

NEXUS BETWEEN LEAN CONSTRUCTION AND CONSTRUCTION 6.0 FOR THE MANAGEMENT OF CONSTRUCTION AND DEMOLITION WASTE (CDW)

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ABSTRACT

The study examines how integrating Industry 6.0 concepts with Lean Construction (LC) principles can enhance efficiency and minimise Construction and Demolition Waste (CDW) in the construction industry. Industry 6.0 concepts emphasise deep human–machine collaboration, high levels of automation, and quantum cloud-connected systems. Construction procedures can become more efficient and value-driven by adopting LC techniques that prioritise identifying client value, minimise waste, ensure efficient workflows, and promote continuous improvement. A quantitative study approach was adopted, and the perspectives of 260 construction professionals and academics were gathered to rank the current CDW minimisation practices in Zimbabwe. The advantages of using LC and Construction 6.0-based strategies included reduced CDW, increased project time, reduced costs, and enhanced collaboration. Based on the findings, the study recommends adopting LC and Construction 6.0-based strategies to minimise CDW.

KEYWORDS

Construction 6.0, construction waste, demolition waste, industry 6.0, waste, Zimbabwe.

INTRODUCTION

The construction sector creates jobs for different countries (Tunji-Olayeni et al., 2023). The construction industry employs 7.6% of the working population in developing countries (Mella & Savage, 2018). Despite all the production, the construction sector faces challenges like project time overruns (Soomro et al., 2019), budget overruns (Xie et al., 2022), reworks (Garg & Misra, 2021), low productivity (Manoharan et al., 2022), poor CDW management and poor health and safety issues (Mavroulidisa et al., 2022). CDW in Zimbabwe is disposed of in waterways, roadsides, and market spaces (Tsiko & Togarepi, 2012). According to Jerie (2018), CDW in Zimbabwe accounts for 13.9% of waste in market areas and 8.7% in industrial areas. Metals and wood waste contribute 39.6% and 12.1% of the CDW dumped, respectively (Jerie, 2018). Zimbabwean policies and implementation frameworks regarding the CDW management are lacking and insufficient in addressing CDW concerns (Magadzire & Maseva, 2006).

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Industry 1.0 (IR 1.0), which is the steam age, began in the 18th century (Xu et al., 2018). Industry 2.0 (IR 2.0) began in the 19th century and introduced electricity, internal combustion engines, and telegraphs (Groumpos, 2021). Industry 3.0 (IR 3.0) began in the 20th century, with production primarily based on electronics and automation (Vinitha et al., 2020). Industry (IR 4.0) has driven the development of smart technological systems, including artificial intelligence (AI), machine learning, and other cyber-physical systems (Lu, 2017). Industry 5.0 (IR 5.0) began around 2017 and focuses on people and the environment (Lu, 2020). Industry 6.0 (IR 6.0), which is still under refinement, focuses on green sustainability, advanced digital systems, product customisation, virtualised digital supply chains and human-centred innovation. The main technologies will include quantum-based systems, robotics, artificial intelligence (AI), and deep convergence of human and machine twins (Roshid et al., 2025).

This study seeks to develop a Construction 6.0 and Lean Construction (LC) based framework for the minimisation of CDW in Zimbabwe. Rather than reinventing the wheel, the study develops a conceptual framework that leverages synergy between Construction 6.0 principles and LC, based on a literature review and an online questionnaire survey. The study complements the current body of knowledge on Construction 6.0 and contributes techniques for implementing LC in Zimbabwe. The framework was developed by first outlining the dominant CDW minimisation practices in Zimbabwe, the most effective strategies for the socio-economic environment, and the outputs of the Construction 6.0 and LC CDW minimisation strategies.

