ndekugri and David Searle (2015)	26
Saidat Damola Olanrewaju and Olabode Emmanuel Ogunmakinde (2020)	27
Amany Lotfy A. S. SAWABY and Goksel DEMİR (2023)	28
Nandhinipriya B, Janagan, S S and Soundhirarajan K (2016)	29
Ademilade Aboginije, Clinton Aigbavboa, Wellington Thwala (2020)	30
Angie Silva, Michele Rosano, Laura Stocker and Leen Gorissen (2017)	31
Jingkuang Liu, Yanqing Yi and Xuetong Wang (2020)	32
M.M. Mortaheb and A. Mahpour (2016)	33
Vite, C., Horvath, A.S., Neff, G. and Møller, N.L.H. (2021)	
Atiq Uz Zaman (2014)	34
Florence Yean Yng Ling and Dinh Song Anh Nguyen (2013)	35

DISCUSSIONS OF FINDINGS FOR THE PROPOSED MODEL FOR CONTRACTORS WASTE MANAGEMENT PRACTICES

AWARENESS

The findings indicate that the management of waste by contractors in South Africa can be significantly improved with increased awareness of construction sites. Contractors improve awareness in terms of adopting more innovative methods of construction waste management^[11]. In addition, Hassan et al.^[21] note that an increase in awareness could spark a coordinated effort in South Africa to reduce waste, save resources, and support a cleaner environment. Contractors need to enforce awareness campaigns in construction worksites to change employees' behaviour and promote innovative waste reduction^[48]. However, higher education institutions' commitment to sustainability and contractors' involvement are critical factors determining the success of sustainability initiatives^[42]. Contractors' lack of awareness and knowledge about waste management issues, and ignorance of the environmental consequences of improper waste management, have exacerbated the problem in Construction 5.0^[59]. Hence, in order to properly manage waste, contractors must be aware of environmental problems [62].

WASTE-RELATED POLICY, LEGISLATION, AND REGULATION

The findings from Table 5 reveal that waste-related policy, legislation, and regulations are significant innovative waste management practices adopted by contractors towards achieving sustainable construction in Construction 5.0. This finding is in line with that of Wahi et al.^[49] who stated that strong regulations give authorities the ability to compel adherence to construction waste management procedures. In addition, the effectiveness of waste collection, recycling, and disposal initiatives is believed to be increased when everyone works together^[28]. Conducting on-site construction waste sorting has a potential impact in reducing construction activities on the environment^[49]. Furthermore, policymakers need to make a collaborative effort towards reducing waste in construction worksites to ensure a significant reduction of landfills in South Africa^[23].

ADOPTION OF BUILDING INFORMATION MODELLING (BIM) TO MONITOR WASTE

The findings reveal that construction project planning and design can be improved by adopting BIM, which enables contractors to produce precise 3D models of their projects^[14]. Contractors can better utilize materials and resources by using exact quantity take-offs and scheduling made possible by BIM^[14]. Additionally, the use of BIM enhances stakeholder collaboration and communication^[10]. Construction waste and non-value-adding activities can potentially be reduced through technological advancement and innovative production techniques^[25]. However, most of the existing waste management tools are not compliant with BIM even though BIM is becoming more popular in building design^[63]. This promotes a significant need to incorporate waste management in building design to assist contractors to effectively manage waste in construction sites.

EDUCATE WORKFORCE

The findings reveal that educating construction workforce regarding waste management practices in C5.0 can significantly contribute to improving contractors' waste management practices in South African. Educating the construction workforce on waste management procedures is crucial for promoting industry sustainability^[50]. Construction organisations can use the C5.0 algorithm to implement a data-driven training strategy, guaranteeing that instructional programs are both targeted and effective^[64]. C5.0 examines many aspects influencing waste management techniques, such as worker experience and existing training methods, and creates a decision tree to emphasize the most important elements^[38]. Educating construction workforce enables the development of tailored training content that meets specific needs and knowledge gaps, therefore increasing the adoption of sustainable waste management techniques^[65]. Contractors may improve the efficiency of these initiatives by continuously monitoring and evaluating them, contributing to a more environmentally responsible construction sector^[50].

