Waste Elimination based on Lean Construction and Building Information Modelling: A Systematic Literature Review

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Abstract

Construction waste (CW) is an abstract, high-level concept and difficult to measure systematically. The conventional management methods have failed to translate the reality in the construction industry context. The integrated Lean Construction (LC) and Building Information Modelling (BIM) streamline several proactive and collaborative solutions to address CW at its source across the whole asset lifecycle. This paper adopts the systematic literature Review method to (i) understand 'waste' and 'waste elimination' concepts through LC perspectives and (ii) to review factors of LC-BIM for waste elimination. Based on thematic analysis applied to 54 relevant documents in the Scopus and IGLC databases, some literature was approached. According to thematic analysis applied to the existing LC-BIM approaches, despite the potential of LC-BIM for CW elimination, the current literature lacks the concept of waste elimination in the number and content of publications. The paper highlights some generic recommendations for future theoretical and empirical developments

Type: Research Article

1. Introduction

Construction Waste is a high-level concept that hinders productivity and innovation that is challenging to measure systematically. The global reports show massive consequences on sustainability's environmental, economic, and social dimensions. For instance, one-third of the construction material resources are diverted to landfills without treatment (Yuan and Shen 2011), while 33% of the global greenhouse gases are released from construction and transportation projects (UN, 2017). According to Horman and Kenley, (2005) meta-analysis, 49.6% of the construction operations are NVA (Non-Value Adding) activities. The literature has approached construction waste using various definitions, including rework (Love and Li 2000), product defects (Josephson and Hammarlund 1999), re-entrant flow (Sacks et al. 2017), transportation administrative (Belayutham, González and Yiu, 2016), and intuitional waste (Sarhan et al. 2017). This disparity in waste measures shows that it is challenging to formulate a holistic framework that hurdles the root causes of construction waste (Formoso, Bølviken, and Viana 2020).

1.1. Lean construction

According to the Toyota Production System (TPS), waste propagates in vicious circles and complex chains. By attacking overproduction and reducing inventory, it becomes possible to reap operational advantages at the production level and increase profits at the organisational level with minimum costs (Ohno 1988). On this basis, lean production is suggested as a waste elimination-focused and value generation philosophy, which considers waste as the actionable language to be used in the production system to bring stakeholder attention to real causes of inefficiency (Womack and Jones 2003). In the construction industry, LC (Lean Construction) is based on Koskela's construction production theory, which is inspired by lean production theories, known as the TFV (Transformation, Flow, and Value) perspectives. TFV emphasises the F perspective to apply waste elimination by decomposing the construction into NVA (Non-Value-Added) and VA (Value-Added) activities. Based on the waste elimination concept, LC draws several principles to reduce cycle time, product and process variability, continuous improvement, and increase transparency (Santos, 1999; Koskela, 2000). In addition, for other principles such as 'map for value stream', 'establish for pull planning', and 'structure the construction process into flows.

During LC implementation, the 'map for value stream' is the first approach used during the earliest stages of design (Dave 2013). The role of Lean Design Management (LDM) is to extract, translate, compare, and decide the value by regulating the relationship between the procurer, the designers, and the constructors. LDM transforms design activities into flows and regulates collaborative production to eliminate waste among architectural, structural, and MEP[1] engineers. Additionally, the value can be mapped through the VSM[2] tool that visualises NVA, such as cycle time, queuing time, and work-in-progress in information and material flows (Rother and Shook 2003). NVA indicators are effective for the decision taken toward reducing production waste and ultimately reducing environmental, economic, and societal losses across the supply chain (Arbulu et al. 2003; Rosenbaum, Toledo, and González 2014; Vilventhan, Ram, and Sugumaran 2019).

The ideal Lean Supply Chain Management is to deliver a Just-in-Time system that relies on information from production signals rather than solely on demand to forecast (Vrijhoef and Koskela 2000; Bortolini, Formoso, and Viana 2019). Production signals can be retrieved from Lean planning and control systems such as the Last Planner System® (LPS), and Location-Based-Management System (LBMS) are applied methods to increase stakeholders' situational awareness about waste. The LPS is a context-specific and socio-technical system that aims to improve planning reliability through successive collaborative sessions to shield the downstream from upstream variability (G Ballard 2000; Glenn Ballard 2020). While LBMS is a spatial-temporal and socio-technical system that plan and structures the construction operations concerning their locations (floor, zones, sections, and floors), LBMS manages the handoff between activities for several trades (Björnfot and Jongeling 2007). LPS and LBMS can be used concurrently to address wastes such as work-in-progress, waiting, space congestion, and overproduction methods. Finally, relational contracts ensure stakeholders awareness and responsibilities towards waste elimination, as legal guidance to urge the

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[1] MEP: Mechanical, Electrical, and Pluming
[2] VSM: Value Stream Mapping

involved parties to use pull planning, value stream mapping, and resolve disputes about waste (Forbes and Ahmed 2010; Sacks et al. 2018).

1.2. Lean construction and BIM

Due to the intensity of waste information, Building Information Models (BIMs) are essential to pave the communication for lean messages. Based on Sacks et al., 2010 BIM is recognised as a coherent and consistent source of information about the construction product and process (Eastman et al. 2008; Sacks et al. 2010). A major example of LC-BIM is the integration of LPS into BIM 4D model to assist lean practitioners in filtering their activities according to their readiness and enable them to track production progress using production metrics (Sacks et al., 2010). Those metrics, including construction flow index, and task maturity, which are translated into Andon signals to bring stakeholders' attention to production bottlenecks (Dave 2013). The empirical research shows that LPS-BIM's effectiveness for waste elimination is partial without real-time tracking, which can be improved through digital tracking, artificial intelligence, and inked data, among others (Dave and Sacks 2020).

