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EXPLORING A LEAN INFORMED FRAMEWORK FOR REDUCING CONSTRUCTION AND DEMOLITION WASTE IN ZIMBABWE

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ABSTRACT

The inadequate minimization of construction and demolition waste (CDW) in Zimbabwe created a need for a framework that combines Lean Construction (LC) and Construction 5.0. This paper thus develops guidelines and a conceptual framework for the minimization of CDW in Zimbabwe through LC and Construction 5.0. A critical review of the LC and Construction 5.0 literature was conducted to extract the most effective ways of integrating the two principles. A questionnaire survey was conducted to identify the most effective techniques for the framework. The frameworks show that certain pillars of Construction 5.0 (human centricity, sustainability, and resilience) and LC (Kaizen, Last Planner System, Just-In-Time, and Standardisation) have the potential for making a difference in the reduction of CDW in Zimbabwe.

KEYWORDS

Construction 5.0, Construction waste, Demolition waste, Lean Construction, Waste, Zimbabwe

INTRODUCTION

The construction sector contributes about 5% to GDP globally and is vital to society (Khaertdinova et al., 2021). The construction industry creates jobs and provides infrastructure (Tunji-Olayeni et al., 2023). In low-income countries, the construction industry employs about 7.6% of the labor force (Mella & Savage, 2018). Despite the employment and production potential, the construction sector faces challenges, including time overruns (Soomro et al., 2019), cost overruns (Xie et al., 2022), rework (Garg & Misra, 2021), low productivity (Manoharan et al., 2022), and poor CDW management with significant health and wellbeing implications (Mavroulidisa et al., 2022). For example, CDW in Zimbabwe is dumped in undesignated areas (Tsiko & Togarepi, 2012), constituting 13.9% of the waste in market areas and 8.7% in industrial areas (Jerie, 2018). Disposed metals and wood constitute 39.6% and 12.1% of waste, respectively (Jerie, 2018). There is a responsible ministry accountable for environmental management in Zimbabwe. However, CDW management policies in Zimbabwe do not address CDW concerns (Magadzire & Maseva, 2006).

According to Maponga & Emuze (2024: 937), the dumping of CDW in market spaces, roadsides, and landfills has been creating eyesores and social obstructions, as well as

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environmental pollution, in Zimbabwe. The application of lean-based CDW minimization can minimize the environmental and health impacts of CDW. Lean CDW guidelines can minimize work rework and increase customer value. Training project team members in lean techniques ensure team members have the necessary lean skills and expertise during the implementation phases. Lean policies and regulatory frameworks can encourage stakeholder buy-in and waste stream identification. Worker engagement is key in combatting worker resistance to change. This study is unique because it builds on other existing lean CDW minimization studies by integrating lean and construction 5.0. This study therefore addresses the following research questions:

- What are the Lean and Construction 5.0 tools for minimizing CDW in Zimbabwe?
- How will the Lean and Construction 5.0 framework reduce CDW in Zimbabwe?

PROBLEM STATEMENT

CDW is costing contractors and clients' money in Zimbabwe as it is disposed of in landfills, riverbanks, roads, and open spaces. In Zimbabwe, 76% of the CDW is dumped in open spaces, 7% is burnt, and the other CDW is dumped on roadsides, industrial areas, and market areas (Jerie, 2018). Minimal regard for the environmental impacts of the CDW is made, and the technology and knowledge needed to employ sustainable CDW management techniques are not available (Magadzire & Maseva, 2006). Therefore, this paper aims to develop a Lean and Construction 5.0-based framework for minimizing CDW in Zimbabwe.

