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Review

Building a safer future: Analysis of studies on safety I and safety II in the construction industry

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ABSTRACT

Purpose: The construction industry is one of the most dangerous, with daily dangers and hazards. The industry commonly employs Safety I, a reactive approach to reduce accidents and incidents by identifying and controlling hazards. Safety II focuses on using worker strengths and promoting ongoing improvement. Nevertheless, both Safety I and II have faced criticism for their excessive emphasis on regulatory compliance (Safety I) and executive constraints (Safety II), respectively. Hence, this paper presents a rich synthesis of Safety I and II literature in the construction industry between January 2000 and December 2023 prior to proposing strategies for integrating them to build a safer future by focusing on the strengths of implementing each technique.

Methodology: In this scientometric research study, 35 related research papers were sought and selected after checking and validating the Web of Science journal database. Bibliometric analysis, through HistCite and VOSviewer software programmes, was then used to create maps from network data and illustrate an exploration of the prevailing literature discourse. Interpretivism was then used to develop application and combination strategies for the new theory of integrating Safety I and II in the construction industry.

Findings: Results reveal that the historical progression of research undertaken has developed from first introducing and identifying the field of research (2011 to 2015) to then providing solutions (2015 to 2019) and finally to making constructive suggestions (post 2019) for a safer future. Notably, prominent topics in recent years have examined resilience and progress toward safety improvements by the combination of Safety I and II concepts.

Originality: This research highlights the positive outcomes that can be achieved via Safety I and II integration in the construction industry. Furthermore, this paper offers efficient and pragmatic techniques for incorporating Safety I and II approaches in the construction industry, which are crucial for promoting a comprehensive integrated approach to safety administration. By combining existing safety practices with a focus on learning from successes, organisations can create a safer work environment, improve productivity and foster continuous improvement.

1. Introduction

Construction project success is heavily dependent upon the implementation of safety management (Ranasinghe et al., 2020). Overwhelming consensus suggests that safety concerns are inherent in the sector (Bayramova et al., 2023a), and these concerns become more urgent as the number of building projects continues to rise. Consequently, ensuring the safety of construction projects and mitigating financial and human losses resulting from accidents are issues confronting the global construction industry (Chan et al., 2021). Despite a decrease in accidents within the sector in recent years, the industry still lags behind other sectors in terms of safety and risk. For example, the United Kingdom (UK) construction industry has the highest number of fatalities among all industries within that nation (Warburton, 2023). Upon closer examination, the latest UK construction data reveals a disconcerting increase in fatal injuries from 37 to 45 deaths, when compared to the five-year average for fatal injuries spanning from 2018/19 to 2022/23 (Warburton, 2023) – these statistics reveal the omnipresent challenge

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confronting the sector (Demirkesen and Tezel, 2021; Seo et al., 2015). The complex issue of construction safety therefore requires immediate resolution and perhaps, more specifically, a revaluation of efforts employed to mitigate safety risks posed. Consequently, it is crucial to focus on advancing and enhancing existing tools, approaches and concepts (such as Safety I and II).

A fundamental concern lies in the emphasis being given to 'hazardous' activities or operations, rather than prioritising 'safe' activities or operations (Chih et al., 2022). The approach that emphasises failures, accidents and losses is referred to as the Safety I perspective. Safety I posits that errors or malfunctions inside a system may be attributed to specific components such as technology, procedures, human workers and the organisations they are a part of (Aven, 2022). In addition, it is possible to construct cause-effect links which enable the implementation of a problem-solving approach. This involves recognising the hazards, taking measures to eliminate or control them, and minimising the potential repercussions in the case of a hazardous occurrence. Conventional approaches for assessing risk, such as fault tree analysis, event tree analysis and probabilistic risk assessments are considered important tools for evaluating the probability and significance of various situations (Sarvari et al., 2019). Adhering to Safety I, requires action to be taken when an incident occurs or when the level of risk is deemed unacceptable (Hollnagel, 2018). This typically involves attempting to eradicate the root causes, enhance protective measures or both (Hollnagel et al., 2015; Martínez-Airesa et al., 2018). Adoption of this safety perspective grew prevalent in safety sensitive industries (e.g. nuclear and aviation) throughout the 1960s to the 1980s (Hollnagel et al., 2015). It continues to be widely embraced in various industries today, including oil and gas (Ojuola et al., 2020). The primary advantages of Safety I lie in its capacity to facilitate the formulation of explicit protocols and guidelines, ensuring that all employees possess a comprehensive understanding of potential dangers and are equipped with the requisite information and training to avert injuries and accidents (Huber et al., 2021). Furthermore, Safety I establishes a system of accountability and responsibility, holding those who undertake risky duties or violate regulations within the organisation accountable (Cutchen, 2021). However, Safety I has inherent limitations. It often perceives accidents as isolated incidents resulting from human errors, without considering any underlying systemic problems. The emphasis on individual performance rather than system design can hinder the identification of the fundamental underlying causes, hence impeding the ability of workers and researchers to uncover them (Ball and Frerk, 2015). Consequently, the documentation of near-misses or minor occurrences may decline as the system prioritises the prevention of significant accidents. Furthermore, Safety I has the potential to cultivate a culture of culpability, when employees are hesitant to reveal their errors or experience scrutiny from their peers (Schobesberger et al., 2022). Traditionally, the construction sector's approach to safety has been rooted in Safety I (Martinetti et al., 2019) and undoubtedly this approach has brought about significant improvements in safety standards over the years (Potter, 2018).

However, as the industry evolves, there is a growing recognition that relying solely on Safety I is insufficient to address the complex and dynamic nature of construction projects (Smith and Plunkett, 2019). This realisation gives rise to the Safety II concept which emphasises learning from successes, adaptability and resilience in the face of unexpected events (Aven, 2022). Safety II therefore focuses primarily on understanding and leveraging the factors that lead to positive outcomes (Hollnagel, 2018). This viewpoint is founded on a proactive methodology, that involves consistently monitoring, anticipating, responding and learning from everyday operations, not just adverse events. (Bayramova et al., 2023a). Safety II recognises that construction sites are dynamic environments where workers constantly encounter new challenges and uncertainties (Franca, 2023). Consistent with the principles of Safety II, humans are perceived as a valuable asset required to attain safety (Elliott, 2016; Chan et al., 2022; Sarvari et al., 2024). Safety II encourages organisations to proactively identify and understand the factors that contribute to success (e.g. effective communication, collaboration and continuous learning (Provan et al., 2020)). The Safety II approach necessitates a distinct array of procedures and techniques (such as functional resonance analysis method (FRAM), operational learning review (OLR) and Bayesian approaches) to effectively handle performance variability. Safety II excels at fostering a culture of open learning inside construction firms and advocates the use and appreciation of workers' talents and expertise. This promotes the unrestricted exchange of information and viewpoints among employees, enabling the timely identification and prevention of hazards, hence diminishing the frequency of accidents (Bastan et al., 2019). This approach acknowledges that safety is an ongoing process that requires constant evaluation and adjustment (Alruqi and Hallowell, 2019). Nevertheless, Safety II may possess certain limitations. The emphasis on extracting insights from successful outcomes and adaptability may potentially undermine the need of adhering to and complying with safety protocols (Provan et al., 2020). Some circumstances prioritise adherence to rules and procedures over adaptability to prevent catastrophic outcomes therefore, implementing and assessing Safety II might be challenging (Sujan, 2018; Rafieyan et al., 2022b).

The focus on intricate systems (such as the management of a construction project) and the use of systems thinking, as well as the social dimension of safety, may necessitate the utilisation of more advanced evaluation methodologies. Hence, it is imperative for a balance to be maintained between the Safety I and II methodologies. While Safety II promotes flexibility and adaptation, it is crucial to prioritise the importance of sticking to and implementing established safety regulations and procedures. Similarly, depending solely on Safety I could result in the development of an inflexible and stringent safety culture that impedes innovation. To attain equilibrium, it is necessary to approach safety from a fresh standpoint, one that fosters and permeates a safety-oriented culture throughout all tiers of the organisation. According to Hollnagel (2018), the concept of resilience is defined as the combination of Safety I and II and refers to a system's ability to adapt its functioning before, during or after events such as changes, disturbances and opportunities. This allows the system to maintain its required operations under both anticipated and unanticipated conditions (Hollnagel, 2017; Akinlolu et al., 2022). Leveraging the benefits of both systems (i.e. Safety I and II) will enable the construction industry to foster a far more proactive and adaptable safety culture (Casey et al., 2017; Kontogiannis et al., 2017). However, to gain a comprehensive understanding of how to ensure safety in the construction industry, it is imperative to conduct a thorough evaluation of the merits and drawbacks of, as well as synergies between Safety I and II (Aven, 2022).

Acquiring a richer understanding of the merits of both approaches, will enable construction professionals to develop strategies that integrate the best practices from each – ultimately leading to safer work environments and improved project outcomes. Hence, a comprehensive analysis of the prevailing discourse within extant literature is needed to delineate the inherent complexities of safety management and premised upon this rich synthesis, generate new reflection and insight for developing integration strategies of Safety I and II approaches in the construction industry (Nawaz et al., 2023). Hence, this paper seeks to evaluate, categorise and examine the incorporation of Safety I and II in the construction sector to provide key approaches for integrating them and establishing a more secure future. In realising this aim, associated objectives are to: engender wider polemic debate within the prevailing discourse to challenge current thinking; generate novel application and combination strategies (e.g. leadership and culture) within contemporary practices for balancing Safety I and II and how such could be further augmented to reduce accident risks; and signpost new directions for future studies in the field.

