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Implementing safety leading indicators in construction: Toward a proactive approach to safety management

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ABSTRACT

Safety leading indicators have been investigated as a proactive management approach to managing construction safety. However, there is a lack of insight into the implementation of safety leading indicators in construction projects and organizations. This causes difficulties in the adoption and consistent use of safety leading indicators in the construction industry. The aim of the research is to explore what and how safety leading indicators can be implemented to improve safety management in the construction industry. Built upon Xu et al. (2021), the study prioritized the relative importance of 17 safety leading indicators through a three-round Delphi survey and voting analytic hierarchy process (VAHP). It was found that organization commitment; client, designer and contractor engagement; training and orientation; safety climate and competence were most critical to safety performance in construction. Furthermore, operational, organizational and strategic barriers to the effective implementation of safety leading indicators were identified through the focus group discussion. The study suggested strategies for addressing these barriers and moving toward a proactive safety management approach. This study contributes to the theories and practices of construction safety management by linking the deployment of safety leading indicators with organizational and strategic issues at firm and project levels and addressing the root causes of poor performance. The effective deployment of safety leading indicators needs the engagement of clients, contractors, designers and supply chains to develop organizational capabilities to drive improvements from the project front-end to completion.

1. Introduction

The UK construction industry has dramatically reduced its fatalities and injuries through safety legislation and regulations. The prescriptive approach of legislation regulates safety standards and procedures. In response, construction organizations and major projects have devised and implemented safety management systems, policies, and behavioral programs to comply with the regulations (Jones et al., 2019; Roberts et al., 2012). Yet the performance has remained at a high plateau for the last 15 years. The fatality rate remains three times higher than all industries (HSE, 2020). It was estimated that, during 2017 and 2020, there were 61,000 cases of non-fatal work-related injury and around 2.8 % of workers suffered from an injury (HSE, 2020). A similar pattern has been found in many developed countries such as Australia, New Zealand and the United States (Lingard et al., 2010; Chen et al., 2018; NIOSH, 2021). Injuries and illness threaten the quality of life of individuals. They also bring about a substantial cost to society and organizations. The total costs of injury and illness in the UK construction industry were estimated at £1.2 billion in 2018/19, which is equivalent to 8 % of the total cost across all industries (HSE, 2020).

The legislative-driven approach has been criticized for helping grow a compliance culture within construction organizations and projects (Ju and Rowlinson, 2020). It overemphasizes formal routines and lagging indicators such as lost time injury frequency rates (LTIFRs) and total recordable injury frequency rates (TRIFRs). Informal and good practices can be eroded and bad behavior ignored as the unintended consequences to formal and explicit practices (Roberts et al., 2012). Moreover, lagging indicators only indicate the safety outputs and are not able to proactively convey the reasons for good or bad performance. They are limited in terms of driving actions to improve the management process (Hinze et al., 2013b). Therefore, lagging indicators are reactive in nature, reflecting a Safety-I approach described in Hollnagel (2014). The reactive approach also encourages blame for human errors, which reduces the reportability and reliability of lagging indicators in practice

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(Lingard et al., 2017; Oswald, 2020).

Against this backdrop, safety leading indicators have gained increasing attention in recent literature (Alruqi and Hallowell, 2019; Guo et al., 2017; Hallowell et al., 2013; Hinze et al., 2013b; Lingard et al., 2017; Xu et al., 2021). Safety leading indicators focus on the organizing process of safety practices and measuring safety performance by identifying the weaknesses and strengths of management systems and situations that might cause incidents (Xu et al., 2021). They provide an early indication of impending adverse events and drive preventive actions (Guo and Yiu, 2016). The monitoring of safety leading indicators can provide knowledge beyond individual incidents, allowing for continuous learning and an adaptive safety system (Salas and Hallowell, 2016). Safety leading indicators form an integral part of a more proactive approach to safety management. Extant research has suggested various safety leading indicators and examined their effectiveness in construction (Akroush and El-adaway, 2017; Alruqi and Hallowell, 2019; Hinze et al., 2013b; Lingard et al., 2017). However, there is a lack of clarity regarding the deployment of safety leading indicators in construction organizations and projects, which can discourage the adoption and consistent use of safety leading indicators in the construction industry. Construction organizations were recognized as reluctant to voluntarily invest and transform the practices (Ju et al., 2018; Smyth et al., 2019). Oswald et al. (2018) found that construction companies typically chose leading indicators that were easy to count or actions that were already undertaken, rather than based on the organization's needs. What remains unclear is the organizational barriers to effectively deploying safety leading indicators. Scholars have analyzed the correlation between leading and lagging indicators (cf. Lingard et al., 2017; Versteeg et al., 2019); yet study on practitioners' perceived relative importance of leading indicators to safety performance is lacking. Understanding practitioners' perception provides a qualitative way to evaluate the impact of safety leading indicators that are hard to quantify and hence ignored (Oswald, 2020). The perceived relative importance of various leading indicators helps guide the gradual deployment of leading indicators in construction organizations and projects.

Thus, this study aims to explore what and how safety leading indicators can be implemented in the construction industry. The research questions are:

1. How are the safety leading indicators implemented in construction?
2. What are the barriers to effectively implementing safety leading indicators in construction organizations and projects?
3. What is the relative importance of safety leading indicators in construction?

Expert focus group discussion was conducted to explore the implementation of safety leading indicators in the construction industry. Through three-round Delphi technique accompanied by the application of voting analytical hierarchy process (VAHP), this research prioritized the safety leading indicators identified by a systematic literature review and expert focus group discussion. Organization commitment at the firm level and the engagement of client, contractor and designer throughout the project lifecycle are of topmost important indicators to safety management in construction. Lastly, the findings were synergized to suggest strategies to move toward a more proactive approach to managing safety in construction organizations and projects. This research argues that the challenges of effectively implementing safety leading indicators in construction are not only operational (e.g., how to select and measure indicators), but also organizational (e.g., how safety is related to other management systems) and strategic (e.g., related to developing the organizational capability of learning). The transactional business model of construction organizations prioritizing costs over investment in capability development hinders systems integration between safety management and other management systems, organizational learning and competence growth. A transformational business model is needed to sustain organizational commitment at the firm level(Smyth, 2021). At the project level, the engagement of project stakeholders requires not only consistent measurements at the execution stage but also investment beyond the minimum requirement at the front end to drive safety learning and a positive safety climate across organizations and along the supply chain.

