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Integration of Lean Construction and Buffer Management – A Systematic Literature Review

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Abstract

Question: How to integrate Lean Construction and buffer management in the construction industry?

Purpose: The application of Lean Construction (LC) with buffer management as the efficient method for improving delivering construction projects has been acknowledged by construction academics and professionals. However, a substantial part of this integration lacks systematization. Therefore, this study is performed to review and categorize the key themes in which the interrelationship between LC and buffer system has been discussed and conceptualized in the attributes

Research Method: A Systematic Literature Review (SLR) including 51 papers from 2003 to 2023 was performed using Scopus, Web of Science (WoS), and ProQuest databases.

Findings: This study examines three topics of LC and buffer management integration which are theoretical aspects of this integration, approaches that enhance this integration, and Lean Construction tools implicate buffer system. The results suggested that few works have been done for the practical dimension of this integration, while great progress has already been achieved for the theoretical dimensions.

Limitations: This study used specific databases with certain keywords, but the number of research repositories and databases are increasing, and those are updated continuously which contributes towards limitations and future research both.

Implications: Owners/developers would do well to embrace buffer management given its strategic contributions to LC. Moreover, it is important to apply the integrated system through all stages of the construction projects to achieve comprehensiveness and applicability.

Value for practitioners: A number of research gaps are singled out within these areas of integration between LC and buffer management, to induce new ways and perspectives in LC and buffer management field of research that may be fruitful in filling these gaps.

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Introduction

Workflow variability is an inherent feature of production systems and is one of the factors that adversely affect the performance of construction projects (Sakamoto et al., 2002). This phenomenon is seen daily in construction projects in the variable behavior of factors such as production rates, labor productivity, and construction schedules (González et al., 2009). Workflow variability leads to a general deterioration of project performance on dimensions of both project cost and planning efficiency (Farag, 2014). The attention on improving the workflow will be a practical way to avoid these kinds of changes (Xue and Chen, 2013). Therefore, construction companies are using a few ways to understand and minimize variability so that construction production becomes more predictable. These ways include buffers and LC to improve workflow in construction activities (Mossman and Sarhan, 2021; Poshdar et al., 2015).

LC is one of the important approaches to create reliable workflow (Xue and Chen, 2013). Buffer system is another alternative often used in construction to prevent the negative impact of variability on projects, such as inventories of materials, budget contingencies, time float, and excess of equipment capacity (Poshdar et al., 2018). Therefore, the strategy of buffer management plays a key role in the lean goal by minimizing the impact of variability within the construction process, even though buffers themselves are considered waste. However, inefficient sizing buffers often results in unnecessarily added time (waste), and consequently, fails to protect the project schedule performance (Farag, 2014). In other words, an excessive number of buffers within a project can be considered wasteful (Dlouhy et al., 2019).

Effective buffers can manage risks and uncertainties within a project, thereby minimizing resource waste (Liu et al., 2012). They are essential for effective risk response, allowing companies to manage variability with fewer trade-offs (Fireman et al., 2023). Buffer management, in this context, is considered a strategic process that involves the deliberate planning, sizing, and placement of buffers to mitigate risks and ensure smooth project execution (Farag, 2014; González and Alarcón, 2010). It encompasses the continuous assessment and adjustment of buffers to respond to changing project conditions and uncertainties, thereby optimizing resource utilization and maintaining workflow efficiency (González et al., 2011b; Jan and Ho, 2006).

From a theoretical perspective, lean thinking identifies buffers as forms of waste (Poshdar et al., 2018). Accordingly, lean ideal suggests avoiding the use of buffers to the maximum possible extent (Mojtahedi and Oo, 2012). However, the absence of buffers induces inefficiencies, deteriorates productivity, increases cycle times and inflates project cost (Poshdar et al., 2018; Tommelein et al., 1999). Thus, it appears that a 'balance problem' exists between the use of buffers to reduce variability impacts and overall production system performance based on lean principles (González et al., 2011a; Gupta et al., 2012). Such paradoxical situation calls for an integration between the lean theoretical goals and the practical norms in buffer management domain. Buffers are implemented as a direct consequence of variability within construction processes. The integration of lean construction and buffer management is crucial for identifying and mitigating the causes of this variability, thereby optimizing the use of buffers and improving overall project performance (Farag et al., 2010). Moreover, the integrating of different approaches enabled the development of new models of cost, quality and schedule optimization across the life cycle of a construction project (Machado et al., 2020).

Systematic Literature Reviews (SLRs) have been widely adopted in recent years to explore the interaction between LC and various other approaches, highlighting their effectiveness in synthesizing existing knowledge and identifying research gaps (De Carvalho et al., 2017; El Mounla et al., 2023; Rashidian et al., 2023). However, despite the increasing use of SLRs in the field of LC, there remains a notable gap in the literature: no SLR has yet investigated the integration of LC with buffer management. This gap is critical, as the combination of these two approaches holds significant potential for enhancing project performance by effectively addressing variability and optimizing resource utilization. Therefore, this study employs the SLR method to comprehensively analyze the existing literature on LC and buffer management, aiming to uncover insights that can lead to more efficient and resilient construction practices. By doing so, it bridges the existing gap and provides a solid foundation for future research in this area.

Besides that, while LC research covers a broad range of topics, a significant portion has primarily concentrated on waste reduction. However, there is a noticeable gap in the literature concerning more advanced concepts such as variability management and buffering (Tomašević et al., 2021). Based on the previous review, a comprehensive analysis that reveals the current trends and common themes in the integration between LC and buffer management is still lacking. Although, many previous studies have touched on the topics of buffer management and Lean Construction, such as the foundational works by Ballard and Howell (1995, 1998) and Tommelein et al. (1999). These studies have provided valuable insights into how buffers can be managed within Lean Construction frameworks. However, there remains a need for more comprehensive analyses that integrate these concepts to reveal current trends and common themes in the construction industry.

In brief, Lean Construction and buffer management have been developed as a promising approach to mitigate the impact of variability and improve overall project delivery. To achieve effective integration between Lean Construction and buffer management, it is important to use buffer sizes that are "good enough" and adjusted based on an intuitive assessment of risk (Newbold, 1998). This approach ensures that buffers absorb variability without causing waste from oversized buffers, aligning with Lean Construction principles. However, the extent and effectiveness of their integration remain areas of exploration.

