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Application of systems thinking and system dynamics in managing risks and stakeholders in construction projects: A systematic literature review

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Abstract

This paper conducts a systematic literature review on systems thinking (ST) and system dynamics (SD) applications in construction project risk and stakeholder management over the past decade. It evaluates current practices' alignment with SD, addressing project complexity and uncertainty. Seventy-three articles are analysed following Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines, using descriptive, thematic and bibliometric analyses. Findings show fluctuating trends in ST and SD applications due to COVID-19 in 2019, with notable contributions from China, Australia and the UK. Building projects are the most studied, employing mixed methodologies. Thematic analysis highlights SD's significant role in system representation and risk management, with 80% of studies utilizing SD models for various risk factors. While less common in stakeholder management, SD enhances communication and understanding of stakeholder dynamics. The study advocates for integrating SD modelling in construction management for improved decision-making, risk mitigation and stakeholder engagement for project management practitioners, urging collaboration between academia, industry and policymakers for effective construction policies. Academics and researchers should focus on standardizing SD modelling tools, exploring hybrid methodologies like agent-based modelling, and integrating emerging technologies like artificial intelligence (AI) and the Internet of Things (IoT) to enhance real-time decision-making capabilities. Collaboration between academia, industry practitioners and policymakers is crucial to ensure SD research translates into effective policies and best practices, particularly in safety and environmental impact assessments.

KEYWORDS

construction projects, risk management, stakeholder management, system dynamics, systematic literature review, systems thinking

1 | INTRODUCTION

Construction projects are particularly complex due to their habit of changing during the dynamic processes of the project lifecycle (Zou et al., 2017) and varying durations and activities (Fateminia et al., 2021), along with the involvement of multiple stakeholders (Ward & Chapman, 2008). Wu et al. (2020) introduce project external complexities and internal uncertainties as the paramount characteristics that make the construction project a complex and dynamic system. Lee (2017) believes that construction projects are inherently dynamic. Such characteristics and inherent risks in construction projects present critical difficulties to stakeholders and project teams (Ansah et al., 2017), contributing significantly to a high level of uncertainty and risk in construction projects (Fateminia et al., 2021). This becomes even more challenging when the stakeholders involved demand different profit levels to keep them in the construction business (Jahan et al., 2022). These stakeholders are the source of multiple risk factors (Mbachu, 2011). Therefore, effective risk management is critical to the success of construction projects (Wang et al., 2016). Although risk management standards have been put forward to guide the best practices for such a complex system as a construction project, they still lack systematic approaches to describe all the interactions among the various types of risks concerning all the complex and dynamic conditions involved (Boateng et al., 2022), as project risks are mostly considered to be independent in risk management, ignoring interdependencies among them, which can lead to inappropriate risk assessment and reduced efficacy in risk treatment (Guan et al., 2021). Wu et al. (2020) believe that traditional methods, such as delay analysis and the critical path method, need help to accurately understand the complexity of projects and evaluate the associated dynamic changes. Hence, it can involve a complicated process when decision-making in an environment with many risks, uncertainties and multiple stakeholders. Complex problems cannot be treated in isolation from the broader systems that form their environments (Mclucas et al., 2012).

Systems thinking (ST) has been described as an analytical tool for expressing complex independent decision-making issues (Omotayo et al., 2020). The methodology has been applied to resolve numerous complex problems in many areas, including project management (Mahmud et al., 2022), and it has been shown that the complexity of project management may be managed by an ST mindset (Sheffield et al., 2012). While a range of systems methodologies exist to solve complex problems, a general distinction is made between 'hard' systems methodologies, which refer to the quantitative dynamic model building (ie, system dynamics), and 'Soft' systems methodologies (SSM), which refer to qualitative, action-based research methodologies (ie, critical systems heuristics) (Carey et al., 2015). While ST forms the basis for all these methodologies, emphasizing the holistic view, critical systems heuristics (CSH) provides a reflective, ethical lens for systems design, and SSM offers a practical approach to handling complex situations through iterative modelling. System dynamics, on the other hand, is more focused on quantifying and simulating system behaviours, offering a different perspective on managing system complexities (Lane & Oliva, 1998; Rodriguez-Ulloa & Paucar-Caceres, 2005).

Historically, ST methodology is embedded in the System Dynamics (SD) methodology (Omotayo et al., 2020) and has the potential to analyse and gain insights from the dynamics of complex systems and become the first stage in the development of a dynamic system (Király et al., 2017). In fact, the field of Systems Dynamics (SD) has developed to operationalize systems thinking (Sterman, 2002), and it has the potential to analyse and gain insights from the dynamics of complex systems and become the first stage in the development of a dynamic system (Király et al., 2017; Miki et al., 2015).

The field of Systems Dynamics (SD) was initially developed by Forrester from MIT in the 1950s–1960s (Forrester, 1958), developed to operationalize Systems Thinking (Sterman, 2002), and is a powerful methodology developed from system theory, information science, organizational theory, control theory, tactical decision-making, cybernetics and military games (Shepherd, 2014). The ability to deconstruct complicated systems into easily understandable subsystems is a key strength of the SD process. Early applications were in business management, but over the past few decades, it has been applied to other areas, including government policy, healthcare, the automobile industry and urban studies (Sterman, 2002). With the increased use of computer simulation approaches, SD's role in project management systems is becoming more prominent, both individually and as part of hybrid approaches (Kedir et al., 2023).

SD has been introduced in many studies as a preferred approach in project management, as it can be used to implement and understand the dynamics of complex processes that cannot be understood by other means (Abotaleb & El-adaway, 2018; Siraj & Fayek, 2019; Wu et al., 2020) through reasonably assessing the dynamic changes in the projects arising either from stakeholder expectations or project's various complexity factors (Rumeser & Emsley, 2016). By applying SD within the construction domain, project managers and leaders will be equipped to identify the emerging system-wide factors and take control of the system and subsequent serious outcomes (Woolley et al., 2020).