2. Research methodology

Interpretivism is adopted as the overarching philosophical positioning of this current research which inductively develops application and combination strategies on the phenomenon under investigation (cf. Roberts and Edwards, 2022; Posillico et al., 2023; Bayramova et al., 2024). Previously studies have validated this approach to theoretical development research that provides the basis for future empirical analysis (via quantitative deductive testing of theories developed) (cf. Ellis et al., 2021; Bortey et al., 2022). As such, this current study provides firm foundations for new avenues of investigative research to unfold.

2.1. Approach to literature synthesis

To comprehensively analyse existing literature on Safety I and II approaches applied in the construction industry, a scientometric analysis was undertaken (Garfield, 2009; Nazir et al., 2020) – refer to Fig. 1. Through searches of Google Scholar sources, 20 related papers were first reviewed to identify keywords. To enhance search precision, the detected keywords were compared with the keywords plus a selection of highly cited relevant papers in Thomson Reuters' Web of Science (WoS) database. The WoS search engine was chosen for this specific search because to its status as the oldest, most widely used and most authoritative database of research publications and citations in the world (Adams, 2018; Li et al., 2018). The keywords Plus terms, which are derived from the titles of cited references, tend to be more broadly descriptive and can capture a wider range of scientific concepts compared to Author Keywords, which are often more specific and narrowly focused (Zhang et al., 2016). This broader scope can enhance the comprehensiveness of a literature review by ensuring that relevant but less obvious articles are included. Additionally, it can further refine the search strategy, ensuring that the selected terms are both relevant and comprehensive, thus improving the accuracy and relevance of the extracted literature (van Wee and Banister, 2023). Dambiski Gomes de Carvalho et al. (2021) stated that user-centred features like keyword comparison can improve search performance and user satisfaction by helping researchers identify the most relevant articles more efficiently. Finally, personalised search methods that consider the influence and trustworthiness of authors can yield more useful and diverse results, further enriching the literature review (Gavgani and Vahed, 2017).

Next, in WoS the document search was undertaken using the following keywords: (*"(construction)"* AND TS=*"Safety I"*) OR (TS=(construction)) AND TS= (*"Safety II"*) OR (*"Building"*)) AND TS=(Safety I) OR (*"Building"*)) AND TS=(Safety II)). In this study, the keywords "*safety construction and safety buildings,*" were searched simultaneously with other keywords such as *"Safety I, Safety II, Safety I, and Safety II"* with conjunctions AND and OR. To ensure a comprehensive understanding of the research scope and relevance, the search string was designed to cover a broad range of related terms to capture all pertinent studies in construction health and safety. The keywords were strategically searched in the title, abstract and keyword section, as these are the primary areas indexed by search engines and databases like WoS (Wang

Fig. 1. The procedure employed in the research.

et al., 2020). Pranckutė (2021) affirms the strategic importance of keywords in titles, abstracts and keyword sections for effective research retrieval. In addition, the search encompassed the period from 2000 to 2023.

Prior researchers proffer that while conducting qualitative literature reviews, a choice must be made between prioritising the thoroughness of the findings or the precision of the studies found (Shaw et al., 2004). When conducting systematic reviews, the most important aspect of the search should be its comprehensiveness, considering the widespread practice of using sub-sections in articles (Methley et al., 2014; Rashidi et al., 2023). Hence, this investigation adhered to the guidelines delineated in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Liberati et al., 2009). Implementing PRISMA began with formulating the research question and developing a protocol that includes inclusion and exclusion criteria. A comprehensive literature search was then performed across the WoS database to gather all relevant published studies. The next step involved screening the identified studies for relevance based on the predefined criteria (i.e. search type (Safety I and Safety II), document type (article, review and early access) and document type language (English)), followed by a detailed review of the selected full-text articles. At the initial first round of WoS search, 61 papers matched the keyword search and were entered into a validation process which were then thematically grouped using keywords (contained within each paper) into direct and indirect categories. Direct status was attributed to papers that explicitly included the words *"Safety I or Safety II"*; whereas indirect status was attributed to papers that embraced the Safety I and II approaches in construction. For example, a paper entitled *"A paradigm of safety management in Industry 4.0"* did not include these words explicitly but embraced the Safety I and II approaches. Ultimately, 35 papers were selected as a sample frame and the analysis phase began. The findings were documented in a structured report, including a PRISMA flow diagram to visually represent the study selection process and a summary of the evidence, highlighting the studies' key strengths, weaknesses and strategies for integrating Safety I and II. Finally, the scientometric analysis and systematic analysis were undertaken and a comprehensive and unbiased summary of the available evidence on the research question was provided.

2.2. Research methods for secondary data analysis

Following the introduction of computer technology, computerised data processing has become common among researchers and this has prompted the development of scientometric and bibliometric software (Chamberlain et al., 2019; Darko et al., 2019). Scientometric analysis is an intellectual structure that generates an exploitable analysis of research publications on a particular topic (Alghamdi et al., 2023). Emergent analysis results constitute the: visualisation of important research patterns and trends in pertinent extant literature; illustration of a map of scientific knowledge; and identification of major research topics (Osei-Kyei et al., 2022; Liu et al., 2023). Various software tools (e.g. Bibexcel, CiteSpace and VOSviewer) allow researchers to generate different kinds of bibliometric networks (Liu et al., 2013). The publications database extracted from WoS was initially analysed using HistCite to generate chronological maps of bibliographic collections grouped into topic, author and author institution categories (Garfield, 2009; Rashidi et al., 2023). Having a wide range of functions for analysing and drawing bibliographic information, Histcite is utilised to provide a list of authors of selected papers, institutions and countries publishing papers, list of journals publishing papers, words along with all sources and citations and the amount of local and global citations to papers and data analysis according to the year of publication (Van Eck and Waltman, 2010; Ismael and Shealy, 2018; Rashidi et al., 2023; Osei-Kyei et al., 2023). Additionally, the open-source software VOSviewer was used to construct and display bibliometric maps (e.g. co-occurrence maps of authors, institutions, keywords) as part of this search (Van Eck and Waltman, 2010).

3. Analysis results

Modern construction safety has evolved significantly from traditional practices, primarily due to integrating systems thinking whichemphasises an holistic approach to managing safety (Ismael and Shealy, 2018). This shift is evident in the growing focus on advanced technologies, safety climate and safety behaviour, as well as the recognition of process-driven and people-driven perspectives in safety research (Newaz et al., 2023). The shift from reactive to proactive safety measures, focusing on leading indicators and continuous improvement, represents a fundamental change in modern construction safety practices (Forteza et al., 2020). Given construction development growth internationally, the number of scientific journal outlets and papers published has similarly increased (Khademi *et al.,* 2022). The 35 selected papers and10 most frequently cited WoS papers and the analysis carried out by HistCite are presented in Table 1. These papers were ranked according to the number of citations as a critical indicator which demonstrates research quality and impact. While the search period started in 2000, the first papers in this section were published in 2011. During this time period, two highly cited papers were published. First, Dekker et al. (2011) emphasised that complexity theory for safety investigations makes particular assumptions about the relationship between cause and effect, foreseeability of harm, time reversibility and the ability to produce the 'true story' of an accident. With inspiration from complexity theory, failures are seen as an emergent property of complexity (*ibid*). Second, Hale and Borys (2013) propose a framework of rule management that uses two paradigms including safety management rules and safety procedures related to hazard workplace levels in organisations. This framework places the monitoring and adaptation of rules central to its management process and emphasises the need for participation of the intended rule-followers in the processes of rulemaking (*ibid*). More important is the continuous modification and revision of these rules that can be enabled by frequent and candid dialogues with top-level managers, as well as using the expertise of technical, safety and legal professionals in assessing system effectiveness. These two highly cited papers can be considered as a notable turning point in this field. In the years shown in Table 1, most papers have focused on the generic topics of construction safety management, safety application procedures and development approaches (cf. Provan et al., 2020; Guo and Yiu, 2016; Smith and Plunkett, 2019; Martinetti et al., 2019; Aven, 2022; Liu et al., 2020). Undoubtedly, the occurrence of health and safety issues in projects cause time delays, financial losses and injuries and casualties, etc (del Carmen Pardo-Ferreira et al., 2020). The focus of researchers on these parts of the research illustrates construction stakeholders intentions to ensure safe implementation and high safety performance in the sector (Nawas *et al.,* 2016).

3.1. Keyword co-occurrence analysis

Keyword co-occurrence analysis and author co-citation analysis provide a general description of the research area before clustering analysis (Van Eck and Waltman, 2010). The co-occurrence network of construction Safety I and II keywords in 2000–2023 is illustrated in Fig. 2 and reveals that keywords with higher frequency are: Safety II (frequency (f) = 13); resilience (f = 11); framework (f = 7); resilience engineering (f = 6); and Safety I (f = 5). Other high frequency keywords included safety, management, risk management, safety management, resonance analysis method, health, model, system, sociotechnical system and construction. Keywords were indicated in 49 cases and over 79 % of the papers had keywords that appeared more than five times. This indicates that the keywords in safety management literature have acceptable centrality. From these keywords, it is apparent that resilience and safety I and II are often inextricably linked in the same paper. Moreover, the outcomes of the work produced are often theoretical or

Table 1
Citation frequencies for the 35 papers analysed.