STAGES OF INDUSTRIAL REVOLUTIONS

Table 1 documents the world's industrial revolutions. The first industrial revolution, Industry 1.0 (IR 1.0), began in the 18th century as part of the steam age (Xu et al., 2018). The second industrial revolution, Industry 2.0 (IR 2.0), which started in the 19th century, was the age of mass production; the era brought electricity and internal combustion engines (Groumpos, 2021). The third industrial revolution, Industry 3.0 (IR 3.0), began in the 20th century, and production was based on electronics and automation (Vinitha et al., 2020). The fourth industrial revolution (IR 4.0) brought about the development of smart computer systems (Lu, 2017). The fifth industrial revolution (IR 5.0) was introduced in 2017, focusing on man and the environment (Lu, 2020). According to Marinelli (2023), Construction 5.0 integrates technology and human creativity in construction processes. Construction 5.0 champions environmental sustainability, minimizes CDW and helps lower carbon footprints (Hu et al., 2023). Construction 5.0 is a construction practice where modern technologies complement humans and do not replace them. It incorporates artificial intelligence (AI), the Internet of Things (IoT), BIM, and cobots (Yitmen, 2023). According to Stephen et al. (2024), Cobots are Collaborative Robots which are a key technology in the Construction 5.0 system, the Cobots are designed to work alongside humans.

Table 1: Industrial revolutions

Industrial Revolutions	Time Introduced	Description	Source
Industry 1.0	18th Century	Steam age and mechanization	(Xu et al. 2018; Akundi et al. 2022)
Industry 2.0	19th Century	Mass production and electric power usage	(Groumpos, 2021; Leng et al. 2022)
Industry 3.0	20th Century	Automation age, electronics, the Internet	(Vinitha et al. 2020)
Industry 4.0	2011	Digital age, machine learning, and AI	(Lu, 2017; Leng et al. 2022)
Industry 5.0	2017	Collaboration with machines	(Maddikunta et al. 2022; Nahavandi, 2019)

BENEFITS AND CHALLENGES OF CONSTRUCTION 5.0

Construction 5.0 technologies include robotics bricklaying, inspection drones, and autonomous machinery (Parn et al., 2018). Musarat et al. (2023) stated that Construction 5.0 could benefit the construction industry by speeding up work and reducing labor costs. Construction 5.0 techniques reduce accident risks in intricate and complex work (Ikudayisi, 2023). Construction 5.0 can lower greenhouse gas emissions (Reja & Varghese, 2019). Modular construction can be utilized, which helps reduce CDW (Musarat et al., 2023). According to Yenita (2023), innovators are needed in CDW management to solve problems that help realise the continuity of economic digitalization in Indonesia and green tech companies should become leading innovators in processing CDW in the industrial 5.0 era.

Cobots can handle dangerous work and improve safety (Sowa et al., 2020; Adel, 2022). Building printing can reduce accidents (Sakin & Kiroglu, 2017). Wearable devices can be utilised to monitor CDW (Salento, 2017). Virtual reality can provide safe worker training (Nahavandi, 2019). Building Information Modelling (BIM) can improve project collaboration (Abbasnejad et al., 2021). AI can be utilized for CDW reduction (Adel, 2022). CDW sorting and management can also be done using AI (Voulgaridis et al., 2022). Digital twin technology can be used for building energy management (Agouzoul et al., 2021). Construction sites can have CDW tracking sensors and reduce environmental impacts (Svertoka et al., 2021). Construction 5.0 technologies utilized for CDW minimization are illustrated in Table 2.

Table 2: Construction 5.0 technologies for minimising CDW

Technology	Uses	Source
Human Centricity		
BIM	Collaboration	Abbasnejad et al. (2021); Yitmen et al. (2023)
Wearable devices	Monitor CDW	Salento (2017); Tunji-Olayeni et al. (2024)
Virtual Reality	Worker training	Nahavandi (2019); Leng et al. (2022)
Environmental Sustainability		
AI	CDW reduction	Adel (2022); Yitmen et al. (2023)
AI	Sorting CDW	Voulgaridis et al. (2022); Leng et al. (2022)
Cyber-physical systems	CDW control	Voulgaridis et al. (2022); Tunji-Olayeni et al. (2024)
Sensors	Tracking CDW	Svertoka et al. (2021); Leng et al. (2022)
Networked sensors	CDW management	Elechi et al. (2021); Leng et al. (2022)
Sensors	CDW management	Ramırez-Moreno et al. (2021)
Resilience		
BIM	Reduced reworks	Parn et al. (2018); Yitmen et al. (2023)
Cloud computing	Data storage	Voulgaridis et al. (2022); Leng et al. (2022)
Cobots	Reduce CDW costs	Maddikunta et al. (2022)
Machine learning	Predict disruptions	Adel (2022); Tunji-Olayeni et al. (2024)