PROPOSED INNOVATIVE CONCEPTUAL MODEL FOR CONTRACTOR'S WASTE MANAGEMENT PRACTICES

The effectiveness of waste management in South Africa is strongly reliant on human-centric waste management practices, which can now be evaluated using the proposed model derived from studies of construction waste management practices that consider both objective and subjective practices.

Figure 4 presents that in Construction 5.0 of human-centric waste management practices, the interconnectivity of key factors such as awareness, waste-related policy, legislation, and regulations, BIM, and educating the workforce. Awareness plays a key role in enabling the effectiveness of human-centric waste management in the South African construction industry, as it has a significant impact on how construction industry practitioners interpret and comply with regulatory requirements^[21;23;24].

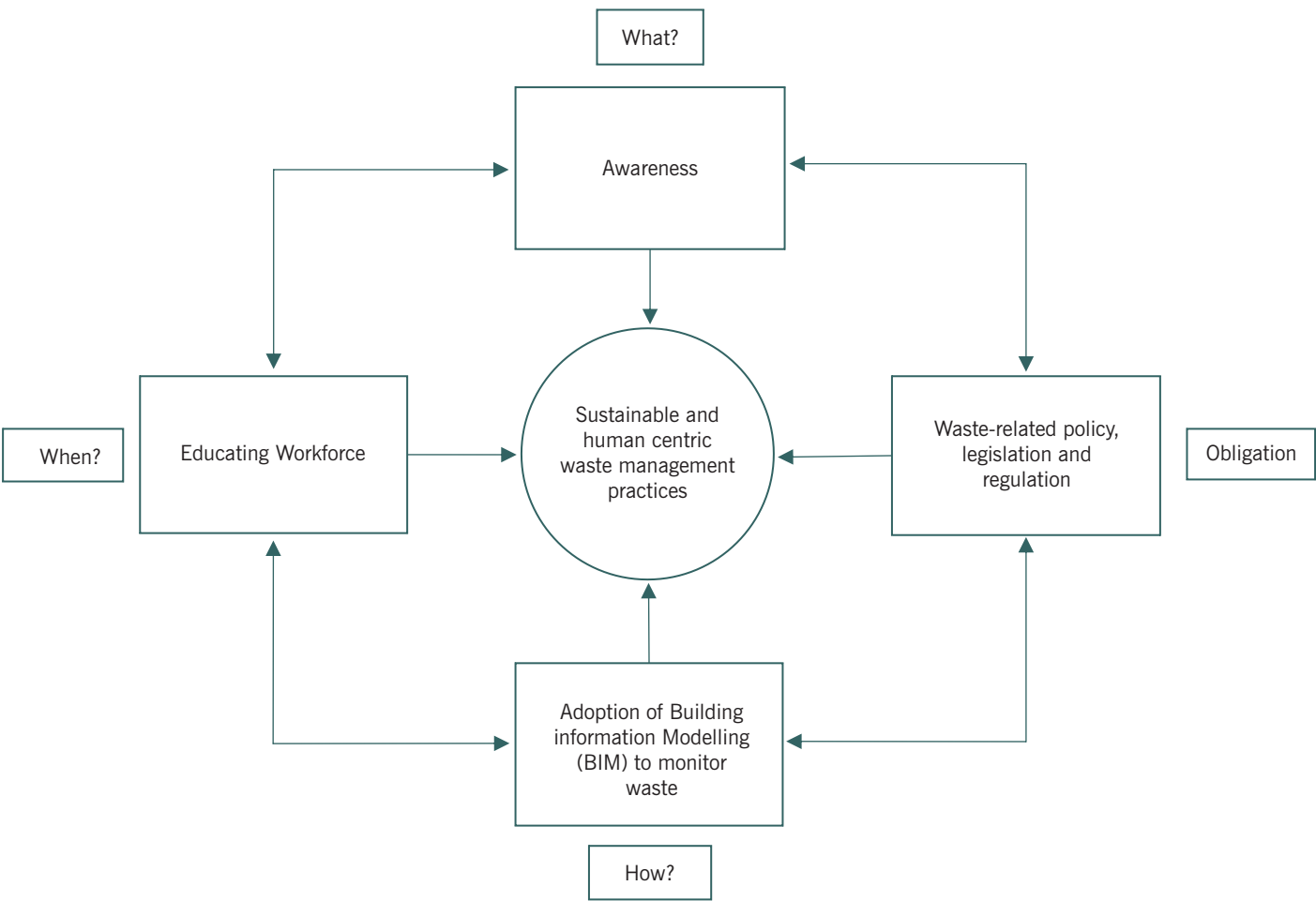


Figure 4: A proposed innovative conceptual model for contractor's waste management practices

According to^[28], if the construction workforce is well-trained and informed, construction regulations are more likely to be translated into practical, site-level actions rather than focusing on compliance. Additionally, BIM serves as a key enabler to effective adoption of human-centric waste management by monitoring waste, quantifying, and reducing throughout project delivery^[14]. Consequently, Figure 4 shows that the effective alignment of workforce awareness, skills development programmes, and the inclusion of waste management regulations provides an enabling environment for effective human-centric waste management to support sustainable construction practices^[38;60].



CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

This paper explored the transformative role of digital technologies in supporting sustainable and human-centered waste management practices within the context of Construction 5.0 (C5.0), with the aim of improving the sustainability of South African construction waste management practices. The findings emerging from the systematic literature review (SLR) disclose that there is an urgent need to adopt effective waste management practices on construction sites to achieve sustainable construction project success. By enabling real-time monitoring, predictive analysis, and transparent decision-making, digital technologies enhance operational efficiency, reduce environmental impact, and empower communities to participate actively in waste reduction. Based on the findings, measures to improve waste management practices can be technological, institutional, or