Rank	Paper Title	Journal	CitationCount	Year	Ref.
1	The complexity of failure: Implications of complexity theory for safety investigations	Safety Science	200	2011	Dekker et al. (2011)
2	Working to rule or working safely? Part 2: The management of safety rules and procedures	Safety Science	133	2013	Hale and Borys (2013)
3	Safety II professionals: How resilience engineering can transform safety practice	Reliability Engineering & System Safety	86	2020	Provan et al. (2020)
4	Developing Leading Indicators to Monitor the Safety Conditions of Construction Projects	Journal of Management in Engineering	86	2016	Guo and Yiu (2016)
5	People, systems and safety: resilience and excellence in healthcare practice	British Journal of Anaesthesia	49	2019	Smith and Plunkett (2019)
6	Safety I-II, resilience and antifragility engineering: a debate explained through an accident occurring on a mobile elevating work platform	International Journal of Occupational Safety and Ergonomics	34	2019	Martinetti et al. (2019)
7	A risk science perspective on the discussion concerning Safety I, Safety II and Safety III	Reliability Engineering & System Safety	24	2022	Aven (2022)
8	A paradigm of safety management in Industry 4.0	Systems Research and Behavioral Science	24	2020	Liu et al. (2020)
9	Using functional resonance analysis method to understand construction activities for concrete structures	Safety Science	19	2020	del Carmen Pardo-Ferreira et al. (2020)
10	A dynamic human-factor risk model to analyze safety in sociotechnical systems	Process Safety and Environmental Protection	16	2022	Zarei et al. (2022)
11	Safety-II and Resilience Engineering in a Nutshell: An Introductory Guide to Their Concepts and Methods	Safety and Health at Work	16	2021	Ham (2021)
12	Balancing Safety I and Safety II: Learning to manage performance variability at sea using simulator-based training	Reliability Engineering & System Safety	16	2020	Wahl et al. (2020)
13	Safety II in practice: developing the resilience potentials	Taylor & Francis	14	2017	Hollnagel (2017)
14	Safety I and safety II: the past and future of safety management	Ergonomics	13	2016	Elliott (2016)
15	Debates and politics in safety science	Reliability Engineering & System Safety	12	2021	Haavik (2021)
16	Using expert perspectives to explore factors affecting choice of methods in safety analysis	Safety Science	10	2022	Farooqi et al. (2022)
17	Safety-I and Safety-II, the past and future of safety management	Cognition Technology & Work	9	2015	Vanderhaegen (2015)
18	Integration of hazard rectification efficiency in safety assessment for proactive management	Accident Analysis and Prevention	7	2019	Liu and Liao (2019)
19	Development of a quantitative resilience model for nuclear power plants	Annals of Nuclear Energy	7	2018	Kim et al. (2018)
20	Systems Thinking Accident Analysis Models: A Systematic Review for Sustainable Safety Management	Sustainability	6	2022	Delikhoon et al. (2022)
21	Integrating Safety-I and Safety-II: Learning from failure and success in construction sites	Safety Science	6	2022	Martins et al. (2022)
22	Qualitative findings from a pilot stage implementation of a novel organizational learning tool toward operationalizing the Safety-II paradigm in health care	Applied Ergonomics	6	2020	Hegde et al. (2020)
23	The Emperor has no clothes: A critique of Safety-II	Safety Science	5	2022	Cooper (2022)
24	Constructs of leading indicators: A synthesis of safety literature	Journal of safety research	4	2023	Bayramova et al. (2023b)
25	Road-safety-II: Opportunities and barriers for an enhanced road safety vision	Accident Analysis and Prevention	3	2022	Papadimitriou et al. (2022)
26	Enhanced safety in complex socio-technical systems via safety-in-cohesion	Safety Science	2	2023	Bayramova et al. (2023a)
27	Integrating Safety-I and Safety-II Approaches in Near Miss Management: A Critical Analysis	Sustainability	2	2023	De Leo et al. (2023)
28	Safety through engaged workers: The link between Safety-II and work engagement	Safety Science	2	2022	Homann et al. (2022)
29	Resiliency, the Path to Safety II	IFAC PapersOnline	2	2018	Bastan et al. (2018)
30	Addressing Worker Safety and Accident Prevention with AI	Proceedings of the 11th International Conference on the Internet of Things	1	2021	Huber et al. (2021)
31	Safety-II-Resilience in the face of abnormal operation	Process Safety Progress	1	2021	Cutchen (2021)
32	A new view of safety: Safety 2	British Journal of Anaesthesia	1	2016	Ball and Frerk (2015)
33	Designing Proactive Safety Systems for Industrial Workers Using Intelligent Mechanisms	Proceedings of the 15th International Conference on Pervasive Technologies Related to Assistive Environments	0	2022	Schobesberger et al. (2022)
34	Redundancy as an important source of resilience in the Safety II concept	IFAC PapersOnline	0	2019	Bastan et al. (2019)
35	Safety I and Safety II	Journal of Contingencies and Crisis Management	0	2014	Dekker (2014)

illustrative in terms of frameworks produced for future deductive testing. Considerably less attention has been given the large-scale case studies and empirical research to validate these in practice. For instance, the keyword co-occurrence analysis shows a significant focus on: theoretical frameworks (Dekker et al., 2011); procedures (Hale and Borys, 2013); sociotechnical systems (Bayramova et al., 2023a); and thematic models (Delikhoon et al., 2022) rather than practical applications. Similarly, a review of captioned articles indicates a shift towards examining human factors (Zarei et al., 2022) and behaviour-based safety (Homann et al. (2022) and their integration into various safety management functions, yet often remaining within theoretical confines. Furthermore, the emphasis on the need for practical implementation of safety management systems to mitigate hazards in the existing literature suggests that much of the literature is more illustrative than actionable. However, the keyword co-occurrence analysis highlights an increase in keywords like accident, accident analysis and accident prevention reflecting both theoretical investigations and practical implications for Safety I and II. Therefore, by examining the co-occurrence of keywords

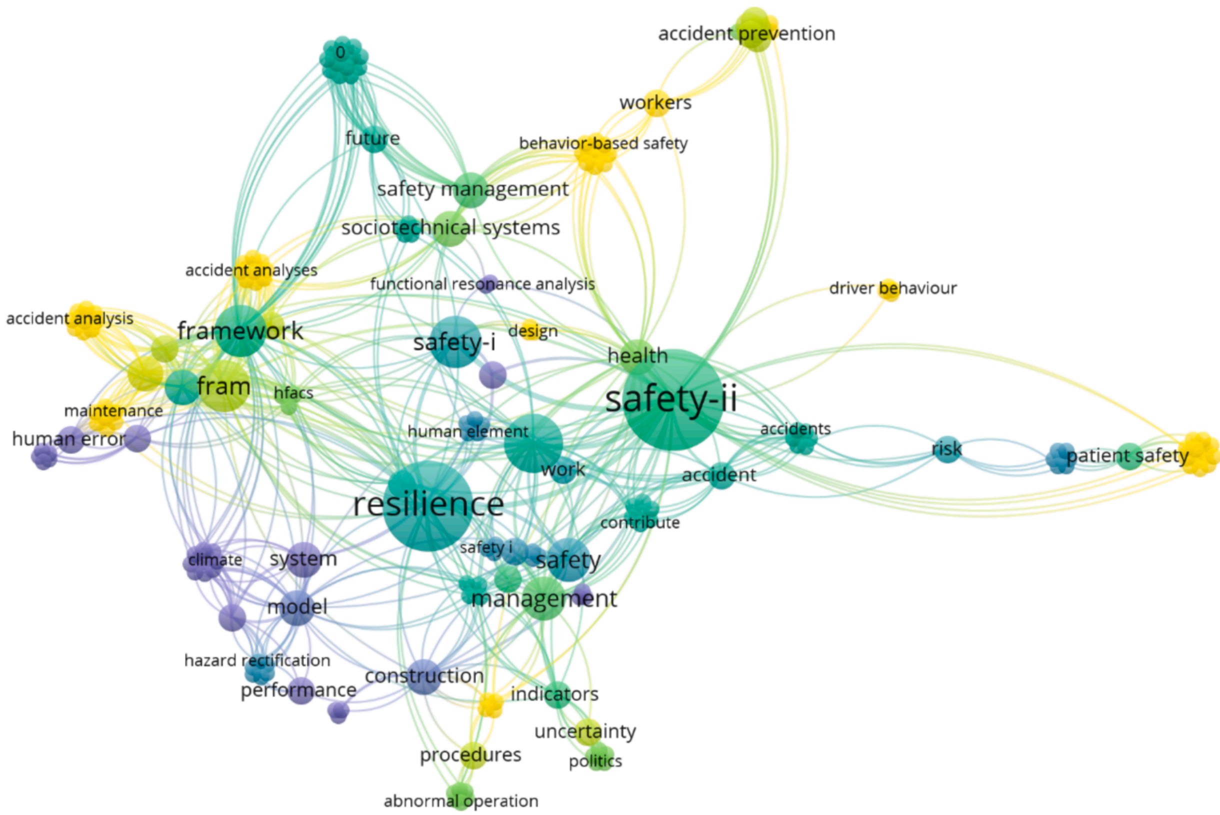

Fig. 2. Keyword co-occurrence analysis.

and the resulting clusters, it becomes evident that the outcomes of work in the fields of Safety I and II are often theoretical or illustrative, as they reflect ongoing theoretical discussions and the application of these theories in practical scenarios.