Similarly, LDM provides waste elimination measures to manage BIM workflow and information LDM combines planning and control, stakeholders' management, and decision-making methods (Herrera et al. 2021). LDM planning and control seek to streamline continuous flow between BIM processes based on LPS and LBMS. This practice proactively eliminates wastes responsible for interruptions in design workflow by structuring information of design processes according to short-term timeframes, balancing production resources, and reporting activities constraints. Additionally, LC-BIM has a positive impact on accelerating the adoption of other initiatives, including 4.0 construction circular economy, design-out-waste (Karaz and Texiera 2020), DfMA (Design for Manufacturing and Assembly) (Gbadamosi et al. 2019). Finally, the integrated LC-BIM approach holds waste elimination opportunities in achieving production sustainability which also addresses economic, environmental, and societal dimensions (Saieg et al. 2018).

1.3. Research questions

The research on LC-BIM lacks explicit definitions and measures for construction waste elimination. This paper attempts to investigate this gap by adopting the SLR methodology to investigate how LC has understood construction waste and then reviews the critical factors imposed by LC and BIM to contribute to waste elimination. So, the formulated review questions in this paper are as follows: How does lean construction conceptualise waste? What are waste elimination factors imposed by lean construction (LC)? What are the factors of LC-BIM that contribute to waste elimination?

This paper is structured as follows: Section 2 presents a detailed description of the systematic literature review methodology, followed by a descriptive analysis of the publications in this field over time. Section 3 presents content and thematic analysis to cluster the existing research into four research themes. Section 4 concludes the performed analysis and discusses further development needed to improve the current understanding and application of waste elimination in construction.

2. Materials and Methods

Year by year, enormous research is conducted with conflicting understandings of construction waste and various interventions to tackle it. An SLR is a method to understand the context-specific problem and appraise the suggested interventions to address that problem by synthesizing the scattered evidence-based literature results. According to

Denyer and Tranfield (2009), the characteristics of SLR are to be transparent, updatable, transferable, and quality exclusive review. However, SLR is limited to a time-consuming methodology and requires additional resources for its implementation than traditional review methods (Mulrow, 1994). This paper adapts SLR methodology as illustrated in **Figure 1**, which comprises four iterative stages as follows: (1) planning for the review, (2) material collection, (3) data evaluation, and (4) results reporting and dissemination (Tranfield, Denyer and Smart, 2003). Firstly, during 'planning for the review', the review question is developed, as an early-stage process, because it conceptualises and formulates complex problems into a contextual frame (Flemming et al. 2019).
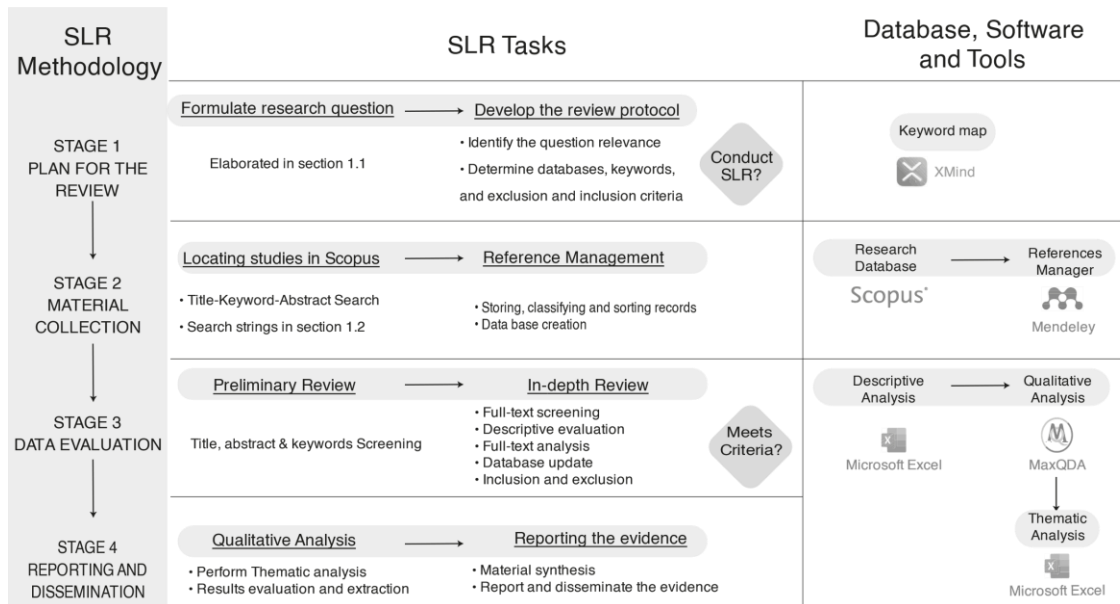