2. Safety leading indicators in construction

Safety leading indicators were commonly recognized as measures of the safety management system (Alruqi and Hallowell, 2019; Hopkins, 2009; Reiman and Pietikäinen, 2012). A safety management system consists of safety rules and resources as well as actors aimed at creating and sustaining the safety of a workplace (Guo et al., 2017). In construction, safety management systems are at two levels: the firm and the project. Safety leading indicators, therefore, measure safety management processes and practices of projects and firms (Xu et al., 2021). They can provide early warning of situations that might cause adverse safety outcomes and trigger proactive actions to correct the deficiencies or further develop the system (Hallowell et al., 2013; Hinze et al., 2013b; Leveson, 2015). They also recognize the positive side so that systems can be strengthened (Reiman and Pietikäinen, 2012).

Extant construction safety research has identified various safety leading indicators used by construction firms and projects. For example, Hinze et al. (2013a) recognized nine essential components of an effective construction safety program, including demonstrated management commitment, staffing for safety, pre-project and pre-task planning, safety education and training, employee involvement, safety recognition and rewards, accident/incident investigations, substance abuse programs and subcontractor management. Construction firms need to monitor these elements as leading indicators to ensure safety performance. Akroush and El-adaway (2017) recognized 48 indicators used by Tennessee construction firms and found that housekeeping, use of PPE and substance abuse programs were the most widely used. They also pointed out that larger companies were more likely to use formal safety programs than small and medium enterprises. Focusing on the execution stage of construction projects, Hallowell et al. (2013) categorized safety leading indicators into owner-, contractor- and vendor-led indicators to stress each organization's roles and responsibilities in the project delivery. Liu et al. (2019) found that safety management leadership and worker training were most used by clients during the procurement stage to select contractors. It was also found that construction firms and client organizations typically employed indicators that were easy to collect or counted the frequency of existing safety management activities (Oswald et al., 2018). The focus was the quantity of conduct and compliance to policies, instead of effective implementation and performance improvement. This reflects a reactive approach to managing safety in construction. To promote a proactive approach, it is paramount to understand the organizational barriers to effectively implementing safety leading indicators in construction organizations and projects.

Researchers have also examined the impact of some safety leading indicators on accidents and injuries. It was found that pre-task safety meetings, pre-job risk analysis and plans and safety inspections were negatively related to injury rates (Aksorn and Hadikusumo, 2008; Hallowell et al., 2020; Rajendran, 2013; Salas and Hallowell, 2016). Versteeg et al. (2019) investigated 47 construction projects of a construction firm and did not find significant relationships between the number of inspections and 'lost time' injuries or medical injuries. Lingard et al. (2017) took into account temporal effects on the relationship between leading indicators and total recordable injury frequency rates (TRIFRs). They found no consistent relationships between the frequencies of toolbox meetings, pre-brief meetings, audits or drug tests, and TRIFRs. It is suggested that the effectiveness of safety leading indicators is more related to the quality than the quantity of the practice (Hallowell et al., 2020; Oswald et al., 2018). Moreover, accident and injury rates are only one aspect of safety performance. The implementation of safety leading indicators in construction organizations and projects might impact the cultural and organizational aspects of safety such as safety culture and climate. This calls for qualitative studies that go beyond quantitative measurements on safety leading indicator and its impacts to incorporate the complexities of safety (Oswald et al., 2018).

Recently, some conceptual frameworks of safety leading indicators have been developed to measure and compare the safety level of construction firms or projects (Biggs and Biggs, 2013; Guo et al., 2017; Liang et al., 2018; Shaikh et al., 2021; Xu et al., 2021). Compared with previous studies focusing on individual indicators, these frameworks demonstrated the conceptual relationships between individual indicators and how they could collectively affect safety outcomes in theory. For example, Guo and Yiu (2016) proposed a framework based on Rasmussen's two safety models. Based on systems theory, Guo et al. (2017) developed a pressure-state-practice model of safety leading indicators to measure and compare the safety levels of projects. Through a systematic literature review, Xu et al. (2021) created an integrated framework that fits the construction industry's complex and fragmented structure for proactive safety management. They categorized the indicators into two dimensions to 1) measure the safety performance of firms, projects or groups and individuals; and 2) identify potential incidents and injuries caused by organizational, operational or cognitive and behavioral issues. Yet there is a lack of clarity in terms of how to deploy the framework in practice and, aligned to this, which indicators are more important to safety management and hence can be prioritized in the implementation. This research fills this gap by prioritizing the relative importance of safety leading indicators identified by a systematic literature review (cf. Xu et al., 2021), recognizing barriers to implementing safety leading indicators in construction and suggesting strategies for transforming practices based on the empirical findings.

3. Methodology

This research aims to explore what and how safety leading indicators can be implemented to improve safety management in the construction industry. The explorative nature made qualitative methodology suitable for the research (Creswell, 2014; Fellows and Liu, 2015).

3.1. Research design and process

This study is based on the data collected in a research project by the authors. The research project examined the selection and implementation of safety leading indicators in the construction industry, which involved three stages: 1) a systematic literature review to identify construction safety leading indicators commonly discussed in the literature; 2) a focus group discussion to refine the indicators and identify barriers to implementing safety leading indicators in construction and; 3) three-round Delphi technique combined with voting analytical hierarchy process (VAHP) to identify the relative importance of the indicators. The focal study focused on the second and third stages. Further detail of the first stage is available in Xu et al. (2021). The research process is illustrated in Fig. 1.