In recent years, SD has been introduced in many studies as a preferred approach in construction management, as it can be used to implement and understand the dynamics of complex processes that cannot be understood by other means (Abotaleb & El-adaway, 2018; Siraj & Fayek, 2019; Wu et al., 2020). By applying SD within the construction domain, project managers and leaders will be equipped to identify the emerging system-wide factors and take control of the system and subsequent serious outcomes (Woolley et al., 2019). Accordingly, with the increased use of computer simulation approaches, SD's role in construction management systems is becoming more prominent, both individually and as part of hybrid approaches (Kedir et al., 2023). The SD approach links qualitative and quantitative models. The qualitative models are best built with the input of the stakeholders and communicated with causal loop diagrams to connect entities through causal relationships. Quantitative models are useful in describing the structure of a system and a dynamic hypothesis based on linking differential equations in terms of 'stocks' and 'flows' via a stock-flow diagram, which keeps the model transparent and easy to understand. A model must present a simplification of a real-world problem and, therefore, will exclude some variables or structures present in the real world to achieve this. If a model were to be truly 'correct,' it would need to be as complex as the real world in every detail, and there would be no benefit in modelling (Mclucas et al., 2012).

Hence, SD models have been widely used in addressing construction management-related issues, such as sustainability and lean construction (Martínez León & Calvo-Amodio, 2017; Ozcan-Deniz & Zhu, 2016; Zhang et al., 2014). Several systematic literature reviews (SLRs) have investigated one or more aspects of construction projects to determine the extent of SD models in construction. SLRs in a specific area are important for identifying research questions as well as justifying future research in said area (P. V. Torres-Carrión et al., 2018). Kedir et al. (2023) review the application of SD in construction engineering management, analysing SD research trends in decision-making, policy analysis, performance, rework and change, scheduling and health and safety. Wu et al. (2020) investigated the applications of SD in the four mainstream themes of "risk management," "waste management," "energy management" and "construction productivity." More studies have been conducted on the application of SD in construction management or a particular aspect of managing construction projects, such as sustainability and safety (Kedir et al., 2023; Solaimani & Sedighi, 2020; Wu et al., 2020).

Since SD has been increasingly used as a modelling tool to understand the behaviour of systems with varying degrees of dynamism and complexity (Kedir et al., 2023), SD models have been developed as risk management simulations (Boateng et al., 2022; Mican et al., 2022) and stakeholders management frameworks (Elias, 2017), yet the study of SD modelling in managing risk and stakeholder in construction management is not thoroughly covered in previous research the present study systematically reviews the literature to explore the existing body of knowledge around the application of ST and SD in risk and stakeholder management for the construction industry through descriptive, bibliometric and thematic analysis over the past decade. The following sections review previously published articles that have applied SD to address one or multiple construction project risk or stakeholder management problems, to find the uncovered aspects by previous studies, and introduce the remaining topics with the potential to be modelled by SD in construction projects. The papers are categorized and systematically analysed to be included in the study. As this is a review, it is not feasible to go into the detailed calculations behind the models. It contributes to determining whether the current state of knowledge in managing risk and stakeholders in the construction domain is consistent with a contemporary systems approach and introduces the uncovered but potential corners in risk and stakeholder management area to be managed and benefitted from SD models.

2 | METHODS

The SLR is a process that allows for the collection of relevant evidence on the given topic that fits the pre-specified eligibility criteria and answers to formulated research questions (Mengist et al., 2020). SLRs provide a comprehensive literature overview and help discover research gaps. Thus, an SLR can be considered a platform for advancing knowledge (Mbachu, 2011).

This review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) 2020 statement, which aims to improve the quality of systematic review protocols by helping systematic reviewers transparently report why the review was done, what the authors did, and what they found. This is expected to lead to more transparent, complete and accurate reporting of systematic reviews, thus facilitating evidence-based decision-making (Page et al., 2021). The overall research process comprises four steps: identification, screening, eligibility and inclusion for review. Figure 1 shows the review's PRISMA flowchart.

2.1 | Identification phase

This SLR ground research is restricted to information concerning the use of ST and SD to address construction project risk and the available databases. Several sources are available to identify relevant literature; however, the Web of Science, Google Scholar and Scopus are the three most frequently used electronic databases across various disciplines (Martín-Martín et al., 2019). Scopus was considered the primary database because it contains a more recent and broader range of journals than such other databases as the Web of Science (Umeokafor et al., 2022) and (Aghaei Chadegani et al., 2013). ProQuest and Google Scholar were also used as secondary databases to ensure the inclusion of the whole literature provided in this review's scope.

The keywords for the search were derived from the research objective, which aims to investigate studies of how ST and SD address various aspects of construction project risk and stakeholder management. Hence, the main keywords used for the search were "SYSTEM THINKING," "SD," "CONSTRUCTION MANAGEMENT," "CONSTRUCTION PROJECTS," "CONSTRUCTION," "INFRASTRUCTURE," "STAKEHOLDERS" and "RISK." Figure 1 shows the search strings adopted based on each database's search tips, which are simple words (AND, OR, NOT or AND NOT) used as conjunctions to combine or exclude keywords in a search, resulting in more focused and productive results.

The initial search resulted in 9203 records among Scopus, ProQuest and Google Scholar. The search was restricted to journal articles and conference papers, documents written in English and published between 2013 and 2023. After importing all records from databases into RefWorks software, as a preferred reference manager tool in this study, duplications were removed between databases, resulting in a total of 1981 records.