Figure 1: Systematic Literature Review Methodology

This paper investigates how LC understood construction waste and then reviews the critical factors imposed by LC and BIM to contribute to waste elimination. So, the formulated review questions in this paper are as follows: (1) How does lean construction conceptualise waste? (2) What are waste elimination factors imposed by lean construction (LC)? (3) What are factors of LC-BIM that contribute to waste elimination?
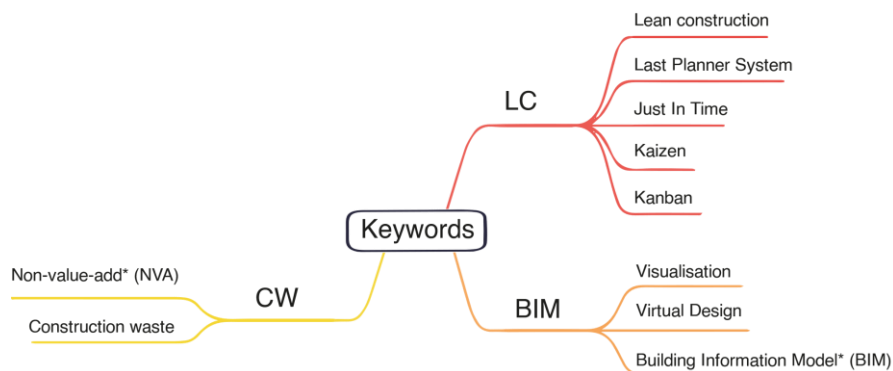

Figure 2: A keyword map combining streamlined keywords

The literature data were collected from the Scopus database, IGLC, and snowballed documents. The major source of the retrieved documents came from the Scopus database using two queries, as shown below. The first query is a preliminary search string that combines only the study keywords 'lean construction' and 'BIM' and 'waste' using the 'AND' operator. The second query was formulated using the 'AND 'OR' operators to extend the search to include the Title-Abstract-Keywords using the streamlined keywords in the tree

map shown in **Figure 2**. The keywords used in this research were adapted from (Viana, Formoso and Kalsaas, 2012; Tezel et al. 2020). And the snowballing technique, according to Wohlin and Claes (2014).

Criteria	Inclusion	Exclusion
Publishing year	1999 ≤ year ≤2022	year ≤ 1999 later than June 2022
Discussed concepts	Combines lean and waste concepts, or the three concepts, LC, BIM and waste	Studies only one of the concepts Studies focused on BIM and waste elimination only
Research domain	Includes construction management documents with a focus on the lean construction concept	Other domains than construction management
Publication language	English language only	Other than English

Table 1: Preliminary inclusion and exclusion logic

After querying the selected databases, the number of included documents for a preliminary analysis was (411) records, as illustrated in **Figure 3**. The inclusion/exclusion criteria are summarised in **Table 1** to filter the number of documents included. The criteria are applied for publishing year, researched concepts, research domains, and language. After applying the specified including/exclusion criteria, the number of research documents was narrowed to (190) after screening Titles and Abstracts. In contrast (136) documents were excluded after full-text analysis, so the number of relevant documents is (54) to be analysed in this paper.
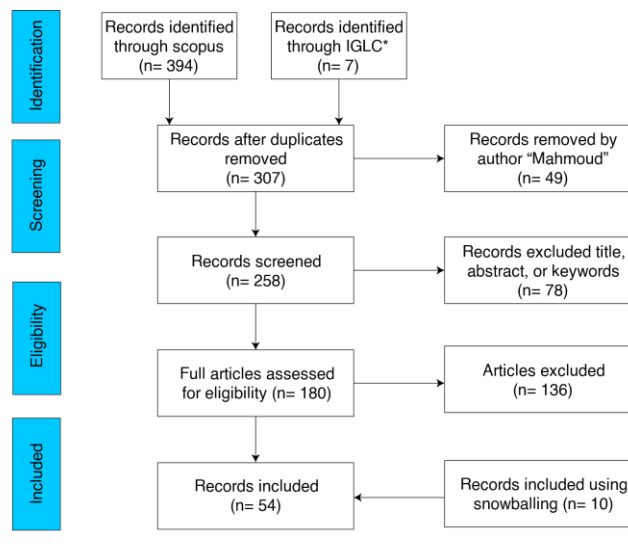
* IGLC: Proceedings of International Group of Lean Construction

Figure 3: Summary of included and excluded records

2.1. Data evaluation

This section employs descriptive analysis to provide a broad overview of waste elimination development through LC and LC-BIM over time. Firstly, the analysis aimed to depict how the topic quantitatively developed over time. **Figure 4** illustrates that the number of waste elimination papers has risen over time. From early 1992 until the first quarter of 2022, most literature recognised waste elimination as a central concept of LC. In 2008, the impact of LC-BIM on waste elimination was recognised (Chuck Eastman et al. 2008). The proportion of

relevant documents that used the LC-BIM approach is 53.70%, while 46.30% of selected records utilised LC theory and methods. **Figure 5** presents an analysis of the objective of waste elimination research, which was classified into: (i) conceptual, (ii) literature review and (iii) empirical. The first class includes papers focused on theory and predominantly on historical and conceptual analysis of construction waste. The second class represents literature review papers to develop integrative solutions based on secondary data from evidence-based literature. Empirical papers are those aimed to provide applications or adaptations for LC and LC-BIM solutions in a specific context of the construction supply chain, for example, (i) reporting problems and prescribing a solution for that problem, (ii) implementation of LC principles, methods, tools, and techniques, (iii) define the requirements for waste elimination solutions-based LC-BIM (iv) evaluation of LC and LC-BIM solutions, (v) use of IT artefacts; among others.
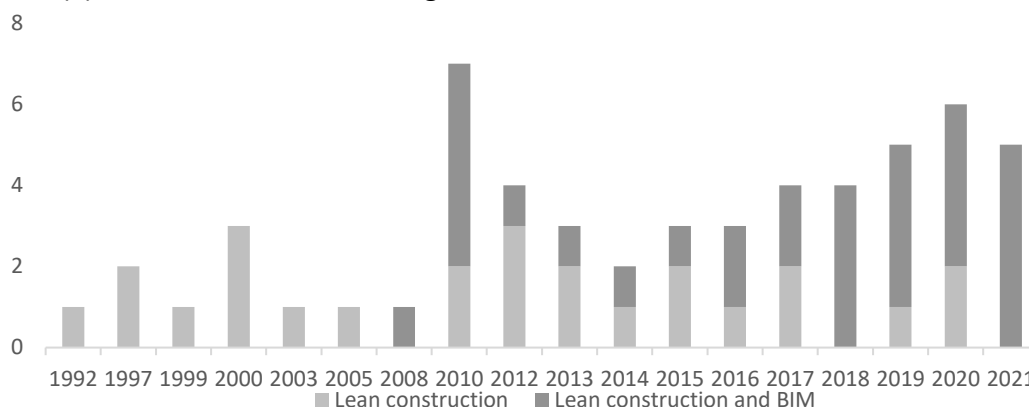