3.1.1. Systematic literature review

Systematic reviews use specific methods to methodically search for research evidence while providing a critical appraisal and synthesis of literature on a particular topic (Sutherland, 2004). This approach to reviewing literature is particularly beneficial when there is a need to map evidence on a topic to provide logically sound and substantiated arguments (Denyer and Tranfield, 2006; Tranfield et al., 2003), as was the case in this study.

To examine the safety leading indicators in construction, peer-reviewed journal articles were searched on Scopus and Web of Science databases, excluding any time boundaries. These search engines were selected because of their credibility, and they are complementary in providing the most relevant academic journals on this specific topic. The search was conducted in June 2019 and used a combination of keywords, such as "safety" and "leading indicator", "safety" and "predictive indicator" and "safety" and "upstream indicator". After removing duplications and non-peer-reviewed articles, the initial search resulted in 291 peer-reviewed journal papers. The articles were then screened to include papers focusing on the construction industry only, which eliminated 242 papers. The remaining articles were manually screened to determine whether they 1) focused on the safety of people working in construction and 2) were related to the identification, analysis or validation of indicators. This process eliminated 17 papers, leaving 32 journal articles for further investigation. In addition, one construction industry report, Australian Constructors Association (2015), was regarded as highly relevant and was added to the 32 articles for detailed review. The systematic review identified 16 safety leading indicators and their associated sub-indicators as well as measurements for sub-indicators. By analyzing the level of measurement, the review also categorized the 16 indicators as firm-, project- and group and individual-level indicators. A more comprehensive account of the systematic review process is given in Xu et al. (2021).

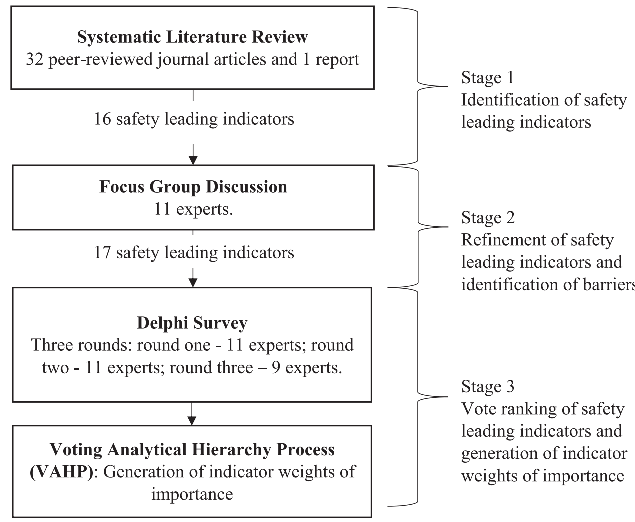

Fig. 1. Overview of the research process.

3.1.2. Focus group discussion

The 16 safety indicators and their sub-indicators from the literature were taken forward into expert focus group discussion. The purpose was to ascertain the comprehensiveness of the 16 indicators identified from the literature review and to identify the barriers to using leading indicators in construction safety management. Focus group discussion is a data collection method that reveals the respondents' thoughts and perceptions on the topic of interest (Fortune et al., 2013). The focus group discussions primarily involved brainstorming exercises aimed at getting information about participants' experiences, feelings and opinions about the research topic. The discussions were recorded by notetaking on open-ended feedback forms as recommended by Fortune et al., (2013). Additional characteristics of the session are provided in Table 1.

Purposive sampling was employed in selecting the participants. They were selected based on their managerial roles (i.e., health and safety management) and the work nature of their organization in the construction industry (i.e., institutional and professional bodies, client, contractor and consultancy/designer). Invitation letters were sent by email to the selected participants, and 11 people replied with the interest to join the group. The profile of the participants was summarized in Table 2.

The focus group discussion began with a presentation of the 16 indicators and associated sub-indicators by the first author. Participants were then organized into two groups, and each group was led by two researchers who took turns to ask questions and make notes. The key

Table 1
Primary characteristics of the preparation focus group discussion.

Primary characteristic	Requirements in literature	Applied characteristic
Purpose	To get information about how participants feel and think about the topic of interest (Fortune et al., 2013)	Brainstorming to examine the 16 safety leading indicators and their sub-indicators
Composition	Multiple groups, each with different participants; same structured agenda (Fortune et al., 2013)	All the participants were in safety management roles in their organizations. Participants were organized into 2 groups
Expertise	Minimum of five years of experience (Hallowell and Gambatese, 2010)	The minimum experience of the participants was 5 years
Number of participants	Six to 12 experts are recommended (Fortune et al., 2013; Hennink, 2014)	11 experts were engaged in the focus group discussion
Data collection	Discussions are recorded and coded (Fortune et al., 2013)	Discussions were recorded via notetaking on open-ended forms.

Table 2
Preparation focus group discussion participants.

Organization	Managerial role	Number of Participants
Institutional body	Division Lead H&S Inspector	2
Professional body	Chair	1
Real Estate Developer 1	Health, Safety and Environment Business Partner	1
Real Estate Developer 2	Principal Estates and Facilities Health and Safety Manager	1
Infrastructure Client 1	Performance and Systems Manager	1
Project Management Consultancy	Project Director	1
Design Consultancy	Principal Consultant and CDM Principal Designer Manager	1
Contractor 1	Head of Safety, Health and Environment	1
Contractor 2	Safety, Health, Environment and Quality (SHEQ) Director	1
	Head of Health and Safety	1
Sum		11

questions discussed were:

1) What safety indicators is your organization currently using?
2) How are the safety indicators measured?
3) What are the barriers to implementing safety leading indicators to improve safety performance?