2.2 | Screening phase

At this stage, title, abstract and keywords analysis was conducted on the records to remove all irrelevant results from the research. The method for this screening was to include records containing the following three criteria together in their abstract, keywords or title:

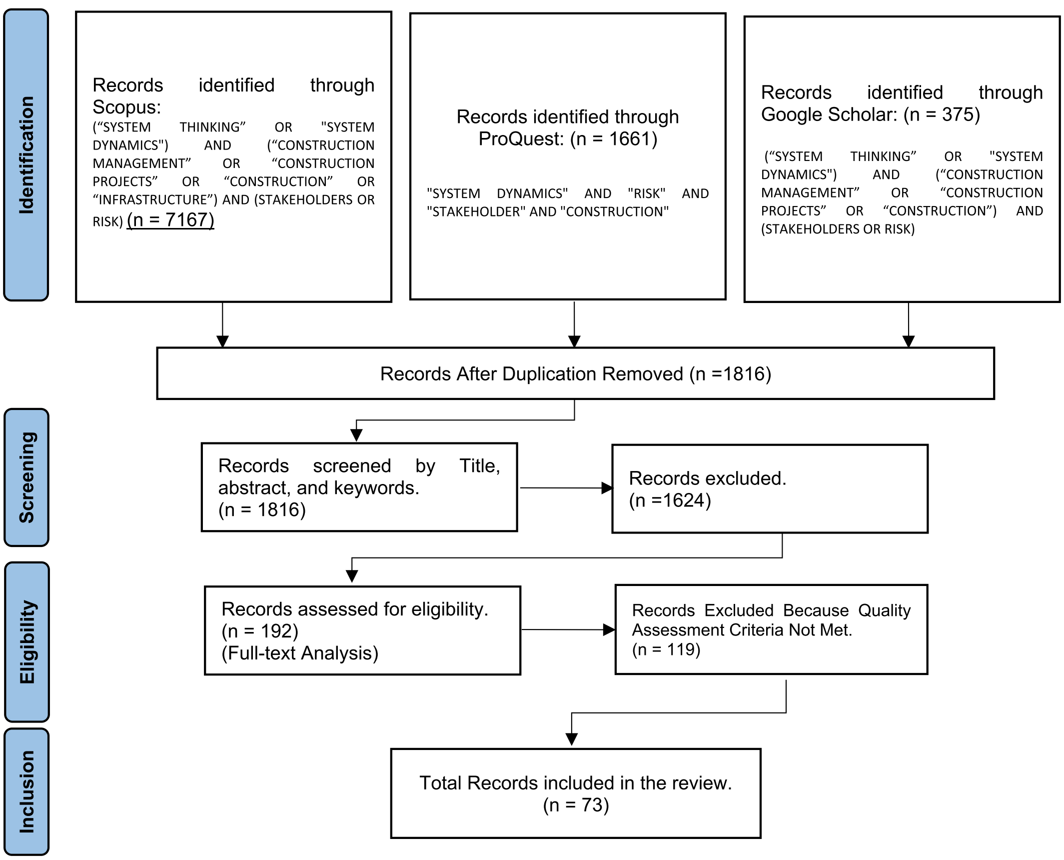

FIGURE 1 The process of systematic review (based on the PRISMA 2020 flow diagram for new systematic reviews). [Colour figure can be viewed at wileyonlinelibrary.com]

a. ST or SD or Dynamic models
b. Construction management or construction projects or construction or infrastructure
c. Stakeholders or risk

This approach excluded 1,624 records from the study, leaving 192 documents deemed eligible for the next stage.

2.3 | Eligibility phase

The 192 selected articles were thoroughly reviewed by the first authors, who had no prior discussion regarding the review, to reduce the risk of biased assessment and raise the veracity of the assessment. Although systematic reviews are designed to produce robust, reliable and reproducible results, they are still open to biases and errors. Thus, the identified studies were also assessed using a quality assessment strategy, a quality checklist designed for a particular study derived from factors that could potentially bias the study results (Yang et al., 2021). The designed quality assessment criteria for this study include four assessment questions to assure the quality assessment of the identified studies, as below:

- Q1: Does the study refer to ST methods OR SD models as a tool to address one of its questions?
- Q2: Does the study answer a question regarding risk or stakeholders of a project?
- Q3: Does the study cover the construction context across the different disciplines?
- Q4: Does the study fully describe the research aims, methods and results?

Records could only be included if all questions were answered positively. Afterwards, 119 records that were not within the scope of the study were excluded, resulting in 73 articles selected for review.

2.4 | Inclusion phase

The remaining 73 articles were gathered in a Google Sheet to analyse the descriptive data and conduct the thematic analysis. To this end, the contents of the selected articles were coded carefully based on their descriptive and bibliographic data, research methods, tools and software, application area, main results and study focus, which were provided in a shared spreadsheet among the research team.

A bibliometric analysis was also conducted using science mapping tools to obtain a thorough descriptive view of the articles, with VOSViewer software adopted. VOSviewer is among the most popular software designs for retrieving, visualizing and analysing publication information (Van Eck & Waltman, 2020). To conduct the analysis, bibliographic data is needed, which can be obtained through bibliographic databases, files, reference manager files and APIs. The bibliographic analysis results are shown and discussed in the Discussion section later.

In conducting the content and thematic analyses of the paper, all authors iterated on, refined and used code categories. After the group assessment and thematic analysis of the contents, the results were discussed to finalize the major themes in a focus group comprising four academics and two professionals with more than 5 years of experience.