3.2. The institutions in producing papers

Of the 35 publications in the sample frame, $f = 21$ (60.00 %) were papers, $f = 6$ (17.14 %) were review papers, $f = 4$ (11.43 %) were proceeding papers, $f = 3$ (8.57 %) were book reviews and $f = 1$ (2.86 %) was a letter. The majority therefore were published as peer reviewed research papers (i.e. $f = 27$ or 77.14 %). The institutions associated with the published papers and the citations they received were reviewed and presented in Table 2. Griffith University is atop the table with 8.57 % of paper publications, while the citation of these productions is more than 17 % of total citations. Moreover, seven institutions (i.e. Delft University Technology, Memorial University of Newfoundland, Birmingham City University, Chosun University, Brno University Technology, Johannes Kepler University Linz, Pro2Future GmbH (Part of the European association of research & technology organisations)) were second placed with a 5.71 % of paper publications. However, among these seven institutions, the highest number of citations belonged to Delft University Technology with 8.00 % of total citations. The publication of at least one article in 48 other institutions on Safety I and II illustrates that these concepts constitute a topic of interest for university researchers worldwide. Out of the 48 institutes, Stellenbosch University, which has 200 citations, has the most number of citations. Publishing research on safety by these universities can be attributed to multiple variables such as funding availability, specialised proficiency and knowledge, resources and equipment, industry collaboration, and the significance of safety (National Research Council, 2014; Baron et al., 2014; Payumo et al., 2014). Moreover, numerous universities engage in active collaboration with industry (cf. Bayramova et al., 2023a; Franca, 2023; Bayramova et al., 2023b). This collaboration may encompass cooperative endeavours such as collaborative projects (Zlotnik et al., 2005), consultancy (Yin *et al.,* 2018) and industry-specific training (Bayramova et al., 2023a) while also leveraging industry expertise and experience in university research. Collaboration enhances the realism and practicality of safety studies conducted in institutions and can underscore the crucial role of safety in diverse industries and the wider economy.

3.3. Top journals

The wider socio-economic influence of research publications can be reflected in the number of citations accrued (Nawaz et al., 2023). Also, the volume of research publications may be proportionate to the scope of industry policies and practices in the specific research area (Osei-Kyei and Chan, 2015). Table 3 presents the journals related to published articles on Safety I and II and indicates: the number of papers published; citation rate; impact factor; and the Quartile of each journal. The Journal of Safety Science (ranked Q1 in terms of Quartile) is a leader in this area by publishing 8 papers. The Journal of Reliability Engineering & System Safety was ranked second with 4 papers. Out of the 21 journals listed, 13 of them are classified as Q1 and 4 are classified as Q2 in terms of Quartile. – thus giving an indication of the quality of work published. Furthermore, out of 21 journals, the publisher Elsevier predominates with 10 journals in their portfolio, while other publishers included ASCE, Taylor & Francis, Wiley, Springer, MDPI, and ACM. These journals are widely regarded as authoritative in the field of safety due to their emphasis on safety and quality issues and have published the work of reputable scholars in this field (cf. Dekker et al., 2011; Guo *et al.,* 2016; Aven, 2022). Notably, journals covers a diverse and wide scope of safety research, including: industrial safety, transportation, occupational health and safety (Safety Science); reliability engineering, and systems safety (Reliability Engineering & System Safety) and patient safety (British Journal of Anaesthesia). The broad spectrum of subjects covered demonstrates the significance of both advancing and enhancing both Safety I and II approaches across various disciplines

Table 2
Institutions involved in publishing papers and citations.

No.	University	No. of paper (%)	No. of Citation (%)
1	Griffith University	3 (8.57 %)	292 (35.78 %)
2	Delft University Technology	2 (5.71 %)	136 (16.7 %)
3	Memorial University of Newfoundland	2 (5.71 %)	22 (2.69 %)
4	Birmingham City University	2 (5.71 %)	12 (1.47 %)
5	Chosun University	2 (5.71 %)	12 (1.47)
6	Brno University Technology	2 (5.71 %)	2 (0.25 %)
7	Johannes Kepler University Linz	2 (5.71 %)	1 (0.125 %)
8	Pro2Future GmbH (Part of the European association of research & technology organizations)	2 (5.71 %)	1 (0.125 %)
9	Univ Stellenbosch	1 (2.86 %)	200 (24.51 %)
10	Univ Ballarat	1 (2.86 %)	133 (16.30 %)
11	Hlth & Safety Technol & Management HASTAM	1 (2.86 %)	133 (16.30 %)
12	Univ Auckland	1 (2.86 %)	86 (10.54 %)
13	Ohio State University	1 (2.86 %)	86 (10.54 %)
14	Royal Lancaster Infirm	1 (2.86 %)	49 (6.00 %)
15	Univ Hosp Birmingham NHS Fdn Trust	1 (2.86 %)	49 (6.00 %)
16	Texas A&M Int Univ	1 (2.86 %)	40 (4.90 %)
17	Imperial Coll London	1 (2.86 %)	34 (4.17 %)
18	Netherlands Railways	1 (2.86 %)	34 (4.17 %)
19	Politecn Torino	1 (2.86 %)	34 (4.17 %)
20	Univ Twente	1 (2.86 %)	34 (4.17 %)
21	Univ Stavanger	1 (2.86 %)	24 (2.94 %)
22	Old Dominion Univ	1 (2.86 %)	24 (2.94 %)
23	Wuhan Univ Technol	1 (2.86 %)	24 (2.94 %)
24	Loughborough University	1 (2.86 %)	19 (2.33 %)
25	Univ Malaga	1 (2.86 %)	19 (2.33 %)
26	Chonnam Natl Univ	1 (2.86 %)	16 (1.96 %)
27	Macquarie Univ	1 (2.86 %)	16 (1.96 %)
28	Norwegian Univ Sci & Technol NTNU	1 (2.86 %)	16 (1.96 %)
30	Finnish Inst Occupat Hlth	1 (2.86 %)	14 (1.72 %)
31	Finnish Transport Safety Agcy	1 (2.86 %)	14 (1.72 %)
32	DNV GL	1 (2.86 %)	13 (1.59 %)
33	NTNU Social Res	1 (2.86 %)	12 (1.47 %)
34	Univ Nottingham	1 (2.86 %)	10 (1.22 %)
35	Univ Valenciennes	1 (2.86 %)	9 (1.10 %)
36	Tsinghua Univ	1 (2.86 %)	7 (0.86 %)
37	Korea Adv Inst Sci & Technol	1 (2.86 %)	7 (0.86 %)
38	Beihang Univ	1 (2.86 %)	6 (0.73 %)
39	Aalto Univ	1 (2.86 %)	6 (0.73 %)
40	Atitus Education	1 (2.86 %)	6 (0.73 %)
41	Unochapeco Reg Univ	1 (2.86 %)	6 (0.73 %)
42	Lorestan Univ Med Sci	1 (2.86 %)	6 (0.73 %)
43	Isfahan Univ Med Sci	1 (2.86 %)	6 (0.73 %)
44	Univ Fed Rio Grande do Sul	1 (2.86 %)	6 (0.73 %)
45	Korea Inst Nucl Safety	1 (2.86 %)	5 (0.61 %)
46	Warsaw Univ Technol	1 (2.86 %)	4 (0.49 %)
47	Cardiff Metropolitan Univ	1 (2.86 %)	2 (0.24 %)
48	Cube Birmingham	1 (2.86 %)	2 (0.24 %)
49	Univ Johannesburg	1 (2.86 %)	2 (0.24 %)
50	Nick Bell Risk Consultancy	1 (2.86 %)	2 (0.24 %)
51	Univ Salento	1 (2.86 %)	2 (0.24 %)
52	Northern Hlth	1 (2.86 %)	1 (0.12 %)
53	AUVA Allgemeine Unfallversicherungsanstalt	1 (2.86 %)	1 (0.12 %)
54	US Chem Safety & Hazard Invest Board	1 (2.86 %)	1 (0.12 %)
55	Royal Childrens Hosp	1 (2.86 %)	0 (0.00 %)
56	Univ Queensland	1 (2.86 %)	0 (0.00 %)

NB: note that more than 35 institutions are present here as some of these 35 papers reviewed included multiple institutions who were involved in collaborative research ventures.

internationally.

3.4. Author co-citation analysis

The number of citations received by a researcher is used to determine their impact on a subject matter (Nawaz et al., 2023) and can be revealed using a 'co-authorship' bibliometric network; where "Author" was the unit of analysis and "full counting" was the counting method – refer to Fig. 3. Sidney W.A. Dekker is the most prolific author in this field with 3 papers and 286 citations for these and has a 'total link' strength of 10. From 2011 to 2020, this author conducted extensive research into construction safety. During the first year, Dekker published a paper on the recognition of the implications of complexity theory for safety investigations (Dekker et al., 2011) Esmaeil Zarei was placed in second position with 2 papers and 22 citations and published a paper regarding the human-factor risk model to analyse safety in sociotechnical systems in 2022 (Zarei et al., 2022). Erik Hollnagel and Sidney W.A. Dekker were among the most influential researchers in the field with high citation records. The book "Safety I and Safety II: The Past and Future of Safety Management" authored by Erik Hollnagel is widely recognised as a highly significant publication in the field of Safety I and II, nevertheless, the books were excluded from this research. The researchers' emphasis on Safety I and II demonstrates their intention to establish a synergy between the two methods within the realm of safety based on both theory and practice (cf. Hollnagel et al., 2015). This demonstrates that the researchers are seeking a thorough and balanced approach to safety, while also focusing on discovering and rectifying the root causes of accidents and errors, as well as capitalising on effective performance and risk management (Aven, 2022).