Figure 4: The percentage of documents contributed to waste elimination-based LC and LC-BIM from 1992 to 2022

The analysis demonstrates that the focus of the literature has been mainly empirical rather than theoretical and literature review, as shown in **Figure 5**. Additionally, this highlights that theory is not evolving at the same rate as practical implementation, and there are limited successful examples, hence weak support to waste elimination in LC-BIM implementation. The analysis in **Figure 6** classified the empirical research into four functional areas of the construction supply chain management, namely (i) Lean supply and logistics management, (ii) Value stream Mapping, (iii) Lean design management and (iv) Lean planning and control. That shows that little empirical research was conducted on post-occupancy stages such as demolition (Elmaraghy et al. 2018) and rehabilitation (Pereira and Cachadinha 2011) and facility management (Bascoul et al. 2018).
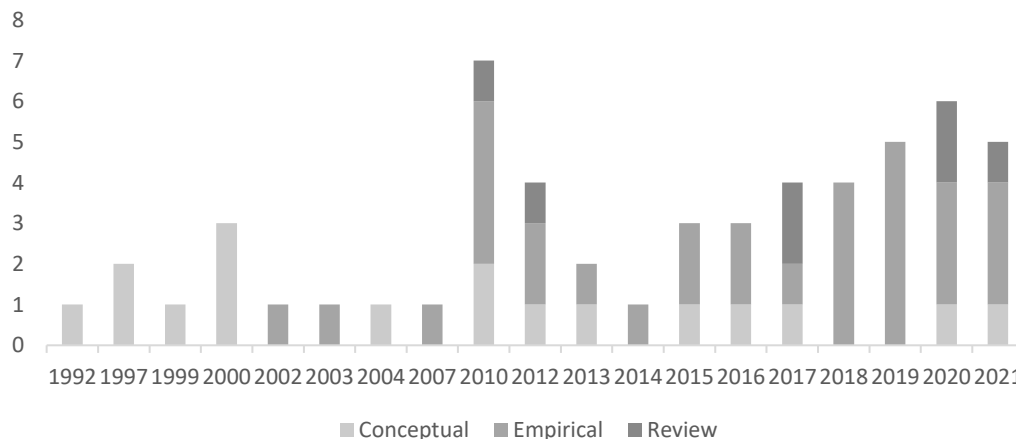

Figure 5: A distribution of the used research methods from 1992 to 2021
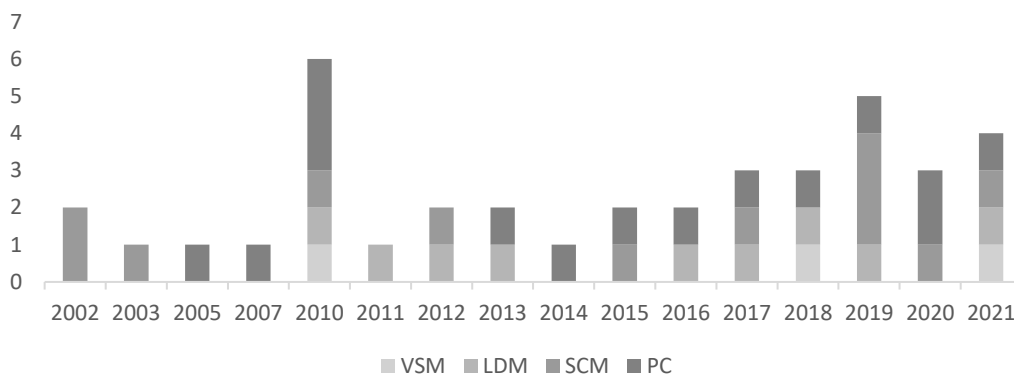
Figure 6: Time analysis of empirical research held between 2002 and 2021

3. Discussion

This section describes construction waste by answering the three questions elaborated in (section 2). Firstly, to answer the RQ1, Section 3.1 and Section 3.2 discuss lean approaches to understanding construction waste concept, nature, and taxonomies and summarise LC principles for waste elimination. Apart from depicting theoretical grounds of waste elimination from LC perspectives, qualitative and quantitative results of the literature are presented to explore potential research gaps in LC and then LC-BIM research and detect future research areas from both approaches to eliminate construction waste. After a brief overview of lean construction methodologies for waste elimination. The following sections summarise waste elimination knowledge in LC and BIM research. Section 3.3. explains the approaches of LCSC (Lean Construction Supply Chain). Section 3.4 reviews the impact of VSM (Value Stream Mapping) on waste elimination. Subsection 3.5 illustrates waste elimination through LPS planning and control and other LC planning and control methods such as LBM (Location-Based-Management. Subsection 3.6 reviews lean measures for waste elimination in the design-context through LDM (Lean Design Management). Subsection 3.7 examines the legal and societal measures to eliminate waste by lean relational, and subsection 3.8 compares the impacts of waste elimination on sustainability measures. The last section 4 concludes this paper's results and provides potential research opportunities through explored research gaps.