Following the focus group discussion, some participants shared organizational documents about safety leading indicators and measurements. Field notes and documents helped refine the list of safety leading indicators. Particularly, 'well-being' was found as a safety leading indicator commonly used by several organizations and thus added to the original 16 main indicators. An interpretative and thematic approach were used to analyze the focus group discussion (cf. Dubois and Gadde, 2002).

3.1.3. Delphi survey

The 17 safety leading indicators and their sub-indicators that emerged from the systematic literature review and the expert focus group discussion were applied in a Delphi survey. The Delphi technique is a systematic and interactive approach to obtaining judgment on a specific topic by an independent panel of experts, allowing the researcher to retain significant control over biases (Hallowell and Gambatese, 2010). Table 3 illustrates the main characteristics of the Delphi method as applied in this study.

The first two rounds of the Delphi study involved the same 11 experts as those joining the focus group discussion (see Table 2). In the last round, two participants could not join the Delphi study (i.e., H&S inspector of Institutional Body and SHEQ director of Contractor 2). The Delphi study involved three rounds of Delphi questionnaire combined with feedback as suggested by Hallowell and Gambatese (2010). In the first round, the questionnaires requested the experts to rank the 17 leading indicators in order of priority based on their level of importance to the safety performance in the construction industry. Likewise, the experts were required to rank the sub-indicators within each indicator. The median ranks from round one of the 17 indicators and their sub-indicators were included in the round two questionnaires. To achieve group consensus, the variability of the responses was decreased by requesting the experts to review their round one responses in addition to the computed median ranks before ranking the indicators a second time. At the end of the third round, there was consensus among the experts regarding the ranking of the 17 main indicators as well as the ranking of sub-indicators for some of the main indicators. There was no consensus in the rankings of the sub-indicators of seven main indicators: 'Principal Designer and Designer Engagement indicator'; 'Principal Contractor Engagement indicator'; 'Supply Chain and Workforce Engagement indicator'; 'Plan for Safety indicator'; 'Hazard Identification and Control indicator'; 'Site Communication'; and 'Wellbeing indicator'.

Table 3
Delphi method design considerations.

Primary characteristics	Requirements in literature	Applied characteristics
Expertise	The experts must have specialized knowledge and experience evidenced by working experience, professional qualifications and relevant publications (Ameyaw et al., 2016; Hallowell and Gambatese, 2010). They should be willing to participate in the Delphi, with sufficient time and have excellent communication skills (Adler and Ziglio, 1996 as cited in Skulmoski et al., 2007)	Participants were construction professionals in roles that were related to H&S management. The minimum working experience was 5 years. Participation was voluntary.
Iterations	Two to six. The results are more accurate after two rounds (Ameyaw et al., 2016). Three rounds with the first being a preliminary round to identify factors (Hallowell and Gambatese, 2010)	Three rounds - a preliminary round was not required as the 17 safety leading indicators had been identified from literature and through expert focus group discussions prior to this.
Number of participants	A range from eight to 20 (Ameyaw et al., 2016; Hallowell and Gambatese, 2010; Skulmoski et al., 2007)	11 participants in the first and second rounds, and nine in the third.
Feedback	Feedback is measured using the mean or median (Ameyaw et al., 2016; Hallowell and Gambatese, 2010; Skulmoski et al., 2007)	Since the 17 indicators were ranked on an ordinal scale, median rankings were used in the Delphi questionnaires.
Measure of consensus	The main tools for measuring consensus are: Deviation, Kendall's coefficient of concordance (W) and Chi-square (χ^2) (Asah-Kissiedu et al., 2021). Standard deviation or absolute deviation (Ameyaw et al., 2016)	Kendall's coefficient of concordance (W) was used because of the ordinal data from the ranked responses. Saturation was determined using the Wilcoxon signed-rank test (Z)

Accordingly, a check for saturation to determine whether a subsequent round was needed (Skulmoski et al., 2007; Manu et al., 2019) was undertaken using Wilcoxon signed-rank test (Asah-Kissiedu et al., 2021) with the aid of IBM SPSS Statistics version 23. The test showed that saturation had been attained as there was no significant difference between the round three ranking and the round two ranking of the sub-indicators of those seven main indicators. As a result, there was no need for a subsequent round.

3.1.4. Voting analytical hierarchy process (VAHP)

Liu & Hai (2005) presented VAHP as an advancement to the Analytical Hierarchy Process (AHP) proposed by Saaty (1980), which only focused on paired comparison. VAHP utilizes a voting ranking approach to rank a set of criteria and sub-criteria in a hierarchical structure based on their weights (Soltanifar and Lofti, 2011). VAHP notably offers its use when the criteria are many (Hadi- Vencheh and Niazi- Motlagh, 2011). Thus, it was deemed appropriate in determining the relative weight of importance of the 17 safety leading indicators and their respective sub-indicators. The process followed six steps provided by Liu & Hai (2005) as detailed as follows.

The first step involved the selection of criteria. The 17 indicators constituted the criteria in this case. The hierarchy of the criteria was then structured in the second step. The respective sub-indicators within the 17 main indicator groups constituted the sub-criteria. However, since 'safety design', 'safety learning', 'recognition and reward' and 'competence' did not have sub-indicators, they formed a category of their own. Prioritizing the order of criteria and sub-criteria was step four, which was achieved by the round three Delphi survey where the experts ranked the 17 indicators and their respective sub-indicators in order of priority. The weights of the 17 indicators and the sub-indicators were then computed using the Hadi- Vencheh & Niazi- Motlagh (2011) equation (Eq. (1)) for determining criteria provided below as step five.

$$w_1 \geq 2w_2 \geq \cdots \geq Sw_s \geq 0 \quad (1)$$

$$\sum_{s=1}^{S} w_s = 1$$

where the coefficient of weight (w) was applied to the vote ranking of each criterion and sub-criterion to evaluate their priority weights, S was the number of positions. Therefore, w_s implies the coefficient of weight for the sth position. That is the coefficient of weight for the first position, second, until the seventeenth position as shown in Table 4. The obtained coefficient of weights was then applied in ranking the data obtained in the third round of the Delphi survey to obtain the weights of the 17 safety leading indicators and the weights of the sub-indicators under each main indicator.