Therefore, this study aims to contribute to the existing body of knowledge by conducting a systematic literature review on the integration themes between Lean Construction and buffer management. Based on this review, this study identifies gaps and inconsistencies in current understanding and practices and proposes future research direction for enhancing this integration. By addressing these gaps, the study aims to pave the way for more effective strategies in managing variability, ultimately leading to improved project outcomes and enhanced industry practices. This review pinpoints existing integration themes offered by Lean Construction and buffer management literature, which provides meaningful and relevant information for further development of this field.

This study is structured as shown in Figure (1). Section 2 covers the research method followed within this study. Section 3 reports on the results using a descriptive analysis and it contains a complementary content analysis. Section 4 discusses the results, highlighting the limits of the research, emerging topics, major findings, and literature gaps in relation to the research questions. Section 5 concludes and presents suggestions for future research.

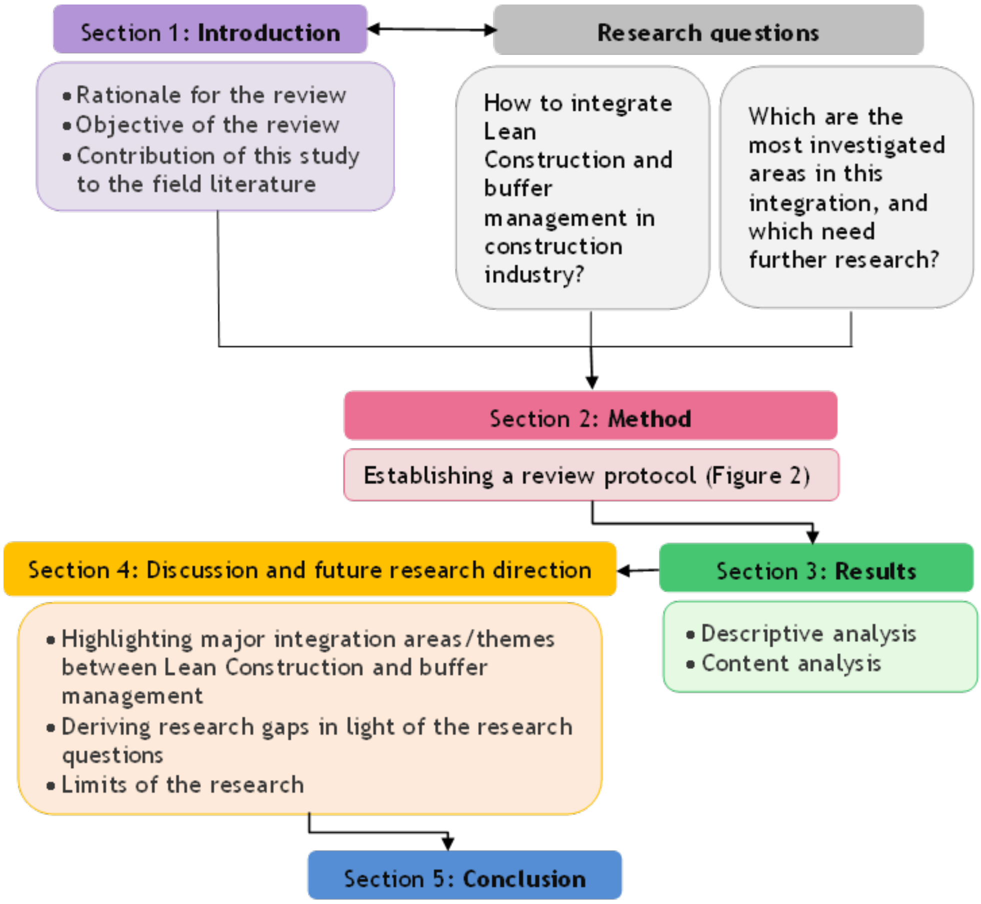

Figure (1): Study's structure.

Research Method

This study aims to review and categorize the key themes in which the integration of LC and buffer management has been discussed and conceptualized in the attributes. To achieve this, a SLR was adopted. The method of systematic review is widely used in various disciplines including construction management (Bataglin et al., 2021; Rashidian et al., 2023). A SLR as a scientific activity extracts data from relevant sources in literature, analyses the data to generate various categories and explores new visions for further investigation (Okoli, 2015).

In this study, SLR is performed based on the steps from other studies in this area. This study adopts the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-

Analyses) approach to ensure a rigorous and transparent methodology. The PRISMA approach is chosen for this study because it provides a standardized method for conducting systematic reviews, ensuring that all relevant studies were identified, screened, and assessed in a transparent and reproducible manner (Belle and Zhao, 2023). Figure (2) outlines the SLR steps implemented in this study.