policy-oriented. By synthesising previous research, an integrated innovative conceptual model has been developed mimicking Sustainable and Human-Centric waste management practices to proffer solutions to the upsurge of waste generation in the construction industry. The four constructs are presented in Figure 2. These solutions may vary from interventions such as education and training, awareness creation, governance systems, where waste management-related policy, legislation, and regulatory mechanisms are instituted, to major approaches such as the adoption of digital technology, specifically BIM, to monitor waste. The South African construction industry can enhance operational performance and long-term profitability by utilising the innovative construction waste management procedures postulated in the conceptual model. Industry role-players, policymakers, and researchers must work in a collaborative manner to achieve a waste-free future, paving the way for a more responsible and resource-conscious construction industry as the sector grows. This will help to achieve not only a waste-free industry, but also Agenda 12 and 13 of the SDGs.

This study recommends that contractors should adopt targeted awareness and workforce education programmes to enhance the understanding of sustainable and human-centric waste management practices, and practical adoption of Construction 5.0. In parallel, waste-related policies should be improved and realigned to promote digital waste monitoring and reporting. This study further recommends that construction organisations should integrate technology in waste reduction across the project life cycle, from the design stage, waste forecasting to on-site waste monitoring.

The paper adds to the body of knowledge by providing insights regarding the status quo of Construction 5.0 technologies in the construction industry and how digital technologies can be leveraged to address waste management challenges in construction. By adopting a systematic review approach, the study also consolidates fragmented research into an integrated conceptual model for contractors' waste management practices in Construction 5.0. This study focuses on contractors' waste management practices on construction sites in the South African construction sector, with the goal of improving sustainable and human-centered waste management practices in the context of Construction 5.0, therefore, the findings may not be generalised. However, the findings may serve as a precursor for collecting empirical data to validate the proposed conceptual model.

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