3.1. Waste elimination and Lean construction

In the TPS philosophy, waste is considered an actionable and instrumental concept to generate meaningful information that guide people in revealing causes of inefficiency in their production systems (Ohno, 1988). Ohno taxonomised waste into seven classes (1) overproduction, (2) transportation, (3) inventory, (4) motion, (5) waiting, (6) overprocessing, and (7) defects. This list has been adopted in industries other than the manufacturing industry, including the construction industry. To adapt to the construction context, LC provided several taxonomies based on this list as generic classifications: TFV-based (Bølviken et al. 2014), dominance-based (Koskela et al. 2013), propagation-based (Fernández-Solís and Rybkowski, 2012; Formoso et al. 2015). Such taxonomies can formalise construction waste understanding across the supply chain, including manufacturing, logistics, design, installation, handover, use, and post-occupancy. Additionally, it is seen as an improvement for stakeholders' situational awareness, encouraging practitioners to participate in tracking, analysing and proactively eliminating construction waste.

The interdependencies between waste cycles are inherent between construction processes, i.e., pooled, sequential, or reciprocal (Formoso, Bølviken and Viana, 2020). Also, waste can be understood as discrete (task-level), synergistic (project-level) and systematic (organisational and contractual level) (Fernández-Solís and Rybkowski, 2012). Systematic waste is related to loosely coupled stakeholders (fragmentation), which is relatively difficult to defeat with traditional management approaches. Formoso et al. (2020) taxonomized the construction waste into previous stages (design, planning and control, material supply, and training), production wastes (quality deviation, making-do, transportation, waiting, work-in-progress, inventories) and terminal waste or traditional waste metrics (rework, defects, material waste, safety issues, gas emissions). The relationships between production wastes defined in Table 2 can be mapped into unidirectional or singular directions, which comprise complex waste networks or waste chains. As the process's complexity rises, the waste propagated is more complex (Formoso et al. 2015).

Production waste	Definition
Making-Do	Negative productivity occurs when the task is started or continued without the full availability of inputs. It may cause decisions such as excessive use of resources to compensate for delay or shortage (firefighting) or leaving unresolved issues in a specific task and moving to another task (low-fruit-gripping).
Quality deviation	Excessive-quality variations arise in resources, suppliers, products, inefficient deviation detection mechanisms, and poor client value capture.
Transportation	Poorly coordinated transport caused the resources, including inefficient transportation operations, setting-up, and poor equipment use.
Inventory	It is the status of accumulated unfinished products between the start and end of a product routing. It hides quality problems.
Work-in-progress	WIP is the number of incomplete and necessary upstream tasks that prevent successive activities from processing. According to little law, WIP is an important production factor that can be determined through the relationship with cycle time.

Table 2: Construction production waste categories according to (Formoso, Bølviken and Viana, 2020)

3.2. Waste elimination principles of lean construction

Lean construction has become relevant in modern construction management education, research, and practice (Forbes and Ahmed 2010). LC sees that the supply chain fragmentations are caused by the conventional 'Transformation' model, providing more emphasis on 'Flow' and 'Value' concepts (Koskela 1992). LC project management refers to managing temporary production systems structured to deliver the product with maximised value and minimised waste (Ballard and Howell, 2003). Akin to lean production, LC methods, tools, and techniques are built on lean principles but with adaptations to the construction context. Among lean principles, waste is addressed directly and indirectly in the five principles: ' reduce the lead time', 'reduce variability', 'simplify', 'increase flexibility and 'increase transparency' (Koskela 2000; Santos 1999). That can be summarised into four direct principles: 'reduce cycle time', 'reduce variability', 'continuous improvement', and 'increase transparency, as shown in **Figure 7**. With the corresponding goal of each principle related theories and potential methods. Even a partial application of these principles can hold disruptive benefits of waste elimination across the construction supply chain (Ballard and Howell 2003).
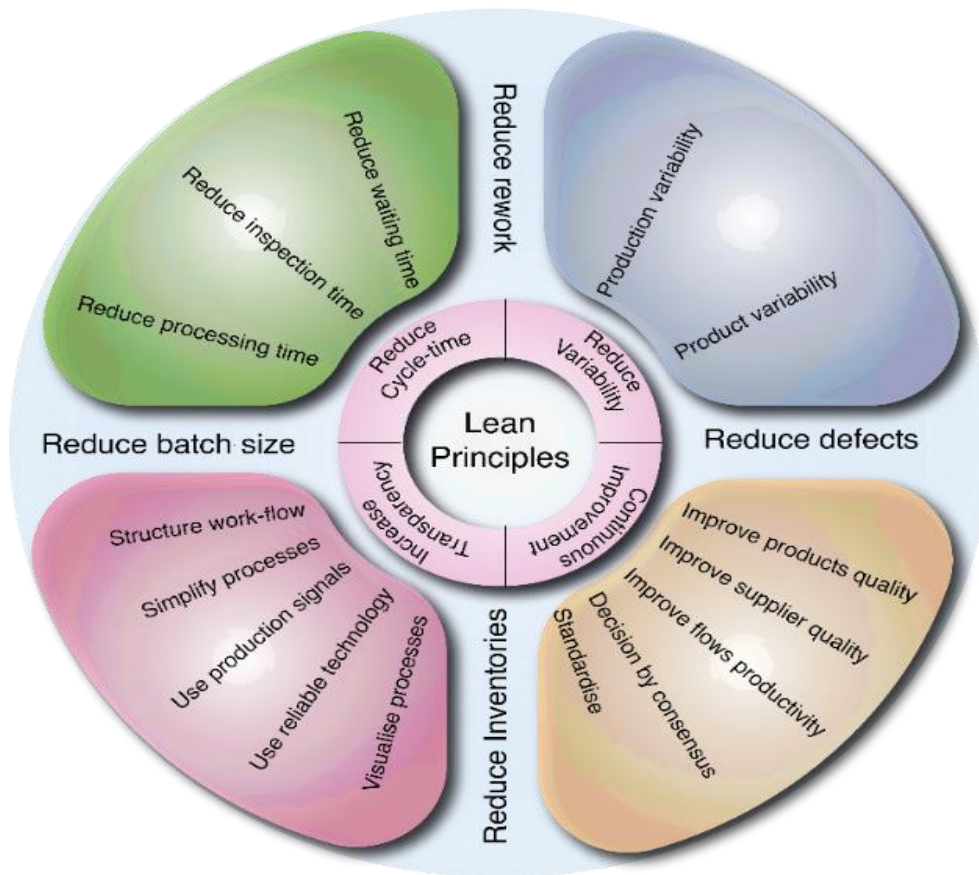
Figure 7: LC principles related waste elimination.