Despite the potential gains of Construction 5.0, it requires much time to work, and specialized software is needed (Musarat et al., 2023). Additional challenges include demands for collaborative robotics, AI, real-time data (RTD), and the IoT to work (Demir et al., 2019). Construction 5.0 is costly since innovative technologies are needed (George, 2020). Communication with networked gadgets requires strict internet security (Paschek et al., 2019). Research on the financial impacts of Construction 5.0 is still in its infancy, and the area is a novel concept yet to be widely accepted (Musarat et al., 2023). The strengths of the Construction 5.0 approach are, that people become more creative and innovative, green construction is possible to implement and there is an improvement in environmental aspects (Voulgaridis et al. 2022; Leng et al. 2022). The gaps in Construction 5.0 are, that different technologies result in new production settings, there will always be different technological

adoption levels and the exact roles of humans in Construction 5.0 may be very trivial (Parn et al. 2018; Yitmen et al. 2023).

LEAN CONSTRUCTION (LC) FOR CDW MANAGEMENT

LC is a technique used to design and produce construction systems to minimize waste and generate value (Ahmed, 2020). Tommelein and Ballard (2016) defined LC as applying lean thinking in construction projects. Pedo et al. (2021) stated that LC can enhance CDW minimization through process standardization and systematic waste analysis. LC can minimize CDW generation and allow stakeholders to be involved. Mawed et al. (2020) state that poor project communication leads to reworks and CDW generation. As an illustration, Erazo-Rondinel and Huaman-Orosco (2021) outlined that the construction industry in Peru is still focusing on the project stage they oversee. LC involves CDW reduction, communication improvement, improved quality, reduced variability, inventory decreasing, and teamwork (Emuze et al., 2014; Srinivas, 2020; Abdullah et al., 2009). Table 3 outlines some of the lean tools utilized in CDW minimization.

Table 3**:** Lean construction tools that can be applied for CDW Management

Lean Tools	CDW Application Techniques	Sources
-Visualize flow -5S	Identify CDW-generating work areas. Sorting CDW	(Hamzeh & Albanna, 2019; Aslam et al. 2020; Jin & Doolen, 2014)
-Standardisation -Clear visualisation	Standard working procedure. Signage on site	(Marzouk et al. 2019; Steel, 2012)
-Value Stream Mapping -Circular economy	Flow charts to depict every work process. Monitor CDW-generating areas.	(Hamzeh & Albanna, 2019; Maponga & Emuze, 2024)
-BIM -JIT -Daily huddle meetings	Digital representation of the project. Models utilised. Supply materials when needed.	(Memon et al. 2018; Bajjou & Chafi, 2018)
-Continuous improvement	Documenting and constantly checking for improvement.	(Marzouk et al. 2019)
-Daily CDW huddle meetings	Short everyday meetings on CDW issues.	(Memon et al. 2018)

While lean tools for CDW management exist, however, there are no obvious financial incentives to adopt lean construction and recycling, as discussed by Mawed et al. (2020). It makes no financial sense to contractors because it takes time and money to recover recyclable materials. Mawed et al. (2020) pointed out that resistance to change is embedded in humans, and people will resist LC because they do not use it as their usual way of working. Ayalp and Anaç (2024) asserted that time and budget constraints would hinder adopting and training lean CDW minimization. Ayalp and Anaç (2024) also confirmed that fear of the new CDW technologies might make workers resist change.