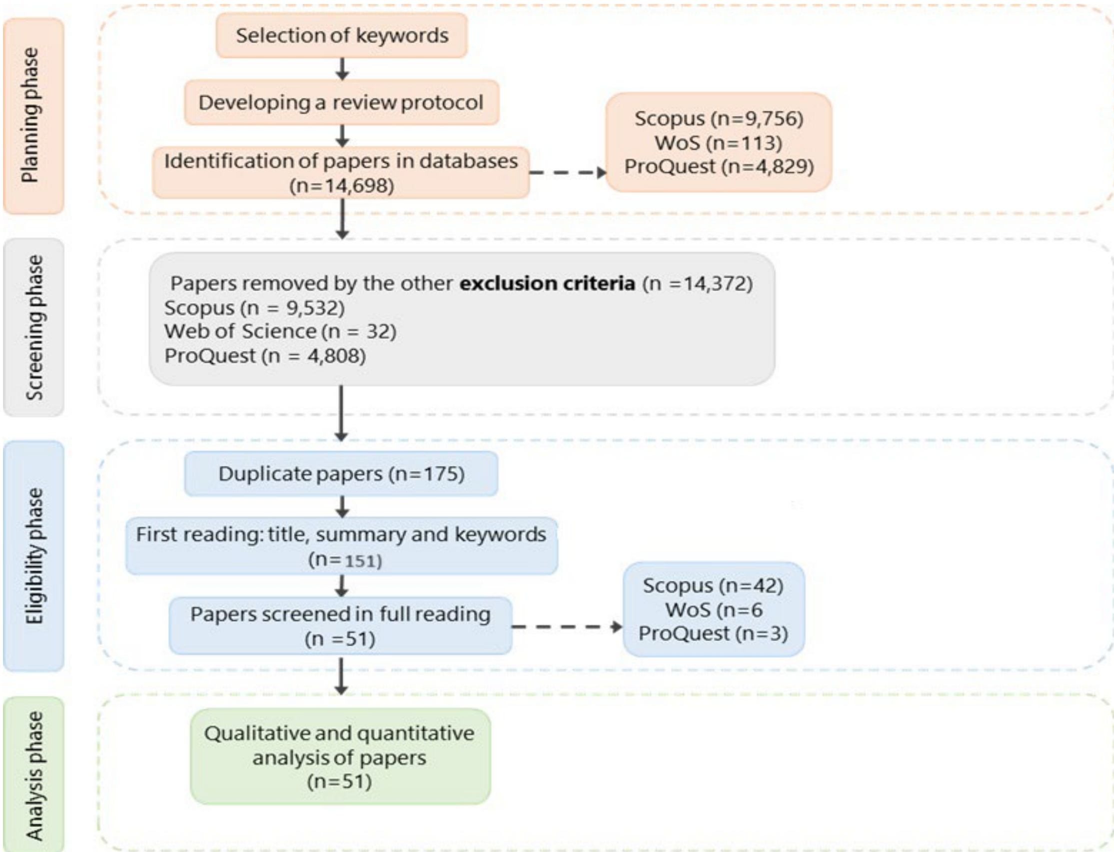

Figure (2): Steps of SLR carried out in the current study.

This structured approach ensures that the literature review is systematic, transparent, and replicable, providing a solid foundation for analyzing the integration of Lean Construction and buffer management. The steps are very clear and easy to follow, as described in the four steps shown below.

Planning phase

Firstly, a well-defined study aim guided the selection of reviewed studies (Xiao and Watson, 2019). Secondly, a review protocol is developed to select the required criteria for searching. Following the commonly used method in previous studies, suitable search engines of Scopus, Web of Science (WoS), and ProQuest were employed for searching (De Carvalho et al., 2017; El Mounla et al., 2023).

Keywords are the critical part of the review and the selected initial keywords in this study to meet the research objectives were "Lean Construction" and "buffer management." The language was restricted to English for articles published from 2003 to 2023. While acknowledging that key literature on Lean Construction and buffer management, including foundational work by the International Group for Lean Construction (IGLC) established in 1992, has significantly contributed to the field, this study focuses on the substantial body of research published in the last two decades. According to the Scopus database, 95% of relevant articles and conference papers were published within this timeframe, indicating a significant increase in research activity and interest in the integration of Lean Construction and buffer management during these years. This period reflects the evolving trends and advancements in the field, making it a pertinent focus for this study.

The inclusion condition was defined to cover the peer-reviewed papers only in journals and leading conferences in the field of construction management. The other types of documents were excluded to maintain the quality of the research. Further refinement was also employed by focusing only on the construction projects and excluding irrelevant papers from other sectors.

Screening phase

In the first search round, Scopus was utilized as it is widely used for reviewing construction literature. The search was then completed using the WoS and ProQuest databases. Using the second and third databases ensured that no relevant document is missed. The search for Lean Construction and buffer management in three databases was conducted in August 2023 with the following code:

- ("Lean") AND ("Buffer*" OR "Slack" OR "Contingency" OR "Inventory" OR "Just In Time" OR "JIT") AND ("Construction")

To get an accurate and specific result aligned with the research aims the first keyword “lean” was selected. According to previous research works other terms used to represent buffer which are contingency and slack. The term contingency refers to a kind of buffer with time and money being the resources of concern (Barraza, 2011). The term slack generally appears to be given a broader meaning than buffer, with buffers being a kind of slack (Formoso et al., 2021; Saurin et al., 2021). In other words, slack is considered as a socio-technical complement to buffers for dealing with variability, addressing both social and technical aspects of project management. Therefore, while all buffers are a form of slack, not all slack is utilized as buffers (Fireman et al., 2023). Including both terms in the research process ensures that a wide range of relevant studies is captured, providing a more holistic understanding of how variability is managed in construction projects.

Moreover, inventory is most widely forms of buffer (Horman and Thomas, 2005). JIT is one of lean tools that focused on reducing buffer through construction process and considered as a common point between LC and buffer management (Bamana et al., 2019). Furthermore, lean is a general word that is used in various industries, and to avoid any misleading by irrelevant documents from the other subject areas, the “construction” keyword was used.

After the initial search of the selected keywords without any restriction, 14,698 were collected, in which 9,756 were from Scopus, 113 from WoS and 4,829 from ProQuest. Refinement was then required because most of the papers collected were irrelevant to the construction industry. The search space included only journals and conference proceedings. According to the study’s aim, the keywords were limited to Lean Construction and buffer related terms (slack, contingency, inventory and JIT) that would lead to more precise results. The second round of search by applying the inclusion and exclusion criteria, resulted in 224 screened papers in Scopus, 81 in WoS and 21 in ProQuest. In total, 326 documents were included for visual examination in the next step.

Eligibility phase

In this step, an in-depth visual examination was performed to select the right papers for further analysis. An efficient way is to follow a two-stage procedure: first start with a coarse sieve through the articles for inclusion based on the review of abstracts followed by a refined quality assessment based on a full-text review (Xiao and Watson, 2019). Accordingly, unsatisfactory papers and publications beyond the research scope were excluded. In this study, all papers' titles were reviewed initially to find out if they were really fitted to the research scope or not. The unfitted papers were removed and the duplicated papers among the three databases were also removed. Eliminating the duplicated papers resulted in 151 published works out of 326 retrieved documents.

The abstract of all remaining documents was scanned to segregate the relevant papers according to research scope. In the first reading of abstracts, 100 out of the 151 papers were excluded as they were not relevant to the research objectives. This step ensured that the final selection of papers is directly pertinent to the integration of Lean Construction and buffer management, allowing for a focused and comprehensive review. The outcome of this process resulted in 42 papers in Scopus, 6 papers in WoS, and 3 papers in ProQuest. In total, 51 papers remained for further analysis.

Analysis and Categorizations

A total of 51 publications were included in this review to be analyzed. The results of this review generally identify gaps in the knowledge and can be used as a starting point for further research on a specific topic. The conceptual boundary of the current review was to involve the interrelationship between LC and buffer management in construction industry.