3 | RESULTS

3.1 | Descriptive analysis

3.1.1 | Publication trends

As shown in Figure 2, the distribution of the articles from 2013 to 2023 reveals a dynamic trajectory characterized by fluctuating patterns. Apart from the significant drop in 2019, which could result from COVID-19's impact on academic activities, there is a distinct downturn in scholarly attention to the research topic. This could be associated with challenges or limitations in implementing SD in projects due to its complexity and time-consuming nature (Loosemore & Cheung, 2015) and limited support from top management (Kopczyński & Brzozowski, 2015), prompting the exploration of alternative approaches.

3.1.2 | Geography and authors affiliation

Regarding the research geographical locations, the top three countries are China, Australia and the UK, with 22, 8 and 7, respectively, included articles in the study. Also, for the authors' affiliations, China, the UK and Australia have the highest numbers. Notably, Australia's contribution as a single country with nine articles is more than America and Africa as the continents with eight and five, respectively. This can be attributed to the increased demand for construction and the subsequent engagement in scientific approaches to construction in Australia.

3.1.3 | Types of projects

Project type is considered as construction for the articles without mentioning the specific project types. Table 1

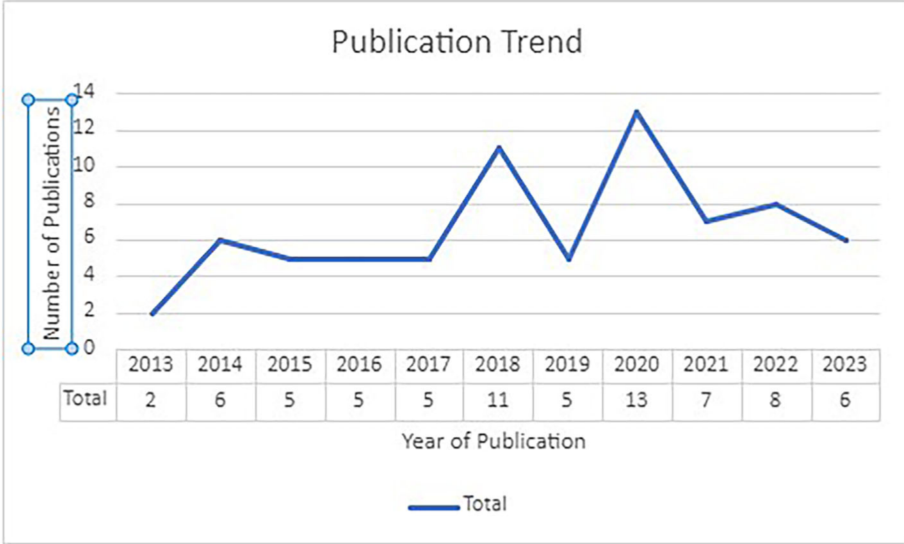

FIGURE 2 Number of related papers published between 2013 and 2023. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Type of construction projects in the articles.

Construction type	Included articles
Construction	29
Building	16
Railway	8
Infrastructure	5
Tunnel	4
Road	2
Tram	2
Highway	2
Power and energy	3
Bridge	1
Tower	1
Total	*73*

shows the profile of projects, with 39 articles that specifically focus on building, railway, tunnel, road, tram, highway, power and energy, bridge and tower projects; 29 focus on construction in general; and 5 mention infrastructure projects. Therefore, the application of SD to construction and building projects is mostly investigated.

3.2 | Bibliographic analysis

3.2.1 | Authorship

A wide range of publications were examined to achieve comprehensive and impartial results. Research and review papers and conference papers were deliberately included in the study to create a holistic understanding of the topic. The analysis results show that of the 73 journal articles, only 3% are authored by a single author and 17% by two. This could indicate diverse research topics or methodologies that may demand extensive collaboration around SD applications in construction risk and stakeholder management topics. A comprehensive overview of prominent authors who have significantly advanced the topic of applying SD in risk and stakeholder management with a higher number of included publications shows that Boateng, Thaheem, Li and Tavakolan are the most frequent contributors with three selected articles in the review. Their extensive publication history, affiliation with academic institutions and accompanying citations all help underline their considerable impact.

3.2.2 | Journals and citations

The articles were chosen initially from three main databases – Scopus, ProQuest and Google Scholar – to ensure the inclusiveness of the systematic review. The final review resulted in 73 articles from the 3 databases, with almost equal proportion between ProQuest and Scopus (50% and 47%, respectively) and only one article from Google Scholar. The 73 articles selected for further analysis were profiled based on the contributing journals. The number of contributions of each journal to the total number of articles was investigated at this stage of analysis. More than 50% of the articles were published in eight journals: *Safety Science* (16%), *International Journal of Project Management* (11%), *Buildings* (5%), *Journal of Cleaner Production* (5%), *International Journal of Construction Management* (5%), *Journal of Management in Engineering* (4%), *Journal of Civil Engineering and Management* (4%) and *Sustainability* (4%).

3.3 | Thematic analysis

3.3.1 | Methodology

A thorough examination of the chosen papers reveals that research procedures have been crucial in pursuing knowledge in this field. Notably, the distribution of research methodologies among the reviewed articles highlights a prominent pattern: 67% of the articles employ a mixed methodology approach, and 27% opt for a qualitative methodology. In comparison, a comparatively modest 6% embrace a quantitative methodology. SD implement qualitative and quantitative approaches to build the model (Kiekens et al., 2022) by linking qualitative and quantitative models. Qualitative data are best built with the input of the stakeholders. They are generally communicated with causal loop diagrams to help gain an increased understanding of how the dynamics interaction occurs in the system, while quantitative data are useful in describing the structure of a system and a dynamic hypothesis to develop feedback models (Luna-Reyes & Andersen, 2003). Most decision-makers then wish to see that quantitative results based on linking differential equations are presented to the user in terms of 'stocks' and 'flows' via a stock-flow diagram that keeps the model transparent and easy to understand. Most researchers have integrated both qualitative insights for understanding complex system structures and relationships and quantitative analysis for testing hypotheses and predicting outcomes. For instance, Yildiz et al. (2020) developed a dynamic strategy map using SD modelling, integrating both qualitative and quantitative methodology to demonstrate how to aggregate and formulate qualitative (e.g., employee soft skills) and quantitative measures (e.g., financial outcomes) in the form of mathematical equations. Their research used a two-stage methodology for SD modelling, including qualitative modelling of a causal loop diagram (CLD), described as a conceptual model, and quantitative modelling, to transform the conceptual model into a computerized model to test findings and discussions. Besides, studying the trends of methodology selection among the articles demonstrates a growing trend for mixed methodology in comparison to the qualitative approach in recent years. Hence, the popularity of mixed methodologies can be attributed to the ability of SD to include both quantitative and qualitative components, providing a holistic viewpoint and enabling a more thorough understanding of the intricate dimensions inherent in construction management risks and stakeholder dynamics.