RESEARCH METHODS

This study aims to develop a lean informed framework for reducing construction and demolition waste in Zimbabwe. The identification of the most effective lean and Construction 5.0 CDW minimisation strategies and their implementation will lead to the formulation of the Zimbabwean CDW minimisation guidelines. To achieve the intended goals, project site case studies were conducted in selected construction sites located in Harare, Gweru, and Bulawayo. Case studies can generate insights from research leading to rich and empirical descriptions, the use of case studies is advocated in the exploratory stages of the study to complement deductive research (Eisenhardt 1989; Saunders et al. 2019). In-depth interviews, questionnaires and a detailed literature review were the major data collection methods. In semi-structured interviews,

the interviewer starts with a list of themes to guide interview conduct, this allows a comparison of the respondents' responses to each theme (Saunders et al. 2019). The construction sites were selected using purposive sampling techniques (Ritchie and Lewis 2003). Only contractors with more than five years' experience having staff with knowledge in lean construction and Construction 5.0 were selected for the study. Construction professionals, contractors, and skilled and semi-skilled workers were selected for the study. The interview questions asked focused mainly on four aspects. These aspects include:

- The most effective lean tools for minimisation of CDW in Zimbabwe,
- The most effective Construction 5.0 strategies for the minimisation of CDW in Zimbabwe,
- The most effective way of integrating lean and Construction 5.0 strategies and,
- The strategy that can be adopted for minimising CDW in Zimbabwe.

The interview was conducted using a semi-structured protocol (McNamara 2009). The researcher interviewed 260 subjects. For interview consistency, the interview duration ranged from 45 minutes to 55 minutes for each interview session. All the interview sessions were transcribed, after transcription, the collected data was then analysed using content analysis (Krippendorff, 2012). The themes obtained from analysed data were validated through follow-up interview sessions (McNamara, 2009). The gathered themes were further validated using attitudinal surveys (McNamara, 2009). Information from the literature analysis was used for the preparation of questionnaires. In the questionnaires, respondents were asked to rank selected lean tools; Visualize flow, 5S, Standardisation, Clear visualisation, Value Stream Mapping, Circular economy, BIM, JIT, Daily huddle meetings, Continuous improvement and daily CDW huddle meetings. The respondents also ranked selected Construction 5.0 concepts; Human involvement essential, Prioritizing human needs, Re-thinking existing methods, Harmony between machines and humans, Cobots working alongside humans, AI CDW minimization and Economy, Environment, and Society. The collected data was analysed using the mean score (MS), standard deviation (SD), and Relative Importance Index (RII) (George and Mallery, 2003). The strategies with the highest MS were ranked first, while those with the least were ranked last. To avoid research bias, the study questions were made very clear, the study objectives were clearly defined and the study included random sampling and snowballing to avoid selection bias. According to Mouselli and Massoud (2018), study bias arises mainly from errors in sampling or testing.

RESULTS

An overall total response rate of 79.3% was obtained for the study. The respondents' profiles are given in Table 4.

Table 5 illustrates the results of the questionnaire survey. It shows the five top-ranked lean CDW minimization strategies were LT1, recycling, with MS = 4.62 and SD = 0.63. The second technique was LT2, Continuous Improvement, with MS = 4.52, and SD = 0.82. The third technique was LT3, Concurrent Engineering, with MS = 4.27 and SD = 1.06. The fourth technique was LT4, the Last Planner System (LPS), with MS = 4.15 and SD 1.29, and the fifth lean tool was Just-In-Time (JIT), with MS = 4.08 and SD = 1.30. The mean score (MS) and the relative importance index (RII) were used for the rankings. The MS was generated by SPSS version 25. Similarly, the table indicates the perceptions related to Construction 5.0 concepts. The top-ranked concept is human involvement, which is essential. The second-ranked concept is prioritizing human needs in CDW minimization. The third-ranked concept is rethinking existing methods, while the fourth is harmony between CDW minimization machines and humans. The fifth concept is that Cobots work with humans. Table 5 illustrates the questionnaire survey results.