The SLR methodology used in this study was meticulously designed to ensure comprehensive and robust data collection, providing a strong foundation for subsequent analysis. Data were gathered using predefined criteria to guarantee thoroughness and reliability. Lean Construction principles and tools were identified based on their definitions and applications in existing literature. Moreover, research was categorized into specific buffer types (time, inventory, capacity) based on explicit criteria. For instance, studies focusing on scheduling and timeline adjustments were categorized under time buffers. Detailed explanations for each categorization were provided to ensure the process is repeatable and replicable, including citations of specific aspects of the research that align with the defined buffer types.

Results

Descriptive Analysis of the SLR Findings

The sample's analysis provided an overview about: (1) the distribution of studies over time; (2) countries leading and concentrating research on the topic; and (3) the preferred research publishing types. Figure (3) presents the number of the publications per year. Publications bloomed after 2011 and peaked in 2021, for which nine studies were registered.

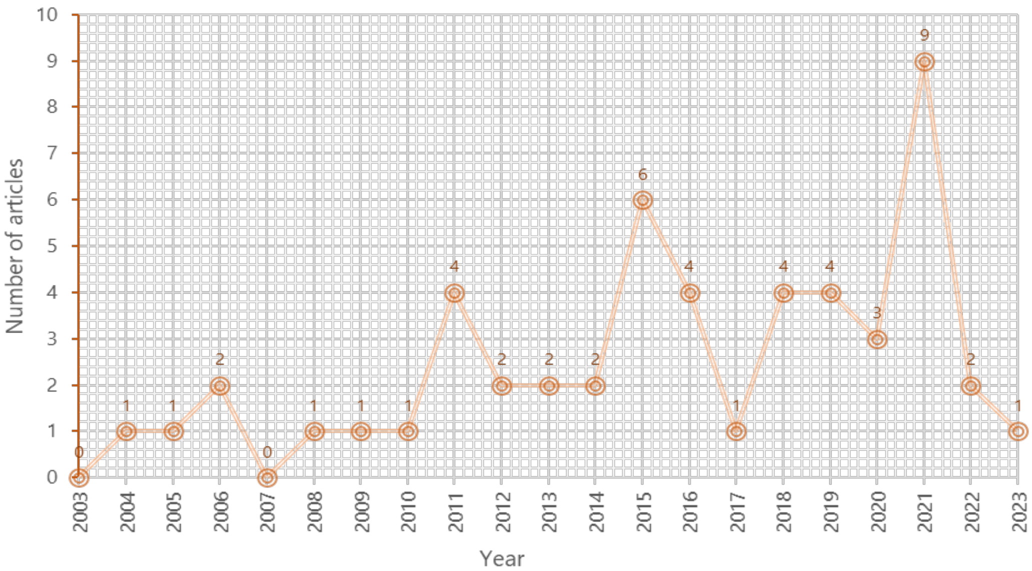

Figure (3): Number of publications per year, between 2003 and 2023.

Brazil and United States (US) concentrate research in this subject where over 30% of the studies were produced by Brazilian or US-affiliated authors (Figure 4). Germany, New Zealand, Canada, China, and Finland follow Brazilian and US lead, and together represent 67% of the studies.

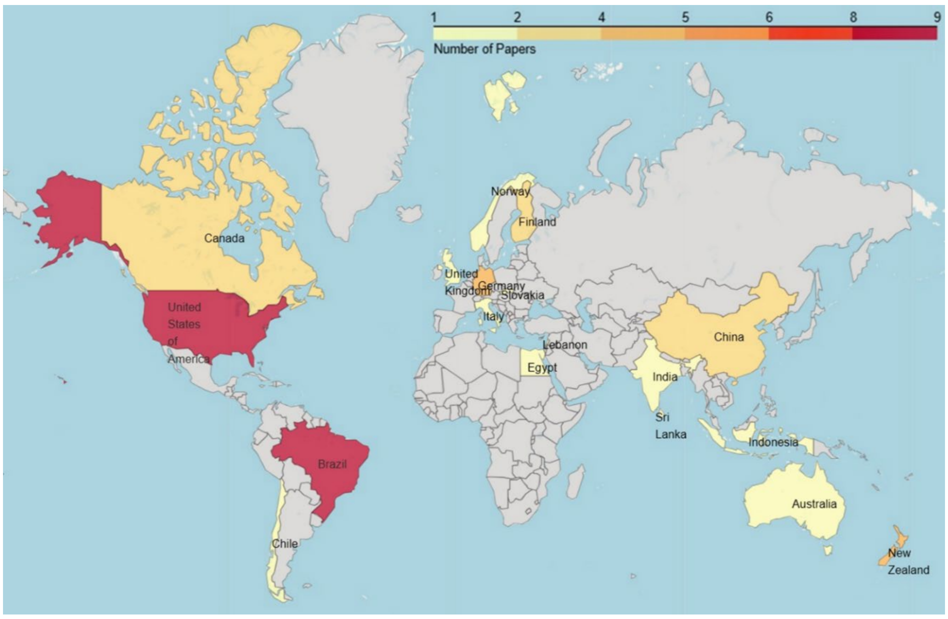

Figure (4): Geographical distribution of studies.

As shown in Figure (5) conference papers are the dominant and 57% of these papers published in the IGLC.