3.5. Countries contribution to producing papers on Safety I and II in construction

The present scientific field has seen greater contributions from some countries than others over time. A network diagram of the countries in producing papers was created to enable readers to view countries dedicated to Safety I and II. Citation was selected as the 'type of analysis' and countries as the 'unit of analysis'. Countries that have published research papers on Safety I and II (as well as related citations of the papers in these countries) are illustrated in Fig. 4. 13 countries have contributed more than two papers in the research area. The top three publishing countries were the UK, Australia and the United States (USA) with $f = 8$, 7, and 4 papers respectively. In addition, Australia leads the list of countries with the most citations ($f = 442$), while the UK and South Africa ranked second and third with $f = 262$ and 202; although South Africa obtained these number of citations with only 2 publications. Other countries with 2 or more publications included the Netherlands ($f = 3$), Norway ($f = 3$), China ($f = 3$), South Korea ($f = 3$), Austria ($f = 2$), Canada ($f = 2$), and Czech Republic ($f = 2$).

Reasons for the UK, Australia and the USA having the biggest percentage of research on Safety I and II in construction can be multifaceted. The specific emphasis placed by these countries on safety laws and regulations might be regarded as one of the main factors in this scenario (Akram et al., 2022). These nations enforce stringent regulations for building safety and make concerted efforts to mitigate any potential hazards to construction projects (*ibid*). Moreover, these nations prioritise the advancement of novel technologies in the realm of construction safety and strive to enhance innovative methodologies and technologies in this domain (Yap et al., 2022). Moreover, these nations possess robust financial and technical capabilities to carry out research and are capable of undertaking more comprehensive study in this domain (Wu et al., 2017). While it may initially appear that the increased focus on safety research in these countries is driven by their high accident rates (Warburton, 2023), it is important to acknowledge that the allocation of additional funds to safety measures signifies a proactive approach by authorities in identifying and resolving existing safety concerns

Table 3
Journals and proceedings in which the selected 35 papers were published.

Rank	Journal	Documents	Citation	Impact Factor	Quartile	Publisher
1	Safety Science	8	377	6.1	Q1	Elsevier
2	Reliability Engineering & System Safety	4	138	8.1	Q1	Elsevier
3	British Journal of Anaesthesia	2	50	9.8	Q1	Elsevier
4	Accident Analysis and Prevention	2	10	5.9	Q1	Elsevier
5	Sustainability	2	8	3.9	Q2	MDPI
6	IFAC PapersOnline	2	2	–	–	Elsevier
7	Journal of Management in Engineering	1	86	7.4	Q1	ASCE
8	International Journal of Occupational Safety and Ergonomics	1	34	2.4	Q1	Taylor & Francis
9	Systems Research and Behavioral Science	1	24	2.7	Q1	Wiley
10	Process Safety and Environmental Protection	1	16	7.8	Q1	Elsevier
11	Safety and Health at Work	1	16	3.5	Q1	Elsevier
12	CRC Press	1	14	–	–	Taylor & Francis
13	Ergonomics	1	13	2.4	Q1	Taylor & Francis
14	Annals of Nuclear Energy	1	12	1.9	Q2	Elsevier
15	Cognition Technology & Work	1	9	2.6	Q2	Springer
16	Applied Ergonomics	1	6	3.2	Q1	Elsevier
17	Journal of Safety Research	1	4	4.1	Q1	Elsevier
18	Process Safety Progress	1	1	1	Q2	Wiley
19	Journal of Contingencies And Crisis Management	1	0	3.1	Q1	Wiley
20	Proceedings of the 11th International Conference on the Internet of Things	1	1	–	–	Association for Computing Machinery (ACM)
21	Proceedings of the 15th International Conference on Pervasive Technologies Related to Assistive Environments	1	0	–	–	Association for Computing Machinery (ACM)

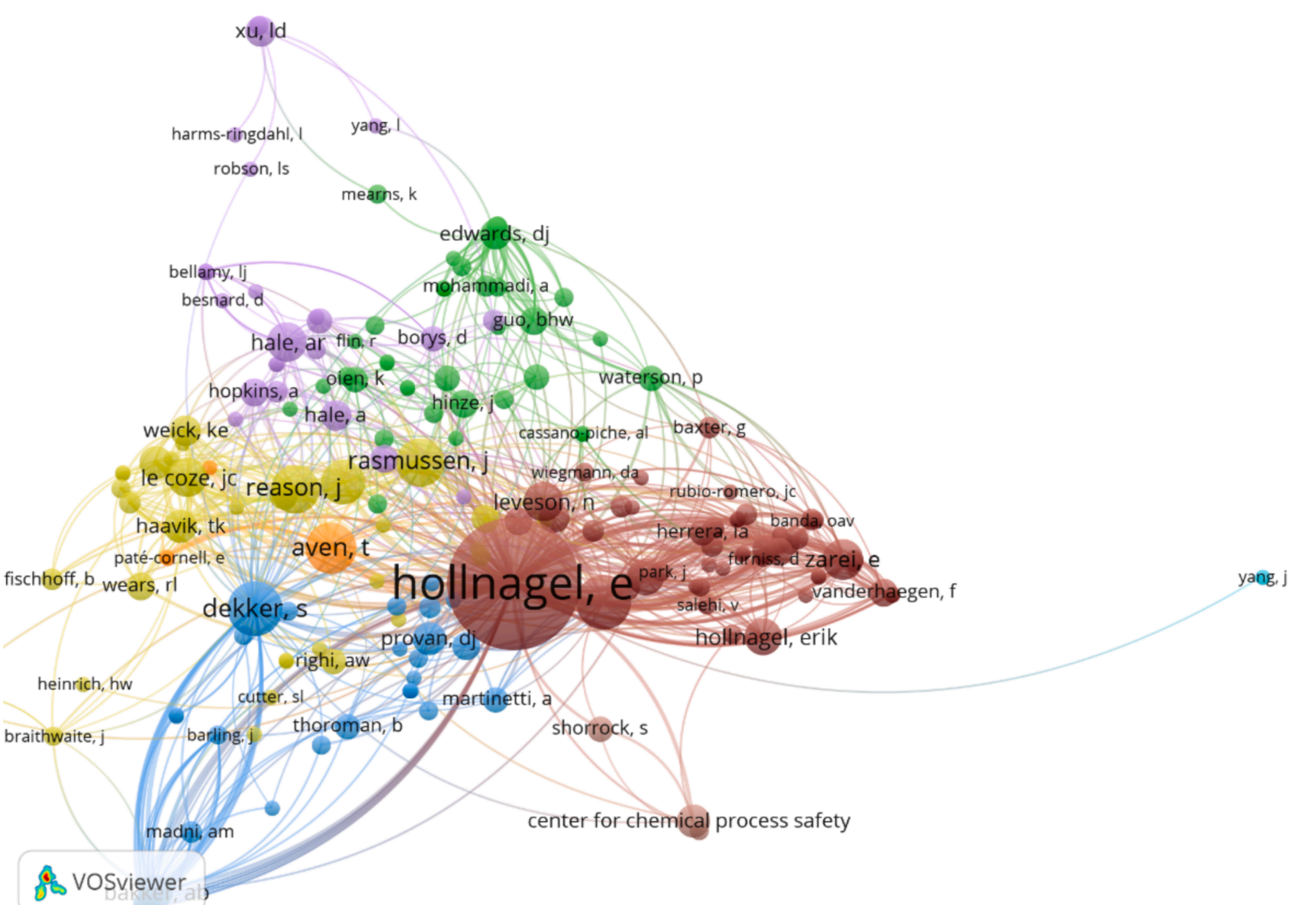

Fig. 3. Author co-citation.

(Department for Levelling Up, Housing and Communities, 2023; National Highways, 2020). The heightened emphasis and concentration on safety can increase documented accidents when a greater number of incidences are recognised and recorded (Falco et al., 2021). Furthermore, the frequency of accidents is influenced by other societal elements, including population density, urban design and cultural perspectives on safety (Gössling and McRae, 2022). The variability of these elements might differ greatly among countries. For example, in the UK,