Table 4: Respondents profile

Attribute	Sub-Attribute	Respondents #	Respondents %
Professional roles	Bricklayers, class one to four	20	7.7
	Semi-Skilled Bricklayers	80	30.8
	Carpenters, class one to four	20	7.7
	Semi-skilled Carpenters	50	19.2
	Painters	20	7.7
	Professionals	43	16.5
	Contractors	27	10.4
General experience in construction	1-5 years	107	41.2
	6-10 Years	68	26.2
	11-15 Years	41	15.8
	More than 15 Years	44	16.9
Experience of contractors	1-5 Years	5	18.5
	6-10 Years	4	14.8
	11-15 Years	15	55.6
	More than 15 Years	3	11.1

Table 5: Questionnaire survey results

CODE	Lean Techniques	MS	STD DEV	Variance	RII	Rank
LT_1	Recycling	4.62	.63	.39	0.92	1
LT_2	Continuous Improvement (CI)	4.52	.82	.68	0.90	2
LT_3	Concurrent engineering (CE)	4.27	1.06	1.12	0.85	3
LT_4	Last Planner System (LPS)	4.15	1.29	1.68	0.83	4
LT_5	Just-In-Time (JIT)	4.08	1.30	1.69	0.82	5
LT_6	Increased Visualization (IV)	4.08	1.11	1.23	0.82	6
LT_7	Standardisation	3.92	1.41	2.00	0.78	7
LT_8	Building Information Modelling (BIM)	3.92	1.39	1.93	0.78	8
CODE	**Construction 5.0 Concepts**	**MS**	**STD DEV**	**Variance**	**RII**	**Rank**
CAI_1	Human involvement essential	4.62	.63	.39	0.92	1
CAI_2	Prioritizing human needs	4.52	.82	.68	0.90	2
CAI_3	Re-thinking existing methods	4.27	1.06	1.12	0.85	3
CAI_4	Harmony between machines and humans	4.15	1.29	1.68	0.83	4
CAI_5	Cobots work alongside humans	4.08	1.30	1.69	0.82	5
CAI_6	AI CDW minimization	3.92	1.11	1.23	0.82	6
CAI_7	Economy, Environment, and Society	3.92	1.39	1.93	0.78	7

CONCEPTUAL FRAMEWORK

The top five ranked Constructs and indicators indicate that human involvement is essential for CDW minimization, prioritizing human needs, rethinking existing methods, harmony between machines and humans, and Cobots working alongside humans. The top-ranked lean techniques were then adopted for the Lean and Construction 5.0 CDW minimization framework in Table 6.

Table 6: A framework for CDW minimization in Zimbabwe (Researcher's construct)

Pillars of Construction 5.0	Technology Used	Lean Tools Used	Human Tasks/Processes	Benefits
Human Centricity	Data cloud storage	CDW recycling	Humans control the system	Job security
	Cyber systems		Human needs observed	Human value
	Environmental sensors		Integrated health and safety systems	Improved worker safety
	AI	Continuous Improvement	CDW inventory	CDW inventory
	AI		Generation of CDW reports	Easy reports
Sustainability	AI	Concurrent Engineering	Recycling, recover and reuse	Recycling
			Circular Economy	SDG 6 achieved
	Humans	Last Planner System	Repurpose CDW	Greening
			Hazardous CDW tracking	Control of hazardous CDW
Resilience	Network sensors	Just In Time	CDW minimisation during pandemics	Uninterrupted work
	Humans		Disaster proof procedure	Minimised risks
	AI	Standardisation	CDW quantification	SDG 8 achieved
	AI		Data cloud storage	Client value

DISCUSSION

The proposed CDW minimization framework is based on Yitmen et al. (2023) and Leng et al. (2022). It uses the essential Construction 5.0 pillars of human centricity, sustainability, and resilience. The Construction 5.0 technologies employed are listed in column 2. The 3rd column lists the lean tools which work with the provided AI technologies. The human tasks and processes are the tasks done by the humans in collaboration with the Construction 5.0 technologies. The implementation stages of the framework are in three stages, explained in the following sub-sections.