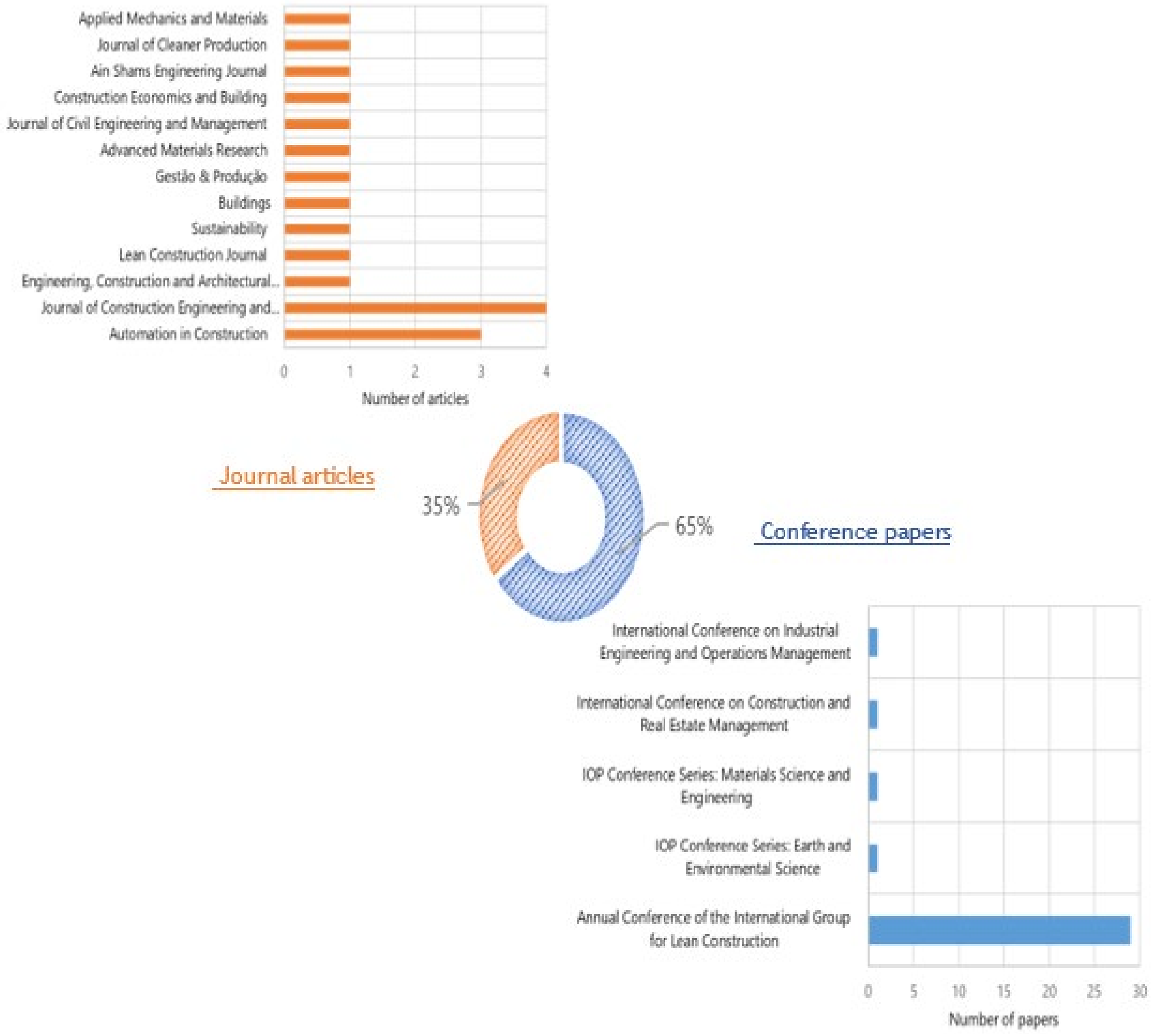

Figure (5): Journal-to-conference publication ratio of the SLR sample.

Interactions between Lean Construction and Buffer Management

To recognize patterns and interactions in the evidence base, previous studies that support the integration between LC and buffer management were identified or that suggested a conditional relation between these approaches. In this context, a conditional relationship refers to optimizing the use of buffers so that they add value without becoming wasteful, based on specific project conditions and requirements. Next, the research works were categorized according to the type of integration and the nature of the relationship studied. In Lean Construction, it is essential to differentiate between tools and approaches to effectively apply lean principles. Lean Construction tools refer to specific, actionable techniques or instruments that target aspects of the construction process to improve efficiency and performance at the operational level (Salem et al., 2005; Womack et al., 1990). For example, the Last Planner System (LPS) serves as a tool to enhance scheduling reliability by fostering collaborative planning and improving workflow predictability (Xue and Chen, 2013).

Conversely, Lean Construction approaches represent overarching methodologies that provide a comprehensive strategic framework for integrating lean principles into project management. These approaches focus on achieving broader process improvements and sustaining systemic benefits by combining multiple practices (Ballard, 2000; Forbes and Ahmed, 2010; Howell, 1999). For instance, Takt time planning exemplifies an approach that aligns production rates with project timelines, promoting smooth workflows and reducing variability (Dlouhy et al., 2018; Frandson et al., 2015).

The results revealed that the most frequent interactions addressed in the investigated literature were focused on LC principles/tools. While buffer management, on the other hand, was not extensively investigated in the literature. This result was unexpected because many sources of workflow variability exist within the construction industry, and this is why studying variability is crucial, especially schedule variations. The management of buffers in construction has been studied implicitly in LC related studies. However, integration of these two approaches is still limited. Therefore, the interactions between buffer management and LC found in the investigated literature were discussed. In addition, gaps on such interactions were identified and described.

Theoretical aspects of interactions between Lean Construction and buffer management

Most studies focused on reducing workflow variability as the integration aim of LC and buffer management (González et al., 2009; Tommelein, 2020). According to Ariyanti et al. (2021) without using buffers, delay in the project was 22 months because of variability in activities workflow. Poshdar et al. (2018) conducted their study in New Zealand to find balance themes between theoretical goals and the practical norms regarding buffer management. One of these themes is that buffers are being used as an auxiliary component of projects that keep the activities running without variability. Moreover, Valente et al. (2013) investigated the improvements that can be expanded to project performance through buffer management, like balance of workflow. In line with this result, many studies concluded that Work in Process (WIP) buffer may not contribute to improving productivity rates, but they provide very good protection to productivity levels in case of variability conditions in projects (González et al., 2011a; González et al., 2011b; Gupta et al.,2012). Besides that, a practical scheduling approach is proposed by González et al. (2006) to apply WIP buffer strategies in construction projects that may allow more realistic and reliable construction schedules.

Buffers are one of the most important ways to mitigate against variability, and mathematical models allow the optimal positioning and sizing of buffers (Formoso et al., 2021). To cope with variability, the challenge is to minimize waiting times by determining suitable buffer sizes (Faloughi et al., 2015). Horman and Thomas (2005) conducted an exploratory analysis of the relationship between inventory buffers and construction labor performance. According to their study, some buffers help achieve the best labor performance in the construction operations by managing workflow variability.

On the other hand, LC ventures three key strategies to enhance the construction performance, namely, stabilization of workflow, reduction of inflow variability, and improvement of downstream performance (Farrar et al., 2004; Poshdar et al., 2018). Employing lean concepts resulted in stabilizing the workflow of the activity and other downstream activities, allowing for more waste reduction, and less inventory (Abou Ibrahim and Hamzeh, 2015; Shaqour, 2022). In the same line, Goh and Goh (2019); Xing et al. (2021) confirmed that improvement of construction workflow along with project productivity and quality were the two most valuable benefits of using lean tools.