PROBLEM STATEMENT

CDW in Zimbabwe is disposed of in undesignated places, such as open spaces, roadsides, and market areas (Jerie, 2018). No sustainable CDW minimisation techniques are utilised, and the technology to do so is not available (Magadzire & Maseva, 2006). Waste in the Zimbabwean construction industry affects performance in terms of quality, cost, and safety, and the implementation of lean tools has yet to be practically operationalised (Moyo & Emuze, 2023).

LEAN CONSTRUCTION (LC)

Forbes & Ahmed (2020) defined LC as a technique for designing construction systems to minimise waste. The Japanese automotive industry developed Lean Manufacturing (LM) in the 1950s and later adopted it in the construction industry (Waheed et al., 2024). Tommelein & Ballard (2018) defined LC as the application of lean thinking to construction projects. Bajjou et al. (2018) postulated that LC principles are process transparency, process variability (PV), continuous improvement (CI), and flow variability (FV). Waheed et al. (2024) stated that LC and sustainable construction share the same agenda of reducing waste. Taiichi Ohno developed Lean Manufacturing (LM) in the 1950s at the Toyota Motor Company; the principles led to the development of the Toyota Production System (TPS) (Ong & Pheng, 2021). LC is reducing and eliminating waste in construction, pursuing perfection and focusing more on value-adding activities (Hei et al., 2024; Marhani et al., 2012). According to Hei et al. (2024), LC utilises tools such as the Last Planner System (LPS), Just-In-Time (JIT), Kanban, Value Stream Mapping (VSM), Waste (Muda), Continuous Improvement (CI), and Total Quality Management (TQM). Some of the principles of LC are illustrated in Table 1.0 below.

Table 1: Principles of Lean Construction

Principles of LC	Description	Source
Increase project output	Increase project output through consideration of customer value	Koskela (1992); Bajjou & Chafi (2018).
The client value	Create good value for the customer.	Bajjou & Chafi, (2018).
Eliminate all forms of waste.	Elimination of all various forms of waste on the construction site	Koskela (1992)
Maintain workflow	Project delivered without delay.	Omar (2022
Continuous Improvement	Permanently improving work procedures and techniques	Koskela (1992); Omar, (2022)
Pursue perfection	Create a procedure which eliminates all waste.	Bajjou & Chafi, (2018).

CHALLENGES OF ADOPTING CONSTRUCTION 6.0

Roshid et al. (2025) stated that some adoption challenges, such as ethical issues, change management, and human resource skills, still need to be addressed. Specific sustainability goals still call for a significant need to establish frameworks that connect sustainability across all industrial sectors (Fernández-Miguel et al., 2024). The application of AI still shows gaps in technological innovation enforcement in emerging economies, without human intervention (Carpanzano & Knüttel, 2022; Nleya & Velepini, 2024). There is no well-developed, real-world framework for the responsible implementation of emerging technologies, and different organisations must design and implement their own plans to achieve sustainability, ethical standards, and technological goals (Jain, 2024).

BENEFITS OF CONSTRUCTION 6.0

Shkarupeta & Babkin (2024) stated that IR 6.0 offers many advantages in supply, optimisation, and industrial product design. Construction 6.0 helps create an ultra-smart construction setup with a new form of hyper-symbiotic intelligence; the biosphere and technosphere will co-exist in harmony (Roshid et al., 2025). Industry 6.0 utilises 6G, the next generation of wireless technology. 6G will provide high speeds, very low latency, and improved connectivity (Shkarupeta & Babkin, 2024).

CONSTRUCTION 6.0 TECHNOLOGIES

Quantum computing, IoT, AI, cloud computing, cyber-physical systems and anti-fragile manufacturing are all part of these cutting-edge technologies in Industry 6.0 (Roshid et al., 2024). Some of the technologies in Industry 6.0 are illustrated in Table 2.0 below.