When assessing the article methodologies, it is also noticeable that nearly 50% of the examined studies used secondary models/techniques in a hybrid way with their SD models during the model-building process. Hybrid research efforts within the construction industry can focus on the potential the industry could gain by using hybrid simulation (Nasirzadeh et al., 2018). Swinerd and McNaught (2012) presented two reasons for the growing interest in hybrid simulation. First, increasing familiarity with more than one simulation methodology might help explain the growing interest in hybrid simulation approaches. The other explanation is that the nature of many of the problems with which operation research analysts are now confronted calls for a multi-methodology or hybrid approach to be taken. For instance, Nabi et al. (2020) incorporated cellular automata into their SD model to exhibit the effects and changes in the individual conditions on site besides the simulated effect of production as well as the managerial safety policy preferences on the individual conditions of labourers by the SD model. In fact, they took advantage of this hybrid model to account for the effect of co-workers in a more innovative way as compared to previous literature works. More studies utilized SD with other methodologies or simulations to get unbiased and accurate estimates (Hai et al., 2022), adopt more innovative and effective solutions (Xu et al., 2018), enhance the validity and cross-verification of results (Wang et al., 2016), and a better understanding of uncertain and dynamic environments (Zhao et al., 2022). However, the possibility of increased complexity, higher costs or the need for specialized expertise is essential to be taken into consideration while adopting hybrid models.

3.3.2 | Software and tools

Seven software packages are used to implement SD in the selected articles: VENSIM, Any Logic®, STELLA, AcciMap Temporal, DEMATEL and STAMP. Although the tools or software used for SD modelling are not clearly mentioned in half of the articles, VENSIM is the most popular Software among the remaining articles. Software selection for use in SD modelling depends on several factors, such as availability and capability. For instance, Dynamo™ is no longer distributed commercially, so it is being implemented in a decreasing number of papers. VENSIM, which is free and more available, is a relatively earlier software with discrete event functionality and simulation capabilities for the Markov chain and Monte Carlo methods. Any Logic® is a newer software that can support a combination of SD, DES and ABM; perform hybrid modelling; and offers a graphical user interface (GUI) for users to execute several types of standalone or hybrid simulations (Kedir et al., 2023).

3.3.3 | Co-occurrence of keywords

Figure 3 shows a network representation of keywords co-occurrence mapped through VOS viewer, in which the results are reflected to depict the most important nodes of research streamlining, displaying connections among the areas of construction, SD, risk and stakeholder management. The interrelationships between these keywords are denoted by the frequency of co-occurrence in the literature (Alkaissy et al., 2020). The node's density in the figure represents the higher level of citations for a study, while the links among nodes represent citations in pair and group articles. These links become stronger (closer nodes) when two neighbouring nodes have similar coauthors or frequent pairs of citations (Van Eck & Waltman, 2020). Additional examination of the network's nodes reveals that risk management, construction industry and ST – components of search strings – are the topics most closely associated with SD as the most frequently occurring term. The most frequently occurring terms in the articles that include the major keywords in a cluster and are illustrated in different colours are safety, construction safety, environmental studies, risk assessment and accidents. Although these are the study's most prevalent themes among the chosen articles, the overall themes are determined only through careful reading of the articles and eliciting the concepts and goals of the authors, as is described in the next section.

3.3.4 | Main application area

To identify the main themes of each article, content analysis was established by thoroughly reading the full text of the articles by the authors and extracting the main area of risk or stakeholder management that SD models address. Multiple SLRs highlight SD's diverse applications in construction management in various areas, underlining its growing importance in this area (Abotaleb & El-adaway, 2018). For instance, Liu et al. (2019) identify eight research topics including sustainability, project planning and control, performance and effectiveness, strategic management, site and resource management, risk analysis and management, knowledge management and organization and stakeholder management. Similarly, Wu et al. (2020) introduced SD applications in mainstream themes like risk management, waste management, energy management and construction productivity from 2011 to 2019. Kedir et al. (2023) further assessed the role of SD in Construction Engineering Management (CEM) and found that scheduling and health and safety gained more attention among researchers from 2017 to 2021. SLRs also show that risk and safety are prominent themes benefiting from SD's applications in this field.