According to the previous results, there is agreement between LC and buffer management where both aimed to reduce workflow variability and thus improving project performance. However, from lean perspective there are two viewpoints regarding buffer in construction projects:

- Buffer is considered as waste or non-value adding activities (Ranadewa et al., 2018). In construction projects, the lean emphasis on waste reduction can contribute to the depletion of necessary buffers for managing unexpected variability (Saurin, 2017).
- Buffer management has a vital role for mitigating the influences of uncertainty on the construction project (Farag et al., 2010). Hence, the method enables shielding the project activities against variability that is one of the steps required to implement lean in construction (Poshdar et al., 2015). Additionally, production strategies based on buffers and lean principles in construction demonstrate project performance improvements and workflow reliability (González et al., 2009; Tommelein, 2020).

To bring these contradictory viewpoints closer together, Saurin et al. (2021) concluded that while buffer has been concealed by the lack of theorization and consistent terminology, it is ubiquitous in LC. The balance problem between LC and buffer can be resolved through finding the optimum size and location of buffers in the system (Du et al., 2023; Fireman et al., 2018). In other words, the need for buffers is context-dependent and their use must be adapted to the nature of projects (Bataglin et al., 2021).

Approaches to enhance the interaction between Lean Construction and buffer management

- Takt Planning

Takt time planning is a work structuring method that aligns the production rates of trades by pacing work through a set of zones in a set sequence to create continuous workflow (Dlouhy et al., 2018; Frandson et al., 2015). The process of takt time planning can help reveal some buffers, with the intent of using them to create improved schedules (Dlouhy et al., 2019). Takt Time helps to establish a continuous flow and, as a result, reduce waste, reduce duration and number of inventory buffers, and therefore reduce costs of construction projects (Kozlovská and Klosova, 2022).

A case study was carried out by Keskiniva et al. (2020) to demonstrate how the scheduling of an apartment building renovation project that utilizes takt time planning can be done. Their study focused on buffers to investigate the uncertainty related to the specified work packages in advance to reduce disturbances in the takt time planning.

The buffers become a part of takt process and integrated into a takt area (Haghsheno et al., 2016). Dlouhy et al. (2019) adopted an overview of all detected buffers during 100 projects and the different ways to optimize these buffers. With this foundation in buffer management for takt planning, construction schedules could be more stable and efficient. Moreover, Takt time achieves substantially shorter schedules. In projects where quantities are similar between locations, takt time performs well if the resources are not demobilized when they run out of work (Seppänen, 2014).

- Material Management

There were many approaches adopted lean and buffer concepts for material management in construction projects. For example, Seppänen and Peltokorpi (2016) supposed a new lean model for material logistics with optimal material buffer to achieve a desired level of protection against material shortages. In the same line, Kim and Kim (2014) introduced a computerized integrated project management system aims to improve the workflow reliability and to reduce the material inventories onsite using a material pull system. Moreover, Kim and Kim (2011) introduced a material management system that incorporates Lean Construction principles such as reliable production planning and material pull strategy. The proposed system also aims to optimize material buffer (inventories) on site using a material pull system. In the context of supply-network visibility, Automated Materials Locating and Tracking Technologies (AMLTT) presents a viable solution to material management and in turn reduce the dependency on material buffers (Young et al., 2011).

- Other Approaches

Critical chain and LC are two inspiring initiatives aiming at dramatically improving project performance through attacking the traditional buffer management methods. The critical chain approach advocates improving throughputs to shorten task duration estimates and deploys various schedule buffers to protect the project due date (Shen and Chua, 2008). Another approach was developed by Jeong et al. (2016), BIM-integrated simulation framework facilitates the reliable prediction of productivity dynamics, and can contribute to improved schedule reliability, optimized buffers allocation, cost savings, and reduced material waste.

Lean tools to enhance the interaction between Lean Construction and buffer management

- Just In time (JIT)

In the last years, JIT has received significant research focus as an innovative solution for the construction industry (Bamana et al., 2019; Rauch et al., 2015). In this research, JIT is defined as a tool because it directly supports buffering strategies by managing buffers and reducing inventory waste. This practical, operational application aligns with the study's focus on actionable tools for addressing workflow variability. While JIT is commonly recognized as a method derived from lean management, emphasizing the principle of pulling work forward from one process to the next (Mojtahedi and Oo, 2012), its classification as a tool highlights its functional role in implementing lean principles at the operational level (Aslam et al., 2022; Singh and Kumar, 2020). The primary goal of JIT implementation is to optimize the use of material buffers (inventory or WIP), reducing the time materials spend sitting in queues awaiting processing. For example, Saad et al. (2021) developed a lean-driven scheduling technique that utilizes JIT and pull-production concepts to minimize WIP buffers, while Dallasega et al. (2016) and Viana et al. (2015) proposed approaches to synchronize off-site and on-site production planning using JIT to control WIP buffer levels and achieve short delivery times.

Arbulu (2006) concluded that the application of pull and JIT tools can drastically improve value delivered. Benefits include reduction in physical inventories, an increase on transparency across the production system, reduction in variability levels, and better collaboration amongst stakeholders (Bamana et al., 2019). The value of integrating JIT tool with buffer between suppliers, fabricators and the site as a way to help the whole supply team create production flow and more environmentally friendly results (Lu and Fang, 2021).

- Other tools

There are other lean tools that are integrated with buffers to improve workflow in construction projects. Lean visual management tools have a great impact on monitoring the movement of the parts in the construction sites. Therefore, management of material buffer can be improved (Kanai and Fontanini, 2020; Kanai et al., 2021). Focusing on the measurement of workflow and the methods to maintain the continuous workflow, Xue and Chen (2013) introduced a combined method of LPS and buffer system. This method can help to improve the whole construction process, constantly improve project management level, eventually improve whole project of performance.

Matrix of Interactions Between Lean Construction and Buffer Management

The prevalence of Lean Construction principles/tools and buffer types in the literature were identified and mapped out in a matrix in Table (1). This matrix reveals that while many aspects have been prevalently discussed, significant areas have not been extensively studied. The rows of the matrix represent LC principles/tools, while the columns represent the buffer types. Each article can include multiple principles/tools and buffer types, depending on the topics it addresses.