The final step constituted the calculation of global (that is, overall) weight of the sub-indicators to identify their priorities. This was attained by multiplying the normalized weight of the criterion (i.e., main indicator) by the normalized weight of the corresponding sub-criterion (i.e., sub-indicators in this case) as presented in the finding section.

4. Findings

This section will present the findings of the focus group discussion, Delphi and the VAHP.

4.1. Current implementation of safety leading indicators in construction

The 16 leading indicators identified in the literature review were presented in the focus group discussion to gather participants' views on how safety leading indicators were used in their organizations and organizational barriers to effectively implementing safety leading indicators in construction.

The understanding of safety leading indicators was largely aligned between academia and industry. It was recognized that different from lagging indicators, leading indicators need to identify and feedback both the strengths and weaknesses of safety management processes and practices. All participants agreed that the 16 indicators identified in the literature were important to providing early warnings of declining performance and driving proactive actions to prevent incidents and injuries. Despite this, organizations showed different levels of maturity in terms of using safety leading indicators in practice. Specifically, Real Estate Developer 1, Project Management Consultancy and Design Consultancy executed some safety management practices similar to leading indicators, such as senior leadership tours to demonstrate the organization commitment. But they did not have formal systems and procedures to consistently monitor and measure them. Real Estate Developer 2 structured the H&S management systems and processes based on ISO 45001, an international standard for H&S at work. Some proactive measures were used such as using worker surveys to evaluate H&S culture. In terms of performance measurements, Real Estate Developer 2 still replied on lagging indicators.

Infrastructure Client, Contractor 1 and Contractor 2 had their own list of leading indicators to diagnose the safety management process, as shown in Table 5. Contractor 1 and 2 primarily focused on the quantity of conducts, for example, whether the inductions were conducted with subcontractors and the number of project safety, health and environment (SHE) inspections undertaken every month. Nevertheless, Contractor 1 tended to stress the role of safety leading indicators in driving performance improvement. They measured 'Hazard identification and control' based on the number of sites that were scored as poor performance in safety inspections, instead of counting the number of safety inspections conducted. This approach could help identify areas that need more attention, design local measures and link the measures to performance. Contractor 1 also developed sub-indicators to reflect different dimensions of indicators, for example, 'organization commitment' indicator involving 'director engagement', 'leading SHE', 'learning from high potential events' and 'fatigue management plans'.

Apart from quantitative measurements, Infrastructure Client 1 designed scorecards to capture the qualitative aspect of indicators. The scoring was based on the number of activities and whether these activities were conducted in accordance with the organization's

Table 4
Coefficient weights.

Number of criteria/sub-criteria (positions)	Coefficient (w_s)
2	$w_1 = 0.6667$
	$w_2 = 0.3333$
3	$w_1 = 0.5455$
	$w_2 = 0.2727$
	$w_3 = 0.1818$
6	$w_1 = 0.4082$
	$w_2 = 0.2041$
	$w_3 = 0.1361$
	$w_4 = 0.1020$
	$w_5 = 0.0816$
	$w_6 = 0.0680$
17	$w_1 = 0.2907$
	$w_2 = 0.1454$
	$w_3 = 0.0969$
	$w_4 = 0.0727$
	$w_5 = 0.0581$
	$w_6 = 0.0485$
	$w_7 = 0.0415$
	$w_8 = 0.0363$
	$w_9 = 0.0323$
	$w_{10} = 0.0291$
	$w_{11} = 0.0264$
	$w_{12} = 0.0242$
	$w_{13} = 0.0224$
	$w_{14} = 0.0208$
	$w_{15} = 0.0194$
	$w_{16} = 0.0182$
	$w_{17} = 0.0171$

Table 5
Safety leading indicator and measurements in practice.

Safety leading indicators in the literature	Safety leading Indicator measurements in practice		
	Infrastructure client 1	Contractor 1	Contractor 2
Organization commitment	Scored as 0–3 based on the number and the quality of senior leadership engagement tours Quality requirement A: At least 1 engagement tour to be completed in conjunction with both Project Manager and main working contractors' H&S Lead. Quality requirement B: Each active worksite needs to be included at least once per period, including engagements with construction operatives.	*Director engagement* No. of directors completed safety tours each year No. of directors completed health tours each year *Leading SHE* No. of directors trained *Fatigue management plans* No. of plans completed and outstanding every month	No. of leadership tours No. of SHE inspections
Safety auditing			
Training and orientation	Scored as 0–3 based on whether the training is conducted with the suitable roles and on time, whether records are in place for supply chain members, and whether occupational health training is in place.	No. of completed introduction to Contractor 1′s organizational culture every month No. of completed introduction to SHE in Contractor 1 every month No. of completed mental health training every month	No. of direct employee inductions No. of supervisor inductions
Client engagement	*Project manager tours with main working contractors' H&S lead* Scored as 0–3 based on the number and the quality of activities *Readiness reviews by program managers* Scored as 0–3 based on whether the review is conducted on time and whether the workforce is engaged in the process		
Principal designer and designer engagement	*Designer engagement with construction teams to address design risks, get feedback on the buildability of the design and learn from the visit to prevent H&S incidents through better design* Scored based on the number of activities and quality of feedback to construction teams		
Principal contractor engagement	*Principal contractor senior leadership engagement tours with Infrastructure client 1 project manager and main working contractors' H&S lead* Scored as 0–3 based on the number and the quality of activities		
Supply chain and workforce engagement	*Supply chain senior leadership engagement tours with Infrastructure client 1 project manager and main working contractors' H&S lead* Scored as 0–3 based on the number and the quality of activities	No. of contracts with repeat reds* over previous 6 months	No. of subcontractor SHE inspections No. of subcontractor inductions
Safety design			
Plan for safety	*Highlighting planned focus inspection in the risk review meeting of the upcoming period* Scored as 0–3 based on whether the risk-based plan is in place, whether the inspections are carried out and closed out on time, and whether the plan improves working practices	No. of sites that have a technical risk management plans No. of sites that receive verifications every 3 months	
Hazard identification and control	*Occupational health and safety inspections* Scored as 0–3 based on the number and quality of inspection and the number of feedback to site teams	No. of sites that are scored 4 reds* or more every 3 months No. of sites that are scored 8 ambers* or more every 3 months No. of actions closed out from previous scored inspections	No. of project SHE inspections undertaken by site managers or supervisors
Safety learning	*Serious incident reporting and investigation* Scored as 0–3 based on the speed of reporting, completing lessons learned and communicating results to site teams *Organizational HSW improvement plan: measures to be introduced following performance review* Scored as 0–3 based on the rate of improvement plan achieved within the timescale and whether the measures are embedded in HSW management	*Learning from high potential events (Part of organization commitment)* No. of high potential events every month Percentage of events learned and actioned, in-progress, outstanding and overdue every month	Sum of learning events
Recognition and reward		No. of contracts that achieved gold status of health maturity every month No. of contracts that achieved bronze status of resource efficiency every month	
Site communication	Scored as 0–3 based on the number and the quality of pre-work briefing. The quality of briefing is reviewed by the workers		Subcontractor and others briefed
Safety climate			