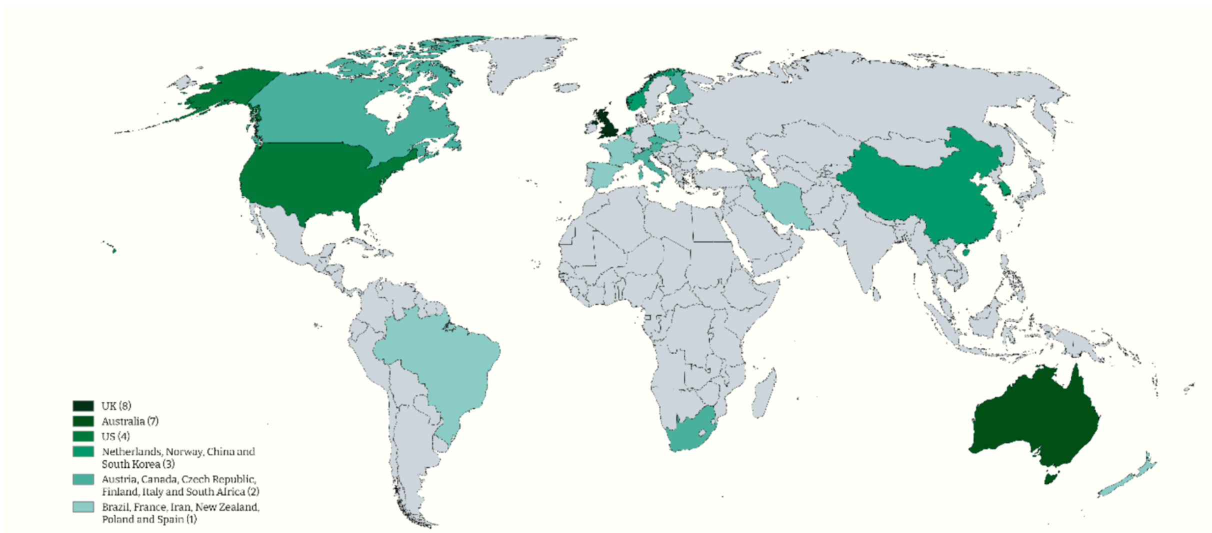

Fig. 4. Contribution of countries to research on construction Safety I and II.

the government has given high importance to ensuring road safety and has made significant investments in implementing measures aimed at decreasing the occurrence of accidents (National Highways, 2020). Investing in road maintenance, traffic management systems and public awareness campaigns has significantly contributed to the decline in accident rates over time (Suresh et al., 2021). According to the UK Department for Transport (2023), accident rates have consistently decreased over the previous ten years, establishing the country as a global leader in road safety. Australia has undertaken a range of safety programmes and allocated substantial resources to mitigate accident rates (Peiris et al., 2020). The USA stands out due to its distinct transportation infrastructure and varying safety standards among states. Despite substantial safety investments, the country has encountered difficulties in decreasing accident rates (Tonn et al., 2021).

3.6. Annual publication and citation trend of Safety I and II in construction

Fig. 5 illustrates that studies began in 2011. Dekker et al. (2011) published the first paper with an investigation into complexity theory for safety investigations. Although no publication was found in 2012, Hale and Borys (2013) proposed a new framework for the rule of safety management in 2013. From 2014 to 2017, several studies were focused on Safety I and II (cf. Dekker, 2014; Vanderhaegen, 2015; Guo and Yin; 2016; Elliott, 2016; Chan *et al.,* 2016; Hollnagel 2017). Notably, Safety I and II received more attention among researchers in 2018 with 2 papers being published. Since 2019, research and publication of papers have continued unabated and have focused on resilience and progress towards improving safety by combining Safety I and II. The years 2019–2023 produced 25 publications and can be considered the most productive years in the period of this study. In the period from 2019 to 2023, a total of 25 related papers have been published, making it the

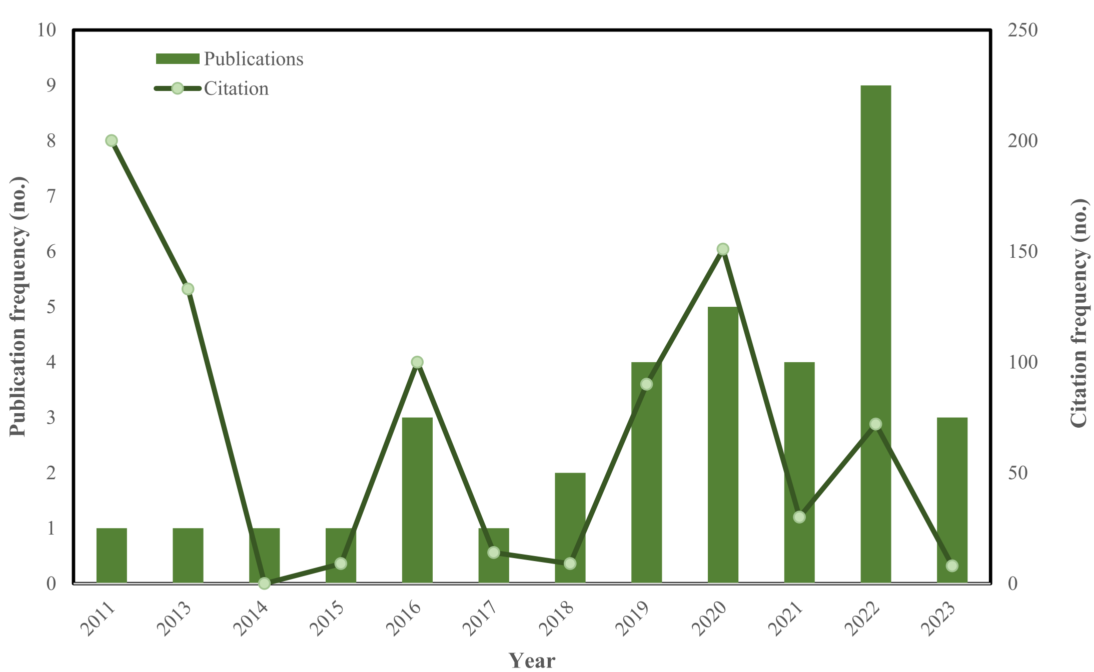

Fig. 5. Annual Publication and Citation Trend of Published Papers.

most productive era in the scope of this study. Overall, the focus of papers has moved from introducing the integration of Safety I and II in early 2011 to providing solutions for the integration of Safety I and II in the middle years of research (i.e. 2014–2018) and making constructive suggestions for the establishment of an integrated approach in recent years for a safer future. This perhaps illustrates the growing importance of Safety I and II in shaping future studies.

4. Discussion: strategies for integrating safety I and II in the construction

The scientometric analysis of previous studies highlights a significant and accelerating trend in transitioning from Safety I to Safety II approaches in the construction industry, emphasising the need for integrating and harmonising both methodologies to address the sector's unique challenges and complexities. The increasing focus on safety II in previous research reflects the broader trend towards enhancing safety through proactive measures and policy-making development. Safety management research in construction also emphasises the importance of modern organisational (Hegde et al., 2020) and technological solutions (Wahl et al., 2020) to improve safety and efficiency. These insights collectively underscore the need for practical strategies that integrate Safety I and Safety II approaches, leveraging technological advancements and interdisciplinary research to address the construction industry's unique safety challenges. By incorporating and harnessing the advantages of both Safety I and II methodologies, construction firms can cultivate a safety culture centred around resilience (Wahl et al., 2020; Cutchen, 2021). This culture not only focuses on preventing accidents but also emphasises the importance of learning from successes and being adaptable (Vanderhaegen, 2015). To develop a comprehensive and effective safety strategy for the sector, it is crucial to identify areas of overlap and potential conflicts between the two approaches. A convergence point refers to the acknowledgment of shared protective goals. The primary goal of both Safety I and II is to safeguard the "diversity of living people" and mitigate the potential for harm and loss of life (Ham, 2021). Both strive to provide a secure working environment and reduce the occurrence of dangers and potential harm (Hollnagel, 2017; Hollnagel, 2018). Simultaneously, there can be divergences on the methods to accomplish these objectives (Hollnagel et al., 2015). To achieve the optimal equilibrium between the two methods, it is necessary to conduct a meticulous evaluation of the circumstances and requirements of each construction site (Wahl et al., 2020). Depending on the specific setting, certain conditions may necessitate strict adherence to the norms, while others may call for a more adaptable and collaborative approach (Rafieyan et al., 2022b). For example, in the case of routine tasks that are well-known to have potential dangers, Safety I measures (such as mandatory personal protective equipment and standardised procedures) may be enough. Nevertheless, in the face of unforeseen hazards or difficulties, the Safety II approach, which emphasises worker engagement, learning and solution-oriented mindset, may offer superior effectiveness.

To identify areas of potential conflict or overlap between Safety I and II transitions, construction enterprises must actively engage in open communication and collaboration among safety experts, workers and management (Carrillo et al., 2013). Establishing safety cultures that actively monitor and respond to regulations and are adaptable can harness the benefits of Safety I and II, resulting in improved safety outcomes and a more resilient workforce (Zimolong B and Elke, 2006). Fig. 6 illustrates the primary strategies that facilitate the integration of Safety I and II approaches in the sector. An effective approach involves