As Figure 4 shows, the six major areas of application of SD models in the selected articles are "Safety Risk Management," followed by "Risk Management in

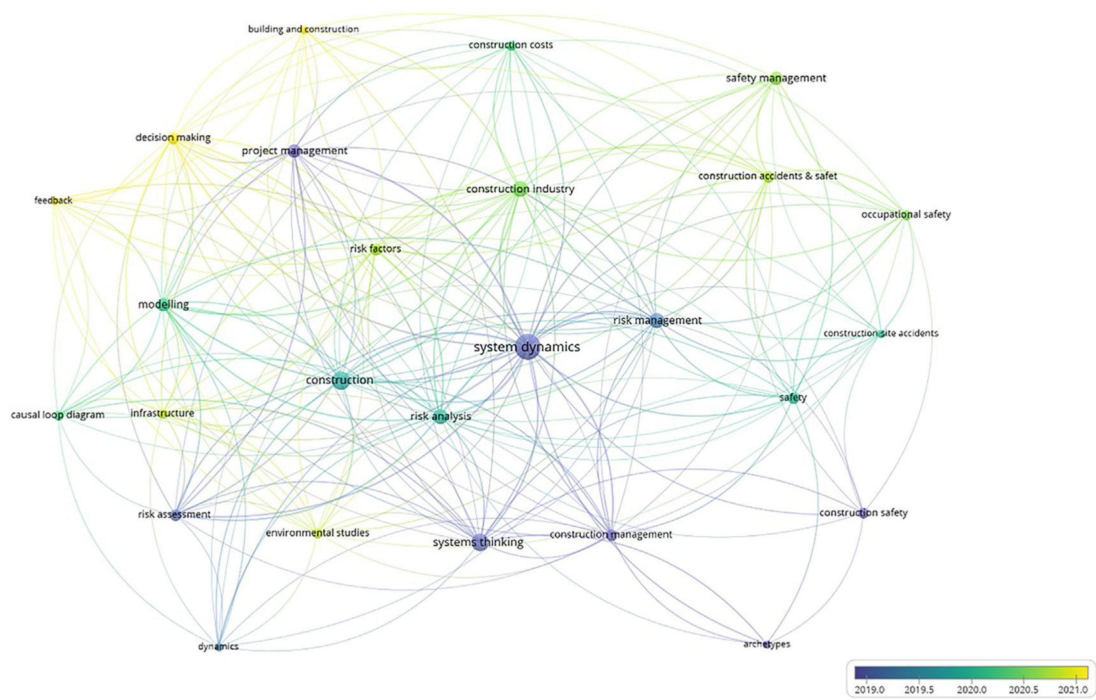

FIGURE 3 Co-occurrence of keywords in the selected articles. [Colour figure can be viewed at wileyonlinelibrary.com]

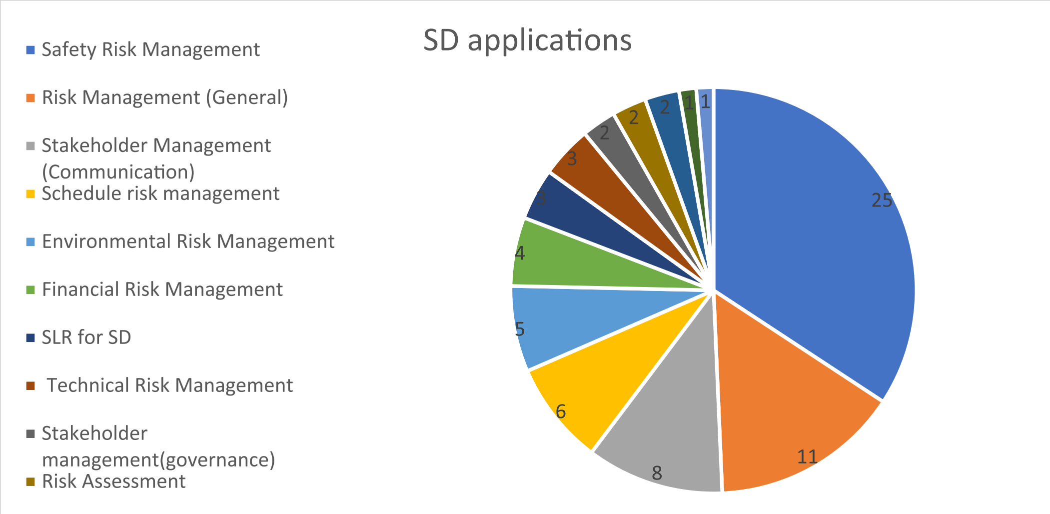

FIGURE 4 Main applications of SD. [Colour figure can be viewed at wileyonlinelibrary.com]

general," "Stakeholder Communication Management," "Schedule Risk Management," "Environmental Risk Management" and "Financial Risk Management." The analysis reveals that risk management research areas have profited more from SD models than stakeholder management areas, which can be mainly attributed to the complexity of stakeholder dynamics, the nature of the available data, the intricacies of stakeholder behaviour and the absence of standardization. Almost 80% of the analysed publications contain a risk management topic, and over 40% examine safety risk management. Other risk management sectors, which are covered in the next section, have also used SD in this way.

4 | DISCUSSION

4.1 | SD modelling applications in risk management

This SLR of 73 articles reveals that almost 80% use SD models in construction project risk management. This is likely to be because of the inherently risk-prone nature of construction projects (El-Sayegh & Mansour, 2015), the dynamic behaviour of internal and external construction industry risk factors (Wu et al., 2020) or the simplicity of defining variables and implementing complex casual-loop relationships using SD in risk management (Liu et al., 2019). Also, of the selected articles, more than 20% apply SD as a means of addressing risk management in general within construction, which has mainly helped evaluate the integrated impacts of decisions concerning project risks (Jahan et al., 2022; Nasirzadeh et al., 2014) or define the risk factors and risk variables in a specific project condition to mitigate their impact (Kim et al., 2020; Mhatre et al., 2017). Two papers also utilize SD to facilitate specific stages of the risk management process, as defined in Project Management Institute (2019), such as the risk management monitoring and control phase (Wang et al., 2017) and risk analysis phase (Hai et al., 2022). Articles are also used in SD in the context of specific contractual conditions. For instance, Loosemore and Cheung (2015) explore the current barriers to adopting a system-thinking approach to managing risk in PPP projects.