(*continued on next page*)

Table 5 (*continued*)

Safety leading indicators in the literature	Safety leading Indicator measurements in practice		
	Infrastructure client 1	Contractor 1	Contractor 2
		Part of wider organization culture surveys	
Worker involvement	*Observation reporting*, scored as 0–3 based on the number of reports, quality of feedback to site teams and learning sessions in the program		No. of VOICE issues raised No. of VOICE issues closed
Competence			Skill cards (direct)Skill cards (other)
*Contractor 1 scored inspection result as green, amber and red (performance ranked from good to bad)			

requirements. For example, the organization required the senior leadership engagement activities to be completed in conjunction with both project manager and main working contractors' H&S lead and include construction operatives. The evaluation considered the number of engagement activities in the period and to what extent the activities met the two requirements. The overall score, ranging from 0 to 3, indicated that whether the practice meets or exceeds health, safety and wellbeing (HSW) expectations, and whether it demonstrates transformational HSW.

Well-being emerged as a safety leading indicator in the focus group discussion. As Table 5 shows, Infrastructure Client 1 and Contractor 1 included elements of health and well-being in their lists of safety leading indicators, such as health inspection and fatigue management. Well-being referred to the physical and mental health of the office and site workers, including ill-health due to the work conditions, fatigue, stress and depression due to overwork, abnormal work shifts, work-away-from-home, alcohol and drug use. Fatigue and mental health were found to lead to safety incidents at work. The health and well-being programs to improve well-being were recognized by institutions and organizations as an emerging approach to break the plateau of safety performance and achieve further improvement. For example, the UK Health and Safety Executive (HSE) has targeted construction health with various campaigns.

Table 6 presents the 17 leading indicators and sub-indicators resulted from the systematic literature review and the focus group discussion.

4.2. Implementation barriers

The barriers to effectively implementing safety leading indicators in construction can be categorized as operational, organizational and strategic. It was found that the challenges of operating safety leading indicators in practices have resulted from organizational and strategic issues that concern how safety management is related to other parts of construction organizations and the business model of the firms.

4.2.1. Operational barriers

It was found that the selection of appropriate indicators and the complexity of measurements hindered the use of leading indicators in operations. Quantitative measurements were widely used and indeed preferred by some construction organizations as they are easy to understand and manage. For example, safety leading indicators were measured by the number of senior management site tours, pre-work briefings and safety observation reports in a specific period. However, the shortcoming of the quantitative measures was commonly recognized by participants; accounting for the quantity of conducts could drive tick-box behavior that does not help learning and improvement. It also encouraged over-reporting especially when the quantitative measurements were linked to performance assessment. Quantitative measurements suggested a narrow understanding of safety performance. To promote proactive actions, leading indicators need to reflect the quality of safety management practices at individual, project and organizational levels. The multidimensions and qualitative aspects of the indicators were considered by Infrastructure Client 1 and Contractor 1. Another operational barrier was that construction organizations typically selected safety leading indicators that were easy to collect and quantify. It was not sure which indicators to be introduced, whether the use of leading indicators could reduce the injury and incident rates, and how the quantitative measurements could drive further actions to improve performance, rather than induce more bureaucratic measures. Participants also mentioned that the implementation of safety leading indicators with appropriate measurements could promote a positive safety culture in construction organizations and projects. It could nurture habits and routines in construction practices that sustain safe behavior. Given these considerations, Contractor 1 and Infrastructure Client 1 used measurements to identify weak signals of poor performance (e.g., hazard identification and control was measured as the number of sites that were flagged as red or amber in inspections) and to indicate the cultural effects of safety leading indicators (e.g., whether safety learning induced transformational practices and whether these practices were embedded in wider organizations). Yet these are the exceptional examples; most participant organizations still chose and measured safety leading indicators based on the convenience.

4.2.2. Organizational barriers

Organizational learning was recognized as a critical part of implementing safety leading indicators, which was currently lacking in construction organizations.

> *So, whilst we've got better, we still have incidents that are quite similar, or can have similar root causes to previous events, and that's because we haven't fully embedded the learning. We might have embedded that learning on one site or on one project. But taking that learning and putting it on another site, or across a whole sector, or across a whole business, it's a lot more difficult.* (Contractor 1).