Discussion and future research directions

The purpose of this study is to make a systematic review of the literature on buffer management within the context of LC. Based on these results, there is a growing interest in these topics, as 38 papers were registered in the last decade coming from a diverse variety of countries (Figure 3).

The analysis of Table (1) indicates a discrepancy in how LC tools are discussed in relation to different buffer types. This matrix reveals that while certain LC tools have been frequently associated with specific buffer types, other potential relationships have not been thoroughly explored. This highlights the need for a more comprehensive examination of how various LC tools can be integrated with different buffer management strategies.

The different lean tools have their own impact and applicability (Singh and Kumar, 2020). Aslam et al. (2022) indicated that many lean tools share almost similar objectives but different functionalities. This variation in functionalities results in disparities in how these tools/principles interact with buffer management. As shown in Table (1), the extensive coverage of the interaction between JIT, takt time planning, and variability reduction with various buffer types was observed across the analyzed research works. For instance, JIT primarily emphasizes and directly engages with inventory management through the efficient handling of materials. In the same context, Takt time planning employs time buffers to facilitate continuous flow in interior construction. This approach accommodates variations and ensures reliable, timely handoffs throughout the construction process (Kozlovská and Klosova, 2022). The reduction of variability is the common objective of LC and buffer management. Therefore, numerous studies, particularly theoretical ones, focus on discussing this aim extensively (Ariyanti et al., 2021; González et al., 2009; Tommelein, 2020).

Table (1): Matrix of interactions of Lean Construction principles/tools and buffer type (n=51).

Lean Construction principle/tool	Buffer type			
	Time	Material		Capacity
		Inventory	WIP	
Value Stream Mapping (VSM)	-	Shaqour (2022)	-	-
JIT	Bamana et al. (2019) Du et al. (2023) Rauch et al. (2015)	Goh and Goh (2019) Jeong et al. (2016) Lu and Fang (2021) Rauch et al. (2015) Seppänen and Peltokorpi (2016) Shaqour (2022) Viana et al. (2015) Xing et al. (2021)	Lu and Fang (2021) Mojtahedi and Oo (2012) Mossman and Sarhan (2021)	-
Pull system	Kim and Kim (2014)	Farrar et al. (2004) Kim and Kim (2011) Kim and Kim (2014) Viana et al. (2015)	Arbulu (2006) Saad et al. (2021)	Saad et al. (2021)
Daily huddles	-	-	-	Saurin et al. (2021)
Waste reduction	-	-	Saurin et al. (2021)	-
LPS	Farag et al. (2010) Mossman and Sarhan (2021) Shen and Chua (2008) Xue and Chen (2013)	Mossman and Sarhan (2021) Xing et al. (2021)	Dallasega et al. (2016) Mossman and Sarhan (2021)	Mossman and Sarhan (2021)
Visual management	Kanai et al. (2021) Poshdar et al. (2018)	Young et al. (2011)	-	-

Takt time planning	Dlouhy et al. (2019) Dlouhy et al. (2018) Frandson et al. (2015) Gardarsson et al. (2019) Haghsheno et al. (2016) Keskiniva et al. (2020) Kozlovská and Klosova (2022) Seppänen (2014)	Kozlovská and Klosova (2022)	Faloughi et al. (2015)	Gardarsson et al. (2019) Tommelein (2020)
Value stream map	-	Kanai and Fontanini (2020)	-	-
5 why	-	Ranadewa et al. (2018)	-	-
Reducing variability	Ariyanti et al. (2021) Bataglin et al. (2021) Fireman et al. (2018) Formoso et al. (2021) Haghsheno et al. (2016) Poshdar et al. (2015) Saurin (2017) Valente et al. (2013)	Abou Ibrahim and Hamzeh (2015) Bataglin et al. (2021) Formoso et al. (2021) Horman and Thomas (2005) Saurin (2017)	Bataglin et al. (2021) Farrar et al. (2004) Fireman et al. (2018) González et al. (2011a), (2006), (2009), (2011) Gupta et al. (2012)	Bataglin et al. (2021) Fireman et al. (2018) Formoso et al. (2021)

Note: Color grading represents number of unique publications (orange = 1 or 2; light orange 3 to 5; yellow = 6 or more)

Even the covered integration areas aren't addressing the integration directly or systematically, but it is concluded from paper analysis. To achieve this, there is a need for a holistic view and integrated project management system that consists of optimized buffer system with comprehensive lean system to achieve the best results of waste reduction and performance improvements. Integration, in this context, refers to the seamless incorporation of all project management elements, ensuring that buffer systems, Lean Construction, and risk management strategies work together synergistically to optimize performance and reduce waste. Current tools, such as the LPS, focus primarily on planning and scheduling but may not fully integrate other critical aspects, such as real-time buffer management and continuous feedback loops, or the proactive identification and mitigation of risks (Aslam et al., 2022; Singh and Kumar, 2020).

A truly integrated approach would involve an adaptive project management system that continuously monitors and adjusts buffer sizes based on ongoing project data and risk assessments, thereby ensuring optimal resource utilization and minimizing waste and potential project disruptions. The use of the integrated system with buffer optimization will play an important role in removing the wasted time that is hidden in buffers before the refining process, and consequently reduce the project completion time. From this point, it is recommended to develop this system for future research works, which should test the improvement in the efficiency of construction projects using integration between buffer model and LC in a single unit to achieve more significant success. Future research should focus on developing and testing integrated project management systems that incorporate these dynamic capabilities, including real-time buffer adjustments and proactive risk management. By doing so, it would be possible to create a more resilient and efficient construction process, capable of adapting to uncertainties and optimizing overall project performance.

Significant advances have been achieved by the international research community on LC and buffer management. However, continued efforts are needed to further integrate these two approaches into construction management to enhance project performance. Theoretical aspects of LC and buffer management integration were the most addressed, as 23 papers out of 51 treat the theoretical dimension of this integration. Despite the significant theoretical advancements, there remains a need for further development of the practical dimensions of this integration. Future research should focus on detailed case studies and practical implementations to fully realize the potential benefits of integrating LC with buffer management in construction projects. Most of the analyzed papers focused on theoretical improvement of integrated LC and buffer management. However, this suggests a more in-depth investigation into the mechanisms operating practice for managing buffers in LC. In other words, some researchers considered buffers with their different types as waste from lean perspective. Therefore, one of the key questions for future research might be how to develop the appropriate portfolio of buffers, and how to manage it through LC, which would ensure the desired level of efficiency.