PRINCIPLES OF CONSTRUCTION 6.0

The principles of Construction 6.0 involve modern green production, smart renewable energy, and hyper-energy-efficient technologies (Almusaed et al., 2023). According to Almusaed et al. (2023), Construction 6.0 introduces smart technological tools and advanced human-machine integration to elevate project productivity in the construction industry. Moreover, Construction 6.0 fosters customer project customisation, enabling robots to achieve higher levels of autonomy and opening opportunities for people with specialised skills (Almusaed et al., 2023). Some of the principles of Construction 3.0 are given in Table 6 below.

Table 2: Technologies used in construction 6.0

Technology	Uses	Source
Artificial Intelligence (AI)	Used for driving automation and optimising decision-making processes	Nnam et al., (2024)
Machine Learning	Provides predictive analytics	Stephen, (2024)
Quantum Computing	Powerful computers	Malik et al., (2024)
Edge Computing	Solution to latency problems	Trinks & Felden (2018)
Internet of Things (IoT) and Cyber-Physical Systems	A combination of computer resources and physical processes to generate highly responsive autonomous systems	Liu et al. (2023); Shkarupeta & Babkin, (2024)
Additive Manufacturing	Prototyping and material manufacturing efficiency in additive 3D printing	Dedeloudi et al., (2024)
Blockchain	Technologies for improving the supply chain	Chandan et al., (2023)
Human-Robot Collaboration	People focus on creative work, while robots handle repetitive and risky tasks.	Dobra & Dhir, (2020)
Antifragility	Resilient, hyper-self-improving systems.	Sun et al., (2024)
Human-Centricity	Prioritising people's well-being	Dedeloudi et al., (2024)

COMPARISON OF CONSTRUCTION 6.0 AND LC

Lean construction aims to reduce CDW and maximise value, while Construction 6.0 integrates advanced emerging technologies such as AI, cobots, and quantum computers. Construction 6.0 is built on existing lean techniques, such as collaboration and pull-based planning (Almusaed et al., 2023). Construction 6.0 digitises lean construction processes for complete synergy. LC advocates continuous improvement and workflow, and Construction 6.0 automates and optimises LC techniques, connecting all construction procedures (Omar, 2022). LC utilises techniques such as LPS, Kaizen, and Value Stream Mapping to minimise CDW. Construction 6.0 utilises techniques such as BIM, Digital Twins, and the Internet of Things (IoT) to minimise CDW (Roshid et al., 2024). Construction 6.0 can proactively minimise CDW to eliminate all construction errors. LC fosters collaborative communication, whilst Construction 6.0 enables digital collaboration and real-time information data sharing.

Table 3: Principles of construction 6.0

Principles of Construction 6.0	Description	Source
Client Product customisation	Hyper customer product personalisation	Almusaed et al., (2023); Roshid et al., (2024)
Technology integration	Intelligent, advanced AI abilities	Ghosh, (2025); Roshid et al., (2024)
Sustainability and resilience	Very strong focus on sustainable processes and production	Roshid et al. (2024)
Human-machine collaboration	Humans actively partner with intelligent machines	Almusaed et al. (2023)
Fully autonomous. Advanced automation	Autonomous cobots perform tasks without human intervention	Ghosh, (2025); Roshid et al., (2024)
Intelligent hyper-connected systems	Hyper-connected technologies like IoT, cloud computing	Almusaed et al., (2023); Ghosh (2025); Roshid et al., (2024)
Quantum cloud-based systems	Using quantum mechanics in complex modernised computers	Almusaed et al. (2023)