The majority of the articles address specific risk categories using SD, including physical (safety and accidents), social, technical, economic, environmental and political risks. In project management standards, much attention has been paid to projects' physical uncertainty, which applies to safety, weather and working conditions (Project Management Institute, 2019). According to the traditional literature, construction accidents are usually caused by unsafe acts or conditions (Shina et al., 2014), while accidents occur due to system failures and not a single factor, such as unsafe behaviour or condition, for instance (Mohammadi et al., 2018). SD modelling's role in project safety has been investigated at behavioural and institutional levels by analysing accidents or organizational safety best practices (Engler Bridi et al., 2021). Identification, categorization, analysis and elimination of construction workers' unsafe acts are investigated in the articles by adopting SD models in several studies (Guo, Goh, & Le Xin Wong, 2018; Nasirzadeh et al., 2018; Shina et al., 2014) to review the impact of unsafe behaviour of different agents throughout the project duration in various condition. The results are beneficial in finding the behavioural patterns to predict the number of safety incidents and better understand their causation factors (Ma et al., 2021; Mohammadi et al., 2018; Nabi et al., 2020; Xu et al., 2018). Several studies also use SD to review the institutional, socio-technical and upstream factors, such as decisions and actions at the level of the government and regulator in the accident and construction safety analysis (Goncalves Filho et al., 2021; Zhou et al., 2018). In addition, Wang et al. (2016) employ an integrated SD model to investigate the mechanism of risk migration that result from the interactions between a contractor's organizational and technical systems. On a broader level, Woolley et al. (2020) deploy a model by applying and extending the Systems Theoretic and Accident Model and Processes (STAMP) method to show the involved actors in managing safety throughout the Australian construction industry.

The distinct variables of time delay and environmental pollution commonly occur during construction, and often construction processes are held responsible for deficiencies due to their direct cause-effect relationship (Belayutham et al., 2016). This is where studies use SD as a single or integrated tool in evaluating the dynamic behaviour and impacts of variables on the construction project objectives. Wang and Yuan (2017) take a holistic view to investigate the effects of dynamic risk interactions on a schedule delay in infrastructure projects using the SD model, the causal loop diagrams and the underlying relations among the variables. In particular, Li, Shen, et al. (2017) apply SD in their study to investigate the potential effect of various risks on the scheduling of prefabrication housing construction projects and categorize the weighted schedule risks of these projects to introduce the SD model as an effective tool for quantitatively evaluating the effect of various risks on the schedules of similar projects. They conducted the same study in 2018 employing a hybrid SD and discrete event simulation (DES) method to show that DES carefully models a system to reveal the dynamic behaviour of each component, while SD uses aggregated data to build a model that can facilitate a system-wide dynamic flow analysis of managerial decisions. In addition, Marzouk and Azab (2014) present an SD model to compare the economic and environmental impacts of recycling and disposing of wastes as the two primary solutions for managing construction and demolition wastes to show the efficiency of recycling in improving the environmental impacts by quantifying the total costs of each solution. Similar studies are conducted to emphasize the environmental performance of lean thinking in the construction industry using causal loop diagrams and SD concepts (Belayutham et al., 2016). Also, Boateng et al. (2022) systematically examine major social and environmental (SE) risks affecting mega-project construction work using a UK case study by designing an SD risk model, which could be considered an essential tool for planners to develop appropriate risk management strategies.

Financial and technical risks are among the most important risks in construction projects, which significantly impact project objectives separately and through their interactions with each other and project parameters (Bakhshayesh & Abbasianjahromi, 2023). Studies identify and analyse the cost-related variables in construction projects using SD models. For instance, Li, Li, et al. (2017) adopt SD in building a risk identification feedback and flow chart to identify investment risks faced by prefabricated construction projects and to process quantitative estimation of investment risk factors. Similarly, Bakhshayesh and Abbasianjahromi (2023) simulate the effect of financial risks on the project cost for evaluating financial risks and their related contractual clauses using an integrated SD model. Other studies aim to understand the key set of triggers affecting the cost performance of various projects (Mahmud et al., 2022). Design errors leading to rework or design changes are considered the primary contributor to schedule delays and cost overruns in design and construction projects (Han et al., 2013). Han et al. (2013) an SD model to capture the dynamics of design errors and systematically assess their negative impacts using a case study to confirm the usefulness of the SD model's rigorous role in assessing the negative and often underestimated impact of design in the delayed schedule, particularly under schedule pressure. Similarly, Etemadinia and Tavakolan (2018) propose a hybrid SD-Interpretive structural modelling model to analyse the uncertainties in the design phase of the construction projects to show the effect of considering the interrelated structures and dynamics of the overall project risk on the accurate estimation of the project objectives such as its cost and completion time. From another perspective, Gashaw and Jilcha (2022) develop a risk analysis model to evaluate the impact of design-related risks on delays and cost overruns of a railway construction project using fuzzy synthetic evaluation and SD approaches to be used as a project risk analysis tool for other construction projects, help managers identify significant risks and analyse the dynamic effects on project objectives.

Therefore, SD models are instrumental in addressing safety risks at both the behavioural and institutional levels, making them valuable tools for enhancing construction industry safety by enabling the identification of unsafe behaviour patterns, prediction of safety incidents and obtaining a deeper understanding of the causation factors. SD models have also emerged as a pivotal tool for analysing schedule risks and environmental, technical and financial risks within construction project management. Notably, integrated models, as exemplified earlier, have gained prominence, allowing for a more comprehensive understanding of the dynamic interplay among variables of schedule risks compared to other risk types, which could be because of the ability of integrated models to accommodate the intricacies and dynamics involved, and offering a more holistic approach to capture the complexity of the risks.