3.3. Lean Supply Chain Management (LSCM)

The construction supply chain (CSC) is responsible for massive material waste generation (Yuan and Shen 2011), GHG emission release (UN, 2017) and excessive non-productive time (Horman and Kenley 2005). The peculiarities of CSC projects are one-of-a-kind, make-to-order, project-based, site-production, and temporary organisation (Vrijhoef and Koskela 2000). Additionally, CSC products are associated with an increased number of parts and inconsistent organisations structures (i.e., variety in stakeholders with conflicting goals and needs) (Glenn Ballard and Howell 1997). The possible wastes in a fragmented CSC are transportation, congestion, doublehanding, movement, and waiting (Pérez and Bastos Costa 2021; Björnfot and Jongeling 2007).

Lean supply chain management embraces JIT (Just-in-time) concept to reduce lead time, inventories, and variabilities across the whole supply. At the urban level, to increase the reliability of the buffer between the supply and site demand, LSCM suggested moving the role of the supply to outside the construction sites by using more prefabrications and decoupling delivery processes or terminal centres that store kitted packages prior to delivery to the site (Elfving, Ballard, and Talvitie 2010). This approach enables the construction industry to limit transportation waste, adding value to productivity and sustainability in terms of contribution toward a circular economy (Vrijhoef 2020). At the logistics level, the workspace management allocates resources according to their spaces, storage, areas, routes, and paths (Pérez and Bastos Costa 2021). At the same time, the production demand is provided by signals from lean planning and control systems that prioritise pulling rather than pushing work packages downstream and assure that the between handoffs trades are discussed and resolved.

BIM is the basis for informed LSCM decisions regarding transportation, inventory, design, and site production (Vrijhoef 2020). For example, 4D (3D + time) plans the supply about the actual demand from the production status (Bortolini, Formoso, and Viana 2019). In addition to BIM cost analysis that allows stakeholders to evaluate the viability of waste elimination options in transportation, movement, and work-in-progress (Vrijhoef, 2020). To increase the transparency of logistics waste elimination performance, tracking technologies such as RFID (Radio Frequency Identification), QR code (Quick Response), and NFC (Near-field communication) (Elfving et al. 2010; Dave et al. 2016). Those technologies are important to harness BIM functionalities to report wastes in logistics management regarding ordering, transportation, congestion and handling processes, material waste, and accidents. Integrating GIS to BIM at a corporate level can inform lean decisions on transportation routes, suppliers, and decoupling centres selection (Deng et al. 2019). Finally, the health and safety factor can be improved through LC-BIM reduce design for workflows and locations, which enable stakeholders to visualise, and filter obstructed and unobstructed workspaces in order to validate tasks before commencement against accidents risk (Rozenfeld et al. 2009; Gambatese et al. 2017).

3.4. Value Stream Mapping (VSM)

Applying the VSM method is essential for lean initiatives to visualise information and material flows and seek potential improvements using waste elimination principles (Womack and Jones, 2003). By a collection of production indicators from the involved parties or through direct surveys and observations, there are two VSMs can be developed as current and future maps using indicators such as NVA (Non-Value-Added), CT (Cycle-time), WIP (Work-In-Progress), Takt Time (TT) and Queuing Time (QT) (Rother and Shook 2003; Nahmens and Ikuma 2012). VSM can address distinct types of construction waste across the CSC, including injuries/accidents, material waste, transportation, waiting, quality deviations, rework, defects, and environmental wastes (Rosenbaum, Toledo and González, 2014; Vilventhan, Ram and Sugumaran, 2019; Nath et al. 2015). The limitation of reviewing VSM systematically is that waste data was collected from professionals at the operational level for specific contexts that cannot be broadly conceptualised (Viana, Formoso, and Kalsaas 2012). Alternatively, some research applied Discrete-Event-Simulation (DES) to investigate VSM using technical measures to enhance waste elimination process (Golzarpoor et al. 2017) and Agent-based-simulation (ABS) to seek social interactions with technical dimensions (Al Hattab and Hamzeh, 2018); however, simulation methods are seen as time-consuming and is restricted to academic applications (Erikshammar et al. 2013).

VSM streamlines meaningful and transparent visualisation for BIM processes and resources information, by evaluating NVA activities, it permits construction actors to collaboratively identify and reduce sources of waste in their processes (Michaud et al. 2019). VSM decisions can visualise BIM workflow constraints to facilitate shorter BIM execution duration by shorting design reviews and verification time, reducing request for information, wating time for information (Nath et al. 2015). Although the abovementioned benefits of the interactions between VSM method and BIM-based design management, the literature lacks automated solutions that assist stakeholders to implement VSM into BIM workflow, where production metrics are necessary to information is control waste in BIM implementation.