Most participants reported that their organizations had a safety reporting system as well as an information management system that gathered project experiences from managers and workers. However, the discussion indicated that the current systems could not support safety learning across projects and business units. For the safety management systems were largely separated from other organizational systems, for example, as an additional performance goal to profits. Moreover, there was a lack of resources to produce generic knowledge from numerous reports and case studies. As a consequence, incidents were managed in a case-by-case way. It was difficult to share and embed good practices beyond the local projects.

However, positive trends were found in the focus group discussion. Contractor 1 included learning from high potential events as part of the leadership performance, promoting senior managers to identify behavioral and procedural learning in site tours and transfer knowledge to contract and business-wide. It was also mentioned that learning means

Table 6
17 construction safety leading indicators.

Safety leading indicator	Description	Sub-indicator	Description
1. Organization commitment	Construction organizations' (e.g., client, designer, contractor, or subcontractor) commitment to safety	1.1 Structure and process integration	Safety management is integrated into business strategies and with other functions
		1.2 Safety resource investment	Provision of sufficient resources and budget for safety management
		1.3 Senior management engagement	Senior management is engaged in safety-related activities.
2. Safety auditing	The process of collecting independent information on the efficiency, effectiveness and reliability of the safety management system and drawing up plans for preventive actions.	2.1 Auditing process	The process of collecting independent information on the efficiency, effectiveness and reliability of the system
		2.2 Preventive actions	The process of drawing up plans for preventive actions
3. Training and orientation	Improving skills, knowledge, attitudes and experiences of managers, supervisors and workers to effectively manage safety	3.1 Training process	The process of conducting training
		3.2 Training engagement	Management and operatives are engaged in training and orientation activities
4. Client engagement	Client is engaged in construction safety throughout a project.	4.1 Engagement with designers	Client proactively engages with designer for construction safety throughout a project
		4.2 Engagement with contractors	Client proactively engages with contractors for construction safety throughout a project
		4.3 Client leadership	Client takes the responsibility for construction safety throughout a project
5. Principal designer and designer engagement	Principal designer and other designers (including designers of temporary works) is engaged in construction safety throughout a project.	5.1 Engagement with client	Designer proactively engages with client for construction safety throughout a project
		5.2 Engagement with contractors	Designer proactively engages with contractors for construction safety throughout a project
6. Principal contractor engagement	Principal contractor is engaged in construction safety throughout a project.	6.1 Engagement with client	Principal contractor proactively engages with client for construction safety throughout a project
		6.2 Engagement with designers	Principal contractor proactively engages with designers for construction safety throughout a project
		6.3 Engagement with supply chains	Principal contractor proactively engages with subcontractors and suppliers for construction safety throughout a project
7. Supply chain and workforce engagement	Subcontractors, suppliers and self-employed workers are engaged in construction safety throughout a project.	7.1 Engagement with principal contractors	Subcontractors, suppliers and self-employed workers proactively engage with main contractors for construction safety throughout a project
		7.2 Supply chain and workforce involvement	Subcontractors, suppliers and self-employed workers are proactively involved in construction safety throughout a project
8. Safety design	Preventing accidents during construction is regarded as one of the objectives of design.	N/A	N/A
9. Plan for safety	Safety in construction is considered in the planning process, including both preconstruction planning and short-term planning.	9.1 Safety plans	Safety plans are included in project plans
		9.2 Risk assessment and method statement (RAMS)	The process of reviewing the activities associated with a construction process and identifying potential hazardous exposures that may lead to an injury before a job starts
10. Hazard identification and control	The process and outcome of identifying and controlling hazards and risks in workplace.	10.1 Hazard Identification	The process of identifying both existing and potential hazards on a worksite, through safety monitoring, formal and informal inspections.
		10.2 Hazard Control	The process of controlling or eliminating hazards on a worksite
11. Safety learning	Learning from accidents, incidents and relevant experiences.	N/A	N/A
12. Recognition and reward	Mechanisms to motivate workforce to comply with safety rules and actively participate in safety improvement activities	N/A	N/A
13. Site communication	Familiarizing operatives with a job, informing risks and improving task-specific competence to prevent accidents	13.1 Communication process	The process of familiarizing operatives with a job, informing risks and improving task-specific competence to prevent accidents
		13.2 Communication engagement	The level of engagement in site communication activities
14. Safety climate	Employees' and workers' perception of the priority an organization and workgroup placed on safety-related policies, procedures and practices.	14.1 Perceived management commitment	Employees' and workers' perception of management commitment
		14.2 Perceived supervisor safety response	Employees' and workers' perception of supervisor's safety attitudes and behavior
		14.3 Perceived co-worker safety response	Employees' and workers' perception of co-worker's safety attitudes and behavior
		14.4 Perceived client safety commitment	Employees' and workers' perception of client commitment
		14.5 Perceived principal contractor safety commitment	Employees' and workers' perception of principal contractor commitment

(*continued on next page*)

Table 6 (*continued*)

Safety leading indicator	Description	Sub-indicator	Description
15. Worker involvement	Workers' level of involvement in establishing, operating, evaluating, and improving safety practices.	15.1 Compliance	Extent of compliance/non-compliance to safety requirements
		15.2 Participation	Extent of workforce proactive involvement to improve safety
16. Competence	Ensuring that employees and workers have the skills, knowledge, attitudes and experience to safely carry out assigned tasks.	N/A	N/A
17. Well-being	Employees' and workers' well-being, including physical and mental health	17.1 Occupational health	Employees' and workers' work-related physical health
		17.2 Mental health	Employees' and workers' mental health, including fatigue and stress due to workload, alcohol and drug issues

active changes in systems and behaviors, in addition to increasing awareness. To reach the highest score for worker involvement, Infrastructure Client 1 looked into not only the number of observation reports from site teams but also feedback to site teams and learning sessions for main contractor teams in the program.