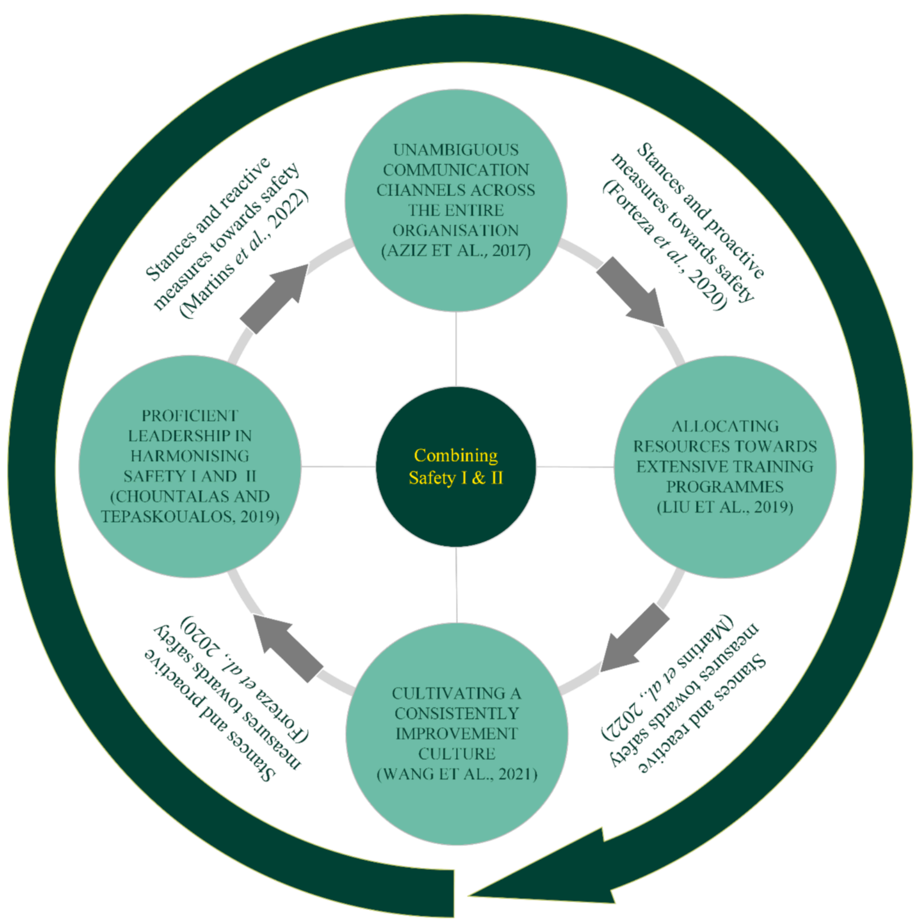

Fig. 6. Strategies for facilitating the integration of Safety I and II.

establishing unobstructed channels of communication throughout the organisation (Aziz et al., 2017). This entails fostering transparent communication among employees, supervisors and top-level decision-makers, as well as creating technical innovations that streamline the flow of information (Wu et al., 2015). An effective approach to strengthen Safety I would involve encouraging employees to promptly report instances of near misses, hazards, and suggestions for enhancing safety (Hale et al., 2010). In addition, Safety II might be promoted by establishing platforms to showcase and commend successful narratives, novel methodologies, and valuable knowledge gained from previous experiences (Homann et al., 2022). Practical and implemented recommendations to establish unobstructed channels of communication, require a multifaceted approach that leverages both behavior-based and culture-based safety management strategies. This involves creating a participatory problem-solving process and a culture change process that work in parallel, fostering a self-regulatory system where the right messages reach the right people, enabling them to solve the right problems with the right solutions (Pedersen and Nielsen, 2013). Effective communication mechanisms, such as policies, procedures, performance statistics, hazard and incident reports, and training, are critical to engage staff in safety activities and maintain a positive safety culture (Wang et al., 2019). Utilising dual-radio communication systems can enhance interoperability between safety and non-safety communications, ensuring that safety messages are transmitted efficiently and without interference (*ibid*). Integrating safety management systems with general management principles can eliminate duplication and reduce costs, thereby streamlining communication processes (Li and Guldenmund, 2018). Regular training and the use of various communication channels, such as formal meetings, project coordination tools, and internal communication software, can help clarify safety requirements and share safety knowledge effectively (Wang et al., 2019).

The second strategy entails establishing an investment in extensive training programmes (Liu et al., 2019). This may involve providing conventional safety training that focuses on teaching individuals how to recognise dangers, conduct risk assessments, and adhere to rules (Safety I) (Hollnagel, 2018). Training should emphasise the significance of adaptation, resilience, and the ability to learn from everyday work (Safety II) (Aven, 2022) simultaneously. Altering one's thinking involves assisting others in perceiving and resolving difficulties from diverse viewpoints. Effective training programs should incorporate elements from both Safety I and II approaches to provide a comprehensive safety education. For instance, integrating visual cues, immersive virtual environments and personalised training experiences can significantly improve hazard recognition and safety performance in construction workplaces (De Leo et al., 2023). Additionally, the integration of behaviour-based and culture-based approaches can foster a self-regulatory system where communication and mutual trust between managers and workers are essential for success (McNab et al., 2016). In the construction sector, specialised training that addresses the interrelations between safety, physical protection, root causes and resilience factors is crucial for developing a robust and resilient safety architecture for the integration of Safety-I and Safety-II (Pedersen and Nielsen, 2013).

It is essential to possess the capacity to surmount unforeseen challenges while adopting a proactive approach to ensuring safety. Developing a culture that continually foresees the future and strives to enhance the present situation is essential (Wang et al., 2021). To cultivate a continuous improvement culture, it is quintessentially important to understand the complex adaptive nature of health and safety systems and integrate theories of quality improvement, reliability, human factors and resilience to achieve sustainable improvements (Yiu et al., 2018). Additionally, fostering a culture where safety is perceived, prioritised and integrated into daily activities reflects a real commitment by all staff to safety at all levels (Cooper, 2018). Implementing a risk-based approach to identify, analyse, and mitigate potential hazards can enhance safety culture, as demonstrated in the construction industry (Sousa et al., 2014). An effective approach to accomplish this is by conducting regular safety audits and inspections to identify current hazards and opportunities for enhancement (Safety I) (Winge et al., 2019). Nevertheless, the incorporation of Safety II concepts necessitates surpassing mere reactivity (Peng et al., 2023). To do this, it is necessary to consistently seek input from employees, have regular safety meetings, and foster an environment where workers can collaboratively propose and implement safety solutions (Mearns et al., 2003). Organisations can facilitate the integration of Safety I and II approaches by exerting authority and demanding that employees take ownership of safety and are provided with the necessary resources to fulfil this obligation (Hollnagel, 2018). By combining these practical strategies, construction organisations can effectively integrate Safety I and II, fostering a culture of continuous improvement and resilience.

Ultimately, effective leadership is required to reconcile both Safety I and II (Chountalas and Tepaskoualos, 2019). Effective safety leadership must involve a strong commitment to achieving zero harm and continuous improvement, as emphasized by the safety culture pyramid and the need for leadership at all levels to instil a safety culture throughout the health and safety system (Daniel, 2018). Practical recommendations include adopting a systematic approach that facilitates workflow assessment and improvement, creating high reliability organisations, and fostering continuous learning (*ibid*). The integration of transformational and active transactional leadership styles is also essential, as these styles positively influence safety climate, participation and compliance, with transformational leadership encouraging employee participation and transactional leadership ensuring rule compliance (Winn, 2016). Additionally, the LEAD model (i.e. Leverage, Energise, Adapt and Defend) can be employed to create a shared social context and influence workers' safety performance through various control strategies (Casey et al., 2019). Practical leadership skills, such as clarifying work roles and providing necessary resources, are vital for organising and coordinating safe task fulfilment (Schöbel, 2020). Moreover, an overemphasis on enforcement and discipline can be counterproductive, and a balanced approach that includes regular and consistent feedback, both positive and constructive, is recommended to motivate safe work practices and reduce hazards (Casey, 2020). Finally, embedding safety practices into existing workflows and using small tests to identify effective strategies can help in achieving sustainable safety improvements (Clarke, 2013). Leaders can exemplify this by prioritising safety, establishing a safety culture through appropriate messaging, and promoting strict adherence to both preventive measures and learning approaches (Pilbeam et al., 2016). Leaders can promote the adoption of Safety II among all staff members by establishing a shared objective through a vision of the desired safety outcomes that integrates both approaches (Ruchlin et al., 2004).

4.1. Future research areas

Organisations must effectively reconcile the two methods to secure a profound comprehension of safety and optimise outcomes. The combination of these two separate approaches enables an organisation to leverage the advantages of each as it develops a more advanced understanding of safety. This includes implementing a proactive risk management plan and fostering a culture of continuous improvement via learning. Essentially, it acknowledges the concept that safety encompasses more than just the absence of negative occurrences like accidents but rather includes the presence of good elements that promote well-being and enhance productivity within the workplace. Integrating Safety I and II is motivated by the fact that accidents and incidents typically do not stem from a singular, uncomplicated cause but instead manifest through a range of intricate interplays among several factors.

Improving the culture and thinking towards safety: Enhancing the culture and mentality of safety is a crucial study focus for integrating Safety I and II in the construction sector. Safety culture refers to the collective attitudes, beliefs and practices that shape the overall attitude towards safety within a company. This is quintessentially important, not only for management but for all individuals or organisations involved with construction. Investigating the transition from a reactive safety mindset, only addresses events and accidents after they happen, whereas a proactive approach consistently identifies potential risks and adapts accordingly. This can be accomplished by implementing safety observations, conducting job-hazard assessments and implementing ongoing improvement methods. Organisations can enhance workplace safety and productivity by comprehending task execution methods and engaging individuals in the decision-making process. Future studies on enhancing safety culture in the construction industry, with a focus on Safety I and II, focus on several key areas. First, there is a need for more context-specific models that account for the unique attributes and complexities of construction environments, such as diverse backgrounds, professions and the psychological traits of workers (Duryan et al., 2020). Additionally, research should broaden theoretical and methodological perspectives, incorporating in-depth qualitative studies to better understand interpersonal relations and the complexity of the industry (Berglund et al., 2023). Strategies to enhance safe behaviour among subcontracted operatives, such as the enforcement of safety practices, operative engagement and motivational incentives should be further investigated (Ajayi et al., 2022). Moreover, research on construction safety climate should focus on its dimensions, evaluation systems and relationship with safety behaviour, aiming to develop effective warning systems for construction workers (Liu et al., 2023).