As shown in Figure (6), a significant trend in the landscape of research works dealing with buffer management in the context of Lean Construction. Notably, papers utilizing mixed methods (theoretical and practical) dominate the field, indicating a robust approach to research that combines theoretical insights with practical applications. However, a deeper analysis reveals a critical gap in how these studies integrate the concepts of buffer management with Lean Construction principles, especially in their practical components.

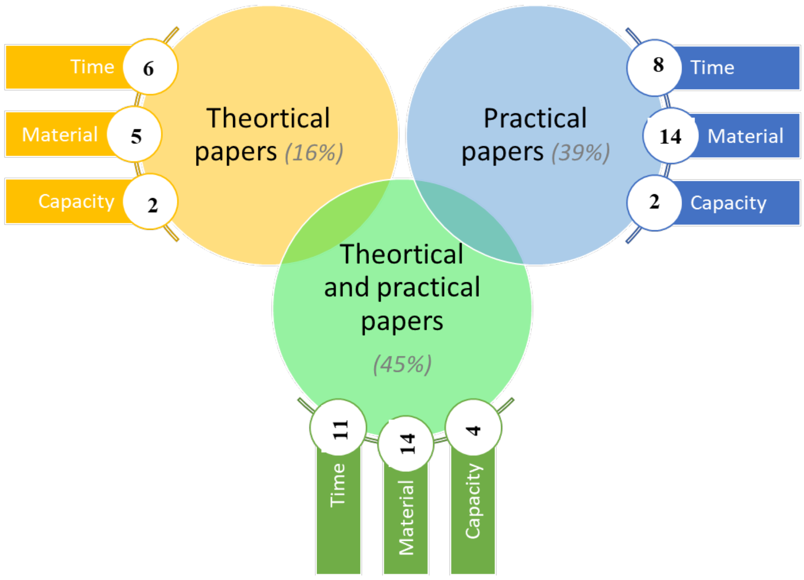

Figure (6): Classification of Papers by Buffer Type and Research Method.

Many papers start with a comprehensive theoretical overview of Lean Construction, highlighting its principles and potential efficiencies. For example, discussions often cover the importance of eliminating waste and enhancing flow in construction processes, with buffer management cited as a crucial component for handling variability and uncertainties inherent in construction projects. When transitioning to practical applications, the focus predominantly shifts to implementing Lean Construction tools such as JIT delivery systems or the LPS. While these are effectively demonstrated through models or frameworks, the application of buffer management concepts often remains underexplored. For instance, while the theoretical sections detail how time, inventory, and capacity buffers can stabilize the construction process, the practical sections frequently neglect a detailed integration of these buffers, focusing more narrowly on lean methodologies without addressing the synergistic potential of combining these with buffer strategies.

This analysis of the distribution of buffer types across various research papers reveals a significant skew towards time and material buffers, with a noticeable paucity of studies focusing on capacity buffers. This trend indicates potential gaps in the research that could be critical for improving overall project management in construction. Addressing this gap could significantly enhance the capability of construction project management to handle variability and uncertainty more effectively, ensuring that projects are not only completed on time and within budget but also with optimized resource utilization.

This research has several important implications for practice. First, managers should take into account buffer management specificities when considering lean implementation, as construction industry require management approaches compatible with their nature. Second, the reduction of waste should not be pursued in isolation; instead, it should be analyzed in conjunction with other crucial aspects of Lean, such as variability reduction and buffer management. As variability can be strategically important, management task is to decide how necessary variability can be buffered in Lean Construction. Third, going beyond theoretical aspects of Lean Construction and buffer management should be encouraged. This means that practical models of buffer management should be considered in combination with lean, as they can help achieving strategic goals. And last, practitioners are encouraged to employ an integrated system of Lean Construction and buffer management, with a specific emphasis on capacity buffers in addition to time and material buffers. The established system should evolve to include new tools aligned with Lean principles that can effectively address unwanted variability within the construction industry.

In terms of study limitations, this study used specific databases with certain keywords, as listed in the methodology section of this study. As the number of research repositories and databases are increasing, and those are updated continuously, the body of knowledge is continuously expanding which contributes towards limitations and future research both. Overall, the systematic review of existing integration themes of LC and buffer management highlighted in this paper are potent enough to set a research agenda for future. The proposed results in this review paper can be followed by semi-structured interviews and case studies that can yield new and valuable insights. Further, empirical studies through quantitative research can further establish the integration between these approaches.

The results obtained through the analysis show that the current state of Lean Construction and buffer management integration in the construction industry leaves much to be desired. This gives opportunities for future research. Possible future directions for research are summarized in Table (2), and all address research gaps identified during the review process. Engaging with these research propositions constitutes a significant stride toward enhancing our depth of knowledge regarding the integration of Lean Construction and buffer management.

Table (2): Future directions for researching Lean Construction and buffer management integration.

Current status	Future direction
Focus mainly on theoretical aspects, mostly oriented on elimination of waste	Analyzing the effects of Lean Construction and buffer management integration on workflow variability.
	Developing an integrated system of Lean Construction and buffer management that encompasses both the theoretical foundations and practical applications in order to enhance generalization of their integration
Focused on the integration of Lean Construction with specific emphasis on both time and material buffers	Expanding the integration of Lean Construction to encompass additional buffer types, with a particular emphasis on capacity buffers.
Some lean tools enforced to enhance the integration with buffer management	Exploring the relevance of certain lean tools in buffer management based on a deep understanding of the purpose of the tool

Conclusion

In this study, a SLR was performed to review and categorize the key themes in the context of the integration between LC and buffer management. Based on the results, it is concluded that the practical dimensions of this integration are less studied. Moreover, there are many construction management approaches that enhance integration of LC and buffer management which are: takt time planning, material management, critical chain, and BIM.

Research efforts need to be taken in the direct integration themes of LC and buffer management, including efficient frameworks to develop integrated systems of these two approaches. Thus, a systematic steps of buffer optimization into lean approach is a major research path. On the other hand, it was observed that a big amount of work has already been done in the scientific community to investigate the theoretical aspects of LC and buffer management integration. This is explained by the fact that there is conceptually a balance problem between these two approaches. Nevertheless, to overcome the misunderstanding of this integration, attention should be focused on the practical and systematic dimensions of LC and buffer management integration. Finally, these different future research paths focused on integrated systems to better understand the connections between LC and buffer management and to reach the full improvements.

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