3.5. Lean Planning and Control through LPS® (Last Planner System)

The primary outcome of the LPS is providing reliable production planning that shields downstream from upstream variability (Ballard, 2000). LPS defined as a socio-technical

system that unites the stakeholders, including 'the last planners' or the last responsible people, to optimise production plans in successive levels of detailing (Ballard, 2020). LPS divides the planning into four successive levels: Master scheduling, Phase planning, Look-ahead planning, weekly, bi-weekly or daily planning, and learning. To streamline continuous and stable flow, LPS practitioners commence working on mature activities only, and a quality check for work backlog is applied for work packages definition, soundness, sequence, size, and learning (Howell and Ballard, 1998). Additionally, the perspective of language/action can formalise language used for negotiation between trades to describe, request, declare, promise, or assert specific information about work packages (MacOmber et al. 2005). Control indicators such as PPC are used to measure the percentage of work completed and task owners, which allow them to investigate and learn about potential wastes (Sacks et al. 2018). This practice can diminish wastes such as making do, moving, waiting, transportation, inventory, reworks, and defects. Hence, LPS formalises communication between multidisciplinary trades during work structuring, sequencing, constraints removal, control, and learning (Koskela and Ballard, 2012).

Information synchronization is necessary to implement LPS, especially, by increasing the planning details enlarge, immense amount of information can be retrieved into the system, which can be tackled using BIM functionalities such as 4D planning, clash detection, and site layout planning (Dave and Sacks 2020). Lean-BIM-based production planning and control systems PCS can streamline flexible production systems that actively respond to bottlenecks, waste should be revealed and understood by improving situational awareness and activating root causes of waste, performing what-if-scenarios, and activating real-time tracking for production bottlenecks. Additionally, location-based management methods (i.e., takt-planning, flow line, Line-of-Balance) can be applied to visualise and stabilise the flow across locations of the construction product, supported by 4D functionality to provide additional insights about work sequencing and related time and spatial conflicts (Björnfot and Jongeling 2007). The available digital tracking methods are enabled for site conditions by LPS and BIM, including surveying methods, laser scanning, indoor positioning, GPS, BLE Beacon, IoT techs (von Heyl and Teizer 2017; Dave et al. 2016), stational touch screens, PDAs, mobiles, tablets, and RFID (Chen et al. 2019). These technologies deliver additional prospective opportunities in automatic waste elimination decisions through artificial intelligence (AI) algorithms, according to the increasing waste data that can be extracted from Lean planning and control systems, which are requirements for system learning, testing and validation (McHugh et al. 2022).

3.6. Lean design management (LDM.)

The LDM provide simultaneous design processes that focus to diminish waste collaboratively at the earliest stages of BIM projects using social, technical, and socio-technical dimensions (Barkokebas et al. 2021; Uusitalo et al. 2019). The social dimension urges people to engage in BIM adoption and enhance their skills towards collaborative production, based on trust and common understanding among the involved parties (Arayici et al. 2011). At the same time the socio-technical dimension eliminates wastes in terms of planning and control, customer requirement management, decision-making methods, and problem-solving techniques (Uusitalo et al. 2017; Herrera et al. 2021). Again, the production indicators are used in LDM to quantify NVA in design workflow and information flow.

The current practice plan for design tasks Kanban based software, but without complete reflection to LC-BIM integration (Mahalingam, Yadav, and Varaprasad 2015). This miss opportunities BIM functionalities that are specific to the construction design context, this

research recommend more research on applying LDM planning and control methods in BIM environment in order to apply waste elimination concepts. At the same time, the research lack of integration of waste elimination in LDM customer management methods, which can potentially steer design processes and products toward customers' value and waste elimination by utilizing methods such as TVD. (Target-Value-Design), CBA (Choosing-By-Advantage) and SBD (Set-Based-Design).

3.7. Relational legal structure for waste elimination

Legal bonds between parties are essential in guiding construction organisations towards value creation and waste generation (Koskela, 2000). Relational contracts emerged and flourished in the late 20th century to facilitate a road map for construction improvements. Integrated Project Delivery (IPD), Integrated Forms of Agreements (IFOA), Partnering, and alliance contract are examples of Relational contracts that may tackle construction waste through cultivating collaboration in defining clear assignments and responsibilities towards project goals that align the interests of multiple stakeholders to optimise their projects globally instead of focusing on local optimization for the production.

Partnering contracts reduce the liaisons between actors to resolve issues and involve the downstream in upstream decisions through improved collaboration and transparency. Material waste is highlighted in partnering contracts by imposing a material waste management plan (WMP), but the terms of partnering contracts lack focus on production waste elimination (Matthews et al., 2000). In contrast, alliance contracts support task completion, manage inventory and toolbox sharing, and allocate responsibilities where lean principles apply to decompose complex wastes and discard NVA through tools such as 5whys, waste walks 'Genchi genbutsu', spaghetti diagrams, quality control histograms and RCA (Root Cause Analysis). Combining lean principles and relational contracts can eliminate about 24% of NVA by facilitating double learning, improved process quality, and safety measures (Vilasini, Neitzert and Rotimi, 2014). However, alliance procurement lacks explicit terms of waste elimination, which causes an absence of legal commitment and measures toward waste recognition, analysis, and responsibility for waste elimination, more research is needed to include the concepts of waste elimination in relational contracts, this gap can be also applied to IPD, alliance contracts, and collaborative Design-Build contracts.