RESEARCH METHODS

This study adopted a mixed exploratory–descriptive design combining a comprehensive literature review and an empirical survey. The literature review established the conceptual foundations of Construction 6.0 and Lean Construction (LC) and identified key technological, managerial, and process-related variables included in the study. These variables were selected based on their recurrent emphasis in prior research and relevance to construction digitalisation and performance improvement. A structured questionnaire was developed using a five-point Likert scale (1 = strongly disagree/not important to 5 = strongly agree/very important) to measure respondents' perceptions of the identified variables. Content validity was ensured through expert review, and a pilot test with construction professionals was conducted to improve clarity and consistency, resulting in minor refinements to the instrument. Data were collected from experienced contractors, quantity surveyors, architects, and construction academics using purposive sampling. This approach was appropriate given the specialised and emerging nature of Construction 6.0 and LC in Zimbabwe, where expert knowledge is limited but essential (Saunders et al., 2019; Farrell et al., 2017). Instrument reliability was assessed using Cronbach's alpha, with a threshold of ≥ 0.70 indicating acceptable internal consistency. This confirmed the reliability of the measurement scale for analysis. Data were analysed using SPSS. Descriptive statistics (mean scores and standard deviations) summarised responses, while the Relative Importance Index (RII) was used to determine the relative ranking of variables. The ranking procedure focused on variables identified from the literature as key enablers and implementation factors of Construction 6.0 and LC. Respondents rated each item using the Likert scale, and RII values were computed using:

$$RII = \frac{\sum W}{A \times N}$$

Where W is the weighting (1–5), A is the maximum weight (5), and N is the number of respondents. Variables were ranked in descending order of RII, with higher values indicating greater importance. Mean scores were used to support interpretation and validate ranking consistency. The combined use of mean scores and RII provided a robust prioritisation approach commonly applied in construction management research. Results were presented in Table 10 and Figure 10 for comparison and visual interpretation. A response rate of 75.3% was achieved, which is considered adequate for survey research and enhances the reliability of the findings.

RESULTS

SURVEY RESPONSE

The respondents' profiles are given in Table 4.0.

Table 4.0: Respondents' profile

Attribute	Sub-attribute	Responses	%
Professional roles	Architects	23	8.8
	Engineers	17	6.5
	Quantity surveyors	44	16.9
	Contractors	56	21.5
	University Academics	120	46.2
Education levels of Architects, Engineers and Quantity surveyors	Ordinary level	0	0
	National Diploma	47	56
	First Degree	27	32
	Master's Degree	10	12
Education Levels of University Academics	Ordinary level	0	0
	First Degree	73	60.8
	Master's Degree	45	37.5
	PhD	2	1.7

Dominant CDW minimisation practices in Zimbabwe

The findings show that the dominant CDW minimisation practices in Zimbabwe are CCM1 landfill dumping with MS = 4.46 and SD = 0.75. The second-ranked dominant CDW minimisation practice was CCM2 open space dumping, with MS = 4.08 and SD = 1.24. The third-ranked dominant CDW minimisation strategy in Zimbabwe was CCM3 pothole filling, with MS = 4.08 and SD = 1.27, and the fourth-ranked dominant CDW minimisation practice was CCM4 roadside dumping, with MS = 3.85 and SD = 1.38. The fifth dominant CDW minimisation strategy in Zimbabwe, CCM5, was river-side dumping, with MS = 3.58 and SD = 1.39.

Table 5.0: Dominant CDW minimisation practices in Zimbabwe

Code	Dominant CDW minimisation practices in Zimbabwe	MS	Std Dev	Variance	RII	Rank
CCM ₁	Landfill dumping	4.46	.75	.558	0.89	1
CCM ₂	Open space dumping	4.08	1.24	1.538	0.82	2
CCM ₃	Pothole filling	4.08	1.27	1.616	0.82	3
CCM ₄	Roadside dumping	3.85	1.38	1.907	0.77	4
CCM ₅	Riverside dumping	3.58	1.39	1.944	0.72	5
CCM ₆	Identifying re-usable materials	3.52	1.33	1.756	0.70	6

Construction 6.0 principles

The respondents ranked the Construction 6.0 principles, and the top-ranked were: Client-driven product customisation, Human-machine collaboration, Sustainability and resilience, fully autonomous, and Technology integration. The scores were ranked using the mean score (MS)

and the Relative Importance Index (RII). The Construction 6.0 and LC principles are given in Table 6.0.