STEP 1: HUMAN CENTRICITY

In the framework, Construction 5.0 technologies will be used for cloud data storage and AI for generating reports and environmental toxic CDW sensing. Lean CI will be implemented to continuously improve the procedure. Humans will control the whole system and monitor all generated reports and activities. AI and Cobots can handle dangerous work improving safety (Sowa et al. 2020; Adel, 2022). Wearable monitoring devices can be used to monitor and capture worker health data (Salento, 2017). Virtual reality and AI can be used for worker training (Nahavandi, 2019). Human centricity in CDW management focuses on the needs of consumers and not preferring machines over humans (Matsuda et al. 2019: Leng et al. 2021). Humans need automation, and a human-centric CDW management system offers flexibility and resilience to pandemic-caused disruption (Rauch, 2020; Sigov, 2022). "Lean Construction 4.0 needs to develop its processes through technology and considering people, and Society 5.0 searches for the better use of technology to improve the human's physical world, it is feasible to say that the relationship between both paradigms is sensitively close, specifically under a

human-centered approach …" (Forcael, 2024: 1289). LC in this case helps construction professionals do more with less (Womack et al. 1994).

STEP 2: SUSTAINABILITY

In the sustainability pillar, AI and cyber systems will be used for hazardous CDW tracking. The LPS and CE will be utilised by humans to implement circular economy, recycling and fostering environmental sustainability. Digital twin, AI, machine learning, and sensors can be used for CDW reduction (Adel, 2022), and sorting (Voulgaridis et al. 2022). Cyber sensors can be used to track air quality, noise and humidity (Svertoka et al. 2021). AI trackers can be used for tracking Co2 levels, pressure, temperature and embodied energy (Nahavandi, 2019). Sustainable innovation is key to providing customized projects and meeting customers' requirements; blockchain technology could be utilized (Leng et al., 2020; Venkatesh et al., 2020). "The circular economy concept (CE) makes a salient contribution towards resource efficiency through product-life extension, redistribution/ reuse, remanufacturing, and recycling as well as re-engineering of organisational processes" (Aneke & Awuzie, 2018, p. 119). Concurrent Engineering (CE) is the design and construction of projects in parallel, not sequentially; CE minimizes CDW, reduces design time, and helps improve designs (Camuffo et al., 2017). CE is one of the techniques that has yielded adaptation in CDW management (Memon, 2018). CE helps overcome fragmentation in the construction sector (Aniekwu & Igboanugo, 2012). CE can reduce construction project schedules by about 20-25% (Camuffo et al., 2017).

STEP 3: RESILIENCE

A combination of network sensors, humans and AI will foster resilience by making sure there is an uninterrupted procedure even during pandemics. JIT inventory systems and a standardised procedure will help with a solid resilient system. Digitalisation can enhance the prediction of disaster and pandemic preparedness as this has been a challenge before (Tunji-Olayeni et al. 2024). Resilience is the industrial system's ability to recover quickly during and after disruptions (Leng et al. 2022). Construction 5.0 emphasizes the resilience of construction industries and involves exposure to national processes for identifying disasters (Schaltegger, 2020). Camuffo et al. (2017) state that the LPS involves all workers in CDW minimization and safety management planning. Involving all workers significantly reduces CDW and improves health and safety at work. Ghosh et al. (2020) stated that involving all personnel promotes safety, improves commitment, enhances self-esteem, and gives workers a sense of belonging.

CONCLUSION

Effective management of CDW in Zimbabwe has been a challenge, as is evident on roadsides, industrial areas, watercourses, open spaces, and market areas. Embracing technology alongside human involvement can help create an effective CDW minimization strategy for the Zimbabwean construction industry. Using technology and considering people using human-centered approaches cannot be ignored as it is essential to create employment for workers. This study offered detailed discussions on Construction 5.0 and how it can be integrated with Lean Construction to create a framework for reducing the menace of waste from construction activities in Zimbabwe. The conceptual framework suggests that prioritizing human centricity, sustainability, and resilience will support the implementation of lean techniques including continuous improvement (kaizen), standardization, JIT, and other tools in the design and construction of projects in Zimbabwe. These exploratory results are limited in terms of generalizability, but rich in insights related to how to expedite future studies in this subject area. Future research on the area could focus on; strategies for worker lifelong learning on Construction 5.0 and LC. Practical case study implementation of lean and Construction 5.0. Re-

thinking of existing construction methods. Human-machine collaboration in co-designing construction projects. Construction 5.0 and lean construction design with a view of AI.

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