3.8. Lean sustainability

From the LC perspective, environmental waste is the negative outcome of the production system that does not add value to the final customers (Formoso et al. 2015; Koskela, Bølviken, and Rooke 2013). LC practices can improve both production and sustainable performance (Kim and Bae, 2010; Rosenbaum, Toledo, and González, 2014; Saieg et al., 2018). The evidence in Table 3 explores the approaches to studying the effect of lean construction on environmental waste reduction and illustrates the reductions for each study. However, lean methods such as JIT (just in time) carbon footprint can cause more carbon emissions due to frequent shipment to satisfy the zero-inventory condition (Hussein and Zayed 2020). Moreover, a comprehensive solution for effective facility management has not been investigated yet with the application of lean management philosophy yet (Elmaraghy, Voordijk, and Marzouk 2018).

Author(s)	Method	Material waste	Carbon Emissions	Energy consumption		Wastewater	Landfills
				Fuel	Electricity		
(Golzarpoor et al. 2017)	DES-I/O	●	41%	41%	-	-	●
(Fu, Sun, and Pasquire 2015)	LCA	-	42-44%	-	-	-	-
(Wu, Low, and Jin 2013)	Low-carbon lean system	●	29.39%	●	-	-	●
(Kim and Bae 2010)	CEDST	●	10-20%	●	●	-	●
(Rosenbaum, Toledo, and González 2014)	VSM	50 to 100%	●	●	-	-	100%
(Belayutham, González, and Yiu 2016)	VS-PM	●	-	-	-	●	-
(Vilventhan, Ram, and Sugumaran 2019)	VSM	13.18-57.37%	-	-	-	-	●
(Nahmens and Ikuma 2012)	SLIK	64%	●	●	●	●	●

DES-I/O = Discrete Event Simulation – Input/output; LCA = Life Cycle Analysis; CEDST = Construction Environmental Decision-Support Tool; VSM= Value Stream Mapping; VS-PM = Value Stream-Process Map; SLIK = Safety and Lean Integrated Kaizen; ● = reported reductions without percentage

Table 3:Environmental waste reduction rates after applying lean methods

The construction waste list has been adapted into the construction context without enough conceptual analysis since it has been proposed for the construction industry through TPS-based models such as lean construction (Koskela, Sacks and Rooke, 2012). Besides the promise of 'respect people' promoted by lean models, some concerns related to human resources may arise, such as mistaken understanding of increasing efficiency and waste elimination by elite management, which might increase profit with fewer resources allocated. However, it can exert extra workloads on people in an inconvenient work environment. More research is required to address this problem that aims to improve the social dimension during waste elimination practices proposed by LC.

4. Discussion and concluding remarks

By the means and ends of LC, reducing the share of non-value-adding activities provides opportunities for dramatic development in the efficiency of a production system (Formoso, Bølviken and Viana, 2020). LC is a systematic approach that production issues through waste elimination principles such as 'reduce cycle time', 'reduce batch size' and 'reduce inventory', 'reduce variability' into actionable problem-solving methods and continuous improvement cycles to address variability in the product and process. LC and BIM concepts support each other interchangeably to systemically eliminate waste at various analysis levels, enabling technological advancements enabled by real-time tracking and reporting the construction bottlenecks and progress, managing resources, and supporting predictive systems that forecast and alert stakeholders about violations or errors in a specific context.

The literature review has been divided into six categories according to thematic analysis applied: (1) Lean supply chain and logistics management; (2) VSM; (3) planning and control using LPS; (4) design management; (5) Relational contracts; (6) Lean sustainability. Major

supply chain management research suggested various applications such as space management and site layout management, location-based management, decoupling centres, and BIM. Benefits from LC-BIM were identified such as, stable demand and supply, transportation management, inventory, and warehouse management. Waste elimination in construction faces a challenge, changing the dominant traditional culture. Such a challenge can be solved with gradual adoption and raising awareness of the advantages of LC-BIM.

The literature presented production planning and control systems based on LC-BIM. However, combining with other tracking technologies like Beacon RFID and IoT shows a strong presence. BIM's current problems, such as complex social and data models, as well as interoperability issues and automated compliance, were also discussed. Lean design management was suggested to manage BIM processes to overcome the deficiencies of understanding BIM as a tool rather than a process. The challenge in this criterion is that value generation has more impact on design than waste elimination; even the interrelationships between them are challenging to understand (Fernández-Solís and Rybkowski, 2012; Bølviken et al., 2014). The literature shows that applications of relational contracts can cultivate a waste elimination culture in construction organisations; however, the current contractual structures lack an explicit definition for waste elimination, and its responsibilities are vaguely discussed. Finally, environmental waste was discussed in the literature by reducing production waste using LC and BIM. VSM integrated with tools such as LCA and LCI was presented as a major application for LC to diagnose production systems. In the design stage, LC was presented as a method to manage BIM processes and instil concepts such as trust and mutual understanding among collaborative teams.

The main shortcomings of this research are due to the sole use of the Scopus database as a major research document source, which may lead to the small volume of literature found, which may reduce the significance of the systematic literature review. Indeed, as is typical of the English language in the Scopus query may avoid important literature in other languages. As lean knowledge is mainly reported by lean organisations, the greater share of the existing conference articles is published in the IGLC database, where discoveries are shown. The potential reviews in the Lean Construction and BIM domains for eliminating waste are enormous. It is expected that future evaluations will focus on LC-BIM implications on waste elimination from case studies Despite the little available literature, an analysis of the recent development in research indicates that in order to reach zero-inventory thinking is that LC-BIM adoption more developed.

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