Table 6.0: The construction 6.0 and LC principles

Code	Construction 6.0 principles	MS	Std dev	Variance	RII	Rank
CPI ₁	Client product customisation	4.23	1.12	.392	0.82	1
CPI ₂	Human-machine collaboration	4.01	.99	.675	0.8	2
CPI ₃	Sustainability and resilience	4.00	1.00	1.124	0.74	3
CPI ₄	Fully autonomous	3.71	1.30	1.675	0.73	4
CPI ₅	Technology integration	3.70	1.09	1.693	0.72	5
CPI ₆	Intelligent hyper systems	3.67	1.14	1.230	0.67	6

Code	LC Principles	MS	Std dev	Variance	RII	Rank
LCP ₁	Generate client value	3.62	1.30	2.002	0.92	1
LCP ₂	Increase project output	3.52	1.09	1.925	0.90	2
LCP ₃	Eliminate all forms of waste	3.35	1.41	1.866	0.85	3
LCP ₄	Continuous Improvement	3.27	1.40	1.990	0.83	4
LCP ₅	Maintain workflow	3.27	1.40	2.003	0.82	5
LCP ₆	Pursue perfection	3.04	1.47	1.717	0.82	6

MEAN ANALYSIS AND RANKING OF CONSTRUCTION 6.0

The top-ranked Construction 6.0 principles: CPI₁ client-driven product customisation minimisation with MS = 4.23 and SD = 1.12. The second-ranked Construction 6.0 principle was human-machine collaboration, with MS = 4.01 and SD = 0.99. The third-ranked Construction 6.0 principle was sustainability and resilience CPI₃, with MS = 4.00 and SD = 1.00. The fourth-ranked Construction 6.0 principle was CPI₄, which was fully autonomous, with MS = 3.70 and SD = 1.09. The top-ranked LC principles were: LCP₁ generate client value with MS = 3.62 and SD = 1.30. The second-ranked LC principle was LCP₂, with MS = 3.52 and SD = 1.09. The third-ranked LC principle was LCP₃, which eliminates all forms of waste with MS = 3.35 and SD = 1.41. The fourth-ranked LC principle was LCP₄ continuous improvement, with MS = 3.27 and SD = 1.40, and the fifth LC principle was LCP₅ maintain workflow, with MS = 3.27 and SD = 1.40. The data presents the synthesised relationships between Construction 6.0 and LC principles. The findings indicate that client product customisation and generation of client value were ranked highly, showing a strong correlation between the two variables. The prioritisation of clients is evident in both theories. These results suggest that human-machine collaboration is directly related to increased productivity. Sustainability and resilience in Construction 6.0 are closely linked to eliminating all forms of waste.

PROPOSED CONSTRUCTION 6.0 FRAMEWORK FOR MINIMISING CDW IN ZIMBABWE

The top-ranked Construction 6.0 principles and LC principles were then combined and adopted for the Construction 6.0 and LC framework in Figure 1.0.