4.2 | SD modelling applications in stakeholder management

This SLR reveals that stakeholder management areas have not profited as much from SD models as risk management areas in construction research. However, several studies employ SD/ST in managing construction project stakeholders. Some focus on using SD models as suitable tools to improve the communication and information flow among various project stakeholders, such as De Marco et al. (2015), for instance, who propose a contingency management dynamic model for application as both a simulation tool for contingency decision-making and to act as a communication method between various stakeholders. Also, Khan et al. (2016) investigate the use of SD in improving the management of the complexity of information flows, using cloud computing to improve construction performance. In a more holistic study, Elias (2017) tests SD for analysing multiple stakeholders with conflicting stakes in a transport infrastructure project to emphasize the need for a holistic approach to solving complex problems involving multiple stakeholders instead of simple solutions. More studies focus on using SD as a useful and practical method to enhance project communication and stakeholder engagement (McKenna & Baume, 2015; Pargar et al., 2019; van der Hoorn, 2020).

Similarly, Dolla et al. (2023) explore the effectiveness of SD in stakeholder management to address the dynamic process of decision-making and project communication by introducing tools and models for the adoption of digital technologies in the construction sector. In another study, Guo, Zhang, and Yang (2018) examine the influence of Chinese stakeholders' interactions during construction quality supervision using an SD model to describe the complex and dynamic interactions among tripartite stakeholders. In short, there are opportunities for more SD applications in managing construction project stakeholders, underlining the potential for SD to provide a holistic and practical approach to addressing the complex dynamics of construction project stakeholder interactions.

4.3 | Identifying the gaps

The current systematic literature review (SLR) of 73 articles reveals a notable research gap. While SD models have been extensively applied in construction project risk management, integrated models that holistically address various risk types, including financial, technical, social and political, are scarce. Additionally, existing studies emphasize SD models' academic applications, without delving into their practical implications for project management practitioners. Furthermore, SD models remain underexplored in managing construction project stakeholders, particularly regarding their role in enhancing communication and coordination. This research gap highlights opportunities for comprehensive SD models that bridge academic research and practical application, integrating risk and stakeholder management.

Moreover, investigating other ST methodologies, such as soft systems methodology (SSM) and critical systems heuristics (CSH), could further illuminate their potential in managing construction project stakeholders. Future research could explore how these methods contribute to a holistic approach to construction project management, integrating stakeholder perspectives more effectively and providing a comprehensive framework for decision-making and coordination.

5 | CONCLUSION, LIMITATIONS, IMPLICATIONS AND FUTURE TRENDS

This paper conducts an SLR of SD modelling in construction management, focusing on stakeholder and risk management. Following PRISMA steps, 73 articles were selected through a systematic review. Descriptive, bibliometric and thematic analysis were investigated in the selected papers to analyse how SD models have been used to manage the risks and stakeholders of construction projects between 2013 and 2023.

It was found that SD significantly improved system representation, modelling and problem abstraction within the construction domain. SD has been applied to risk management in construction projects, with almost 80% of the reviewed articles using SD models to address various risk factors. It is shown that the dynamic behaviour of internal and external risk elements, such as safety, environmental, financial, technical and scheduling concerns, can be captured by SD, and this provides a useful framework for understanding risk interrelationships and their effects on project goals. This approach enhances risk identification, prediction and mitigation, significantly improving project management.

Although SD appears less frequently than risk management in stakeholder management within construction projects, various studies show its usefulness. A dynamic framework for studying complicated stakeholder interactions, SD models have been used to improve communication and information flow among project stakeholders. These studies highlight the demand for a comprehensive strategy to handle the complex problems involved in managing various stakeholders in construction projects.

This study is limited by the observed fluctuation in publication trends, with a significant drop in 2019 possibly due to COVID-19 disruptions. In addition, the dominance of China, Australia and the UK in contributing to the literature might indicate a geographic bias. A further issue is that most studies emphasize risk management, with stakeholder management receiving comparatively less attention. Moreover, while VENSIM appears to be a popular software choice, some articles do not specify the software used for modelling. Further research is therefore needed to improve this situation. Future research can also incorporate risk categories, such as safety, environmental, financial, technical and scheduling hazards, into thorough SD models. Additionally, the application of SD to stakeholder management can be broadened to handle the changing complexity of construction projects. The ability of SD to operate in an integrated model with other approaches has been explored in this study. However, it has the potential to be analysed in further research to classify best practices and appropriate applications in employing hybrid SD models.

This study advocates for strategic integration of System Dynamics (SD) in construction management, particularly during initial project planning phases, to facilitate informed decision-making and robust risk and stakeholder management. For project management practitioners, adopting SD models can lead to quantifiable improvements, such as reduced cost overruns and improved safety compliance. In parallel, there is a need for standardization in the selection of SD modelling tools, with a recommendation for comparative analyses of software like VENSIM to establish industry-wide guidelines for academics and researchers for future works. The integration of emerging technologies such as artificial intelligence and the Internet of Things with SD models presents a fertile ground for future research, promising enhanced real-time decision-making capabilities in construction projects. Moreover, the development of nuanced stakeholder management models and the exploration of hybrid methodologies, combining SD with approaches like agent-based modelling or other ST methodologies, such as SSM and CSH, is essential to address the multifaceted challenges of construction projects. These advancements hold significant implications for industry standards and practices, urging construction bodies to incorporate SD into best practice guidelines and training programs. Lastly, the findings of this systematic literature review underscore the importance of collaborative efforts between academia, industry practitioners and policymakers in translating SD research into effective construction policies, particularly in areas of safety and environmental impact assessments, thereby fostering a more holistic and pragmatic approach to construction project management.

CONFLICT OF INTEREST STATEMENT

The authors whose names are listed immediately above certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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