Integration of technology to enhance safety results: the application of advanced digital technology has made significant progress in improving safety outcomes in the construction sector (Umeokafor et al., 2022). Utilising these emerging technologies (cf. Newman et al., 2021) allows for the effective utilisation of their innate potential to improve on-site safety. For example, the utilisation of wearable devices and sensors (cf. Torku et al., 2022). These technologies have the capability to track several work aspects on a construction site, including: the mobility of personnel (Aryal et al., 2017); the physical environmental conditions (Fernández-Muñiz et al., 2017); and the utilisation of construction machinery (Chinda and Pongsayaporn, 2020). By utilising real-time data, sensor-based technologies can facilitate the acquisition of crucial information on potential hazards and enable proactive measures to be taken (Awolusi et al., 2018). For example, in situations where a user is in proximity to a hazardous location or when equipment exhibits signs of malfunction, notifications can be transmitted to both the user and site supervisors, enabling prompt intervention to prevent any adverse incidents. However, it is important to understand the motivation behind the individual's decision to expose oneself to potential danger. Technological safety regulations should always be implemented by an individual responsible for record-keeping, ideally using a well-designed and safety-conscious knowledge management system that includes regular monitoring and interpretation.

An additional area of research investigates the application of virtual reality (VR) and augmented reality (AR) technology in the realm of safety training (Li et al., 2018). VR and AR technologies can replicate and simulate various surroundings and dangerous scenarios inside a controlled setting (Rokooei et al., 2023). This can provide workers with direct exposure and knowledge of potential dangers without subjecting them to actual life-threatening perils (Li et al., 2018). The simulated immersion situation provides a secure setting for workers to engage in safety protocols, comprehend utilised skills and develop crucial decision-making capabilities (Stefan et al., 2023). Moreover, these technologies can be integrated into on-site inspections conducted by a supervisor to detect and address potential hazards, ensuring a secure working environment prior to deploying workers (Rokooei et al., 2023). Various research literature also suggests the incorporation of artificial intelligence (AI) and machine learning (ML) algorithms to improve safety outcomes. Through the analysis of extensive big data collected from construction sites using these algorithms, it is feasible to identify recurring patterns or indications based on pre-established criteria to anticipate potential safety hazards in the future (Lu, 2019). By utilising predictive algorithms, stakeholders can proactively take measures to mitigate hazards and improve resource optimisation (Jia et al., 2020). AI can detect near misses or possible accidents and provide guidelines for recognising recurring safety problems. Once these issues are discovered, AI may implement targeted interventions and propose adjustments to current safety regulations (Kroll and Berzins, 2022). Nevertheless, it is imperative to guarantee that these technologies possess a user-friendly interface, are readily available, and can be seamlessly integrated into a construction site to accommodate the precise needs of the building industry. It is crucial to comprehend the restrictions as well. For instance, although being popular, AI is not a sentient entity and is restricted to the patterns it was trained on. In a complicated and dynamic building environment, preprogrammed rules are not the ultimate solution that IT experts often propose. They are simply an additional valuable resource for the safety professional. To fully leverage the benefits of technology and strive for improvement in site safety, it is essential for all stakeholders in the construction industry, including technologists and safety practitioners, to engage in ongoing research and adopt an integrated strategy.

Improving communication and collaboration among construction stakeholders: An essential study objective in combining Safety I and II is to cultivate efficient communication and engage stakeholders effectively. The building process involves various parties, such as architects, engineers, contractors, subcontractors, and regulatory organisations of suppliers. Every one of these stakeholders has a crucial responsibility in guaranteeing safety on the construction site. Nevertheless, instances of inadequate communication and participation, misguided approaches to collaboration, and disjointed workflow might result in multiple safety risks (Aziz et al., 2017). For instance, if the design team fails to confirm that the building team has properly received the necessary safety requirements, it can result in potential dangers that may be deemed dangerous when construction begins. Likewise, the exclusion of stakeholders such as subcontractors and suppliers from the communication loop can significantly contribute to misunderstandings regarding safety laws and norms, ultimately jeopardising the safety of the entire project. From a behavioural standpoint, it is important to recognise that a skilled and knowledgeable worker has the potential to initiate a chain of events through their actions or inactions, ultimately leading to an accident. For instance, some personal tragedies occurring at home, such as the loss of sleep, the passing of a close loved one, or financial stress, might all contribute to a singular 'moment of madness' on site. Teams are crucial due to this reason. Hence, it is imperative for research to prioritise the development of highly efficient methods for communication and collaboration among stakeholders (modelled off of Posillico and Edwards (2024)), enabling them to exchange crucial safety information. Utilising a digital platform or programme that facilitates collaboration, document sharing and real-time communication helps efficiently achieve this goal. Furthermore, it is imperative for research to investigate novel approaches to augment stakeholders' engagement in safety deliberations. This may necessitate regular safety meetings and workshops, as well as a training session, to establish a shared understanding of safety objectives and responsibilities among all participants. In summary, enhancing communication and engagement among stakeholders in the building sector can contribute to a more secure future. Through performing thorough research and implementing cutting-edge solutions, stakeholders can effectively enhance their understanding of safety measures, streamline their work processes, and foster the participation of all stakeholders in the development of a more secure construction environment.

Resilience and adaptability within construction projects: Given the fast-paced nature of the construction industry, stakeholders in the sector must prioritise resilience and adaptation in their building projects. To ensure a safer future for the site and personnel, it is possible to integrate the Safety I and II approaches (Aven, 2022). An essential aspect of fostering resilience in construction projects involves establishing robust systems and procedures that are capable of withstanding unexpected obstacles and interruptions. This involves the effective implementation of resilient risk management, the development of contingency plans, and the fostering of a proactive problem-solving culture (Munir et al., 2024). Through the early identification of potential hazards and vulnerabilities, construction project teams may effectively mitigate the related risks to enable optimal project implementation while considering uncertainties. Furthermore, flexibility can enhance building projects by enabling them to accommodate unforeseen alterations promptly and proficiently in circumstances and requirements. This entails the integration of modern technologies and procedures that facilitate the adaptability and agility necessary for project delivery. Therefore, further investigation is required to examine the characteristics of resilience and adaptation in the construction sector and to improve their capabilities. Investigating the resilience and flexibility of building projects holds considerable potential for advancing the execution of Safety I and II. By employing efficient strategies and modern methodologies, the construction sector can effectively navigate challenges and uncertainties, ensuring the successful and secure execution of projects that ultimately benefit all users of these infrastructures. Fig. 7 illustrates the future research areas for safety in the field of Safety I and II.

5. Conclusions

The present systematic literature review provided a comprehensive overview of recent trends and advances in Safety I and II in the construction industry. The research presented demonstrates that achieving a balance between Safety I and II, and effectively implementing a safety management system inspired by Safety II, is still a work in progress. Both the Safety I and II systems have their own strengths and limitations when it comes to interpreting safety management. By combining the benefits of these two approaches, organisations can establish healthier work environments. This involves not only identifying and effectively managing risks (Safety I), but also creating a culture that promotes learning, adaptability and resilience to internal challenges (resilience). When considering the future direction of safety integration, it is important to consider the practical challenges that organisations may encounter when implementing new tools and processes. Additionally, organisations must also consider the necessary cultural changes that may be required to fully adopt the Safety II model and ensure lasting change. By using both Safety I and II approaches, stakeholders in the industry can make significant progress towards creating a safer and more efficient future for everyone involved.

Integrating Safety I and II is an additional step that businesses can take to advance towards a safer future across all industries. This study showed that a promising approach is the development of comprehensive risk and safety assessment framework that organisations can use to incorporate, prevent and reduce potential harm or injury to individuals, equipment and the environment. This approach would also encourage and support a safety mindset that focuses on systems, learning and proactive measures. This approach will use the knowledge acquired from previous incidents (Safety I) and highlight the significance of system resilience and adaptability (Safety II). One effective approach to enhance the integration between Safety I and II is to leverage advanced technology and data analytics. In the era of Industry 4.0 and the Internet of Things (IoT), organisations will have the capability to gather real-time

Fig. 7. Future research areas for safety performance promotion.

data from many sources. Subsequently, a determination could be reached by considering the existing data. These tools would facilitate both early detection of potential injury and real-time decision-making. In the future, the integration of Safety I and II could involve the implementation of extensive training and educational programmes. Organisations can furnish staff with the essential information and expertise required to effectively transition between the Safety I and II methodologies. The primary objective is to provide training to employees and enable them to actively engage in ongoing safety improvement. The establishment of a more robust safety culture can be achieved by incorporating both reactive and proactive elements. In addition, the future progression of incorporating both Safety I and II will necessitate the integration of collaborative efforts among experts in the respective field. Knowledge may be disseminated, scientific inquiry should persist and effective methodologies can be swapped. The sector has the potential to foster innovations and strike a balance between the two distinct safety paradigms and solutions. In conclusion, this would improve the performance of businesses by fostering innovation, increasing efficiency, and ultimately contributing to a more effective and secure future. An ultimately coherent future is one that is both safe and autonomous. Organisations can facilitate the integration of the different components of Safety I and II in a cohesive manner. They can adopt innovations, provide money for training and foster a culture of ongoing enhancement.

CRediT authorship contribution statement

Hadi Sarvari: Writing – original draft, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **David J. Edwards:** Writing – original draft, Visualization, Validation, Supervision, Project administration, Data curation, Conceptualization. **Iain Rillie:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources. **John J. Posillico:** Writing – review & editing, Visualization, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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