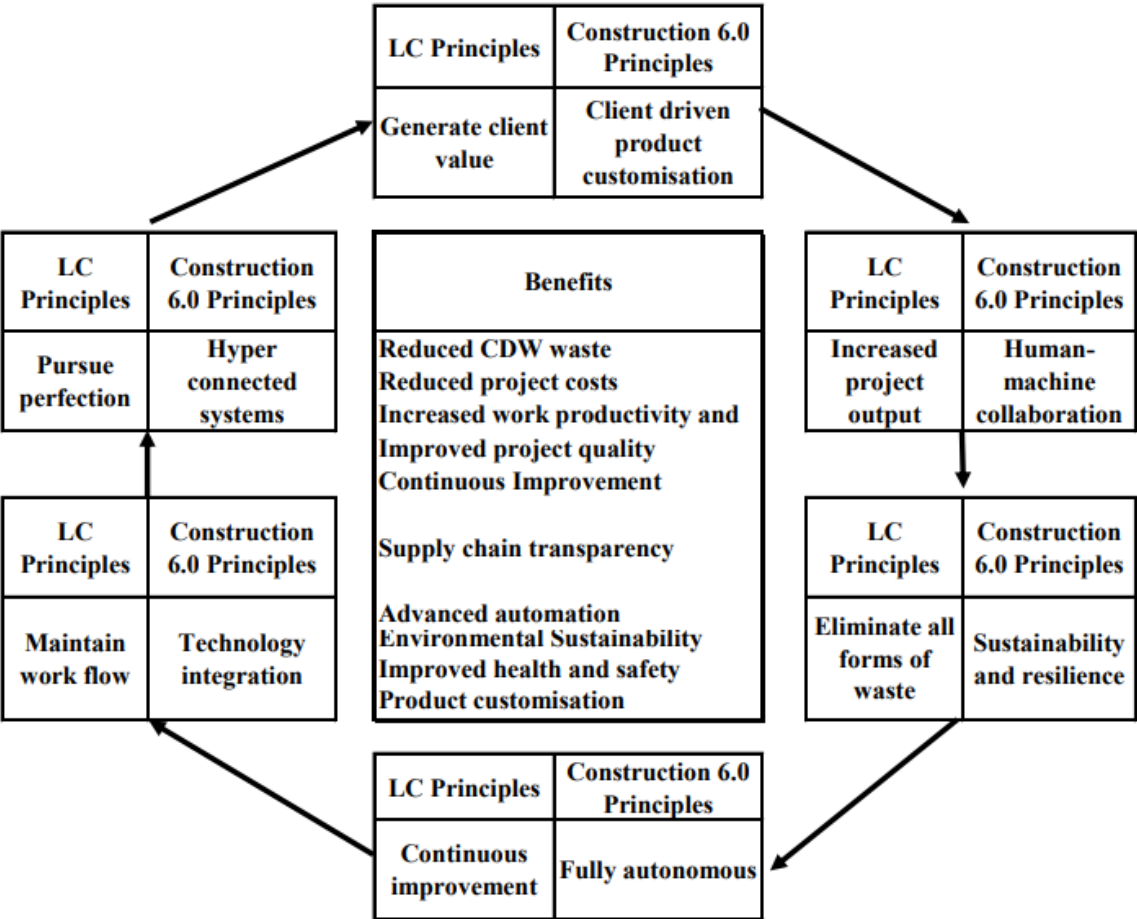


Figure 1.0: Conceptual framework

DISCUSSION

This article investigated the strength of the relationships between LC and Construction 6.0 and how they can be utilised in the management of CDW. After a thorough analysis of the concepts and principles, the derived results are discussed in the next section.

CLIENT-DRIVEN VALUE AND CLIENT-DRIVEN PROJECT CUSTOMISATION

The relationships between the two concepts are very close, especially under a human-centred approach (Forcael, 2024). The findings show that Construction 6.0, like LC, is a customer-driven, standardised production system. Construction 6.0 introduces high-mass customer personalisation, whilst Lean Construction aims to meet customer needs and minimise waste by using less of everything (Aziz & Hafez, 2013; Forcael, 2024; Howell, 1999). The expectation for construction 6.0 is to create a hyper-interface, mass project customisation, and mass customer personalisation.

HUMAN-MACHINE INTEGRATION AND INCREASED PROJECT OUTPUT

There is a synergy between LC and Construction 6.0. Construction 6.0 combines human creativity with technical machine marvels (Almusaed et al., 2023). Construction 6.0 is the 6th

phase of the architectural and construction industry, aiming to harmonise processes to facilitate building design, improve efficiency, and enhance sustainability (Almusaed et al., 2023). Construction project output increases as cobots are designed to meet customer needs quickly, and the dialogue between designers and cobots enhances creativity, innovativeness, and efficiency (OZKESER, 2018; Almusaed et al., 2023).

SUSTAINABLE WASTE ELIMINATION AND RESILIENCE

The findings indicate that sustainability in Construction 6.0 has a strong positive relationship with waste elimination in LC. Sustainability is fostered through Construction 6.0, which encourages sustainable designs utilising energy-efficient materials and emerging intelligent technologies (Grech et al., 2023). Construction 6.0 emphasises eco-friendly designs and sustainable practices that promote efficient energy consumption (Chourasia et al., 2022). Construction 6.0 enables eco-friendly structures utilising energy-efficient materials and smart technologies (Grech et al., 2023). According to Almusaed et al. (2023), cobots aid design inventiveness and performance optimisation, and sustainability and human-centric paradigms guide the construction 6.0 trajectory. The lean approach requires a balanced strategy that simultaneously minimises waste and maximises value (OZKESER, 2018).

AUTONOMOUS CONTINUOUS IMPROVEMENT

Autonomous technologies can help foster continuous improvement in construction. Advanced cobots can autonomously navigate construction sites and perform maintenance procedures (Ghosh, 2025). Almusaed et al. (2023) stated that the harmony between AI and autonomous technologies redefines the Construction Industry. There is a strong correlation between autonomous technologies and continuous improvement, as continuous improvement encourages the introduction of small incremental refinements and helps achieve higher quality (Serrano, 2020). Construction 6.0 can offer fully autonomous systems that bring continuous improvement and minimise human error. Continuous improvement helps attack the main root causes of defects on a construction project and reduce them to achieve zero defects (Serrano, 2020).

TECHNOLOGY INTEGRATION AND WORKFLOW MAINTENANCE

According to Madanayake (2015), LC enables the optimisation of project process flow and contributes to sustainable construction. LC enhances project efficiency by fostering a smooth construction workflow (Madanayake, 2015). Technology integration is the coordination of new or existing equipment to produce a complex data framework, incorporating planning or building applications (Roshid et al., 2025). Construction 6.0 integrates circular economy concepts, emphasising energy saving, resource reuse, and waste elimination (Chourasia et al., 2022; Karim et al., 2025). Construction 6.0 promotes waste reduction and the integration of alternative energy sources (Roshid et al., 2025).

PURSUE PERFECTLY CONNECTED SYSTEMS.

The hyper-connected system in Construction 6.0 can help pursue perfection. Lean thinking helps set goals based on measurements of work performance. Perfection is attainable in a zero-waste, zero-defects and zero-carbon environment (Madanayake, 2015). Perfection can be achieved when construction sites are sustainable environments with no defects (Gregory, 2011). Perfection can be pursued in LC and Construction 6.0 by implementing continuous improvement in all processes. Industry 6.0 provides virtualised manufacturing, anti-fragile, customer-centric services, and super-connected industries (Chourasia et al., 2022). Construction 6.0 provides interconnected construction systems, devices, sensors, and very autonomous functionalities. Interconnected systems promote a dynamic construction industry, enabling flexible supply chains, global information sharing, and adaptable networks.

CONCLUSION

This study critically examined the correlation between LC and Construction 6.0 in minimising CDW. By focusing on the current CDW minimisation techniques in Zimbabwe, the study created the synergy between LC and Construction 6.0 and how Construction 6.0 complements LC. The findings outline that Construction 6.0 contributes to the digitisation of LC, and that the digitisation of LC brings client-driven value, client-driven project customisation, human-machine integration, increased project output, sustainable waste elimination, resilience, autonomous continuous improvement, technology integration, workflow maintenance, and perfectly connected construction systems. The proposed conceptual framework was derived from inputs in the construction process and the benefits of implementing it. This contribution of Construction 6.0 complements LC by introducing emerging technologies, fostering environmental sustainability and introducing resilience. Several study limitations stem from the fact that the literature and surveys heavily inform the conceptual framework and lack robust practical validation. Future studies may expand the focus to practical onsite testing of the proposed conceptual framework and to the implementation of AI in developing countries.

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