Safety in design was raised as an area that, if improved, can significantly enhance safety in construction. This highlighted the important role of designers. Nevertheless, it was mentioned that designers lacked the awareness and capability to consider construction safety issues. Institutional bodies strongly stressed the important role of BIM to aid safety management in construction. However, it was reported that the level of collaboration between the principal designer and contractors was low. BIM has been grafted onto existing ways of working. Therefore, it is not surprising that BIM was seen primarily as a tool for design and technical information demonstration and processing and not a potential forum for improving H&S collaboratively among different stakeholders. Client engagement and commitment was also stressed in the discussion, especially by the participants from contractor organizations. Clients currently have largely static procurement practices for qualification and tender, which did not provide sufficient resources to drive improvements in supply chains. There is minimal investment and commitment to project planning.

4.2.3. Strategic barriers

One challenge of deploying safety leading indicators in construction firms was the ambiguity and uncertainty of the effects of using leading indicators. Participants commented that to evaluate the effectiveness needs well-designed systems, procedures and measures for outcomes, which requires investment and can lead to increased operational costs in the short term. It also takes time for the new practice to take effect. However, it was widely agreed that the competitive bidding process drives construction firms to keep investment and expenditure low in order to secure contracts. Contractors tended to prioritize short-term efficiency and were reluctant to invest beyond the minimum requirement. Consequently, the use of safety leading indicators could be inconsistent, subjective to other organizational goals.

Participants also agreed that safety leading indicators ought to drive practices beyond legal compliance toward safety engagement of workers as well as supply chain members. For example, Infrastructure Client 1 noted in their safety leading indicator guideline that the focus of leading indicator measurements should be promoting proactive and preventive actions, such as the extent to which the principal designer was engaged with construction teams, rather than checking the level of adherence to legal requirements. Safety culture, leadership and trust were regarded as essential to worker engagement. In other words, the successful implementation of safety leading indicators needs strategic investment in organizational systems to not only structure the process but also nurture a positive culture to sustain the engagement behavior. Moreover, construction projects involve multiple organizations and the safety performance depends on the collaborative efforts of all stakeholders. However, for many client organizations, construction project development is only part of the business portfolio and they lack the incentives to invest in construction safety beyond legal requirements. The lack of investment in supply chains was repeatedly raised in the discussion. The current practices to ensure safety performance in tier-two contractors and those further below the supply chain mainly focused on procurement, checking the insurance, and auditing the safety management system of supply chains. Clients and main contractors imposed the safety policies and procedures onto supply chain members without concerning about the potential interruptions to the operations. Few participants mentioned the provision of support for developing supply chain capability.

4.3. The relative importance of safety leading indicators in construction

The 17 safety leading indicators in construction identified in the literature review and the group discussion (Table 6) were presented and explained to the participants, before indicators and sub-indicators were ranked. Table 7 below provides the rankings of the indicators and their respective sub-indicators as per the VAHP results. 'Organization commitment' was the highest-ranked safety leading indicator; accounting for 21.79 per cent of the weights of the 17 indicators. This implies that, at the firm level, the senior management of the client, designers, principal contractors as well as subcontractors, should be committed to safety. 'Client engagement', 'principal contractor engagement' and 'principal designer and designer engagement' were regarded to be the second, third and fourth most important indicators, respectively. Collectively, these three formed 32.43 per cent of the total weight of the main indicators and they relate to key stakeholders' engagement to ensure construction H&S at the project level. 'Recognition and reward' formed 1.64 per cent of the weights and was regarded as the least important indicator, followed by 'well-being'. Taking a further look at the relative importance of the sub-indicators within each main indicator reveals that although the main leading indicators might be important, the different sub-indicators within the main indicator have varying levels of importance as well. For instance, under the main indicator 'organization commitment', 'senior management engagement' was regarded as the most important, followed by 'structure and process integration' and then followed by 'safety resource investment'.

Table 8 below provides the overall ranking of the sub-indicators in order of priority. This global ranking specified the significance of each sub-indicator in comparison to the other 36 sub-indicators- including four of the main indicators that did not have sub-indicators (that is, 'safety design', 'safety learning', 'recognition and reward' and 'competence'). Based on the global weights, the top ten most important sub-indicators, accounting for 48.57 % of the global weights for all the 36 sub-indicators (including four of the main indicators that did not have sub-indicators) were: 1st) senior management engagement; 2nd) client leadership; 3rd) structure and process integration; 4th) safety resource investment; 5th) competence; 6th) client engagement with designers; 6th) client engagement with contractors; 8th) principal designer and designers engagement with contractors; 9th) principal designer and designers engagement with client and; 10th) principal contractor engagement with designers.

5. Discussion

This research explored how construction organizations and projects can implement safety leading indicators from three perspectives, the current implementation of safety leading indicators in construction, the implementation barriers and the relative importance of safety leading indicators. The findings were reported. This section synergizes the empirical findings and discusses strategies that can help the implementation of safety leading indicators in construction.

The organizational maturity varied among construction organizations in terms of implementing safety leading indicators. Understanding the relative importance of indicators to safety management performance is thus helpful for integrating safety leading leadings into construction practices, especially to less matured organizations. The finding highlighted the importance of organizational commitment, project stakeholder engagement, training and safety climate. Despite the importance, operational, organizational and strategic barriers were identified that deter the use of key leading indicators in construction organizations and projects. In line with Oswald et al. (2018), the research found that the current way of selecting and measuring safety leading indicators do not help learning and improvement. It reflects a reactive approach to managing safety, that is to comply with policies and procedures (Dekker et al., 2007; Hollnagel, 2014). This counteracts the purpose of using leading indicators to drive proactive actions. The dominant use of quantitative measurements results in a narrowed understanding of safety. For example, most organizations used the number of senior leadership tours to demonstrate organization commitment to safety. While senior management engagement is critical, the research found that the integration of safety management with other functions is another aspect of organization commitment. Senior management engagement and systems integration ensure organizations allocating sufficient and consistent resources for managing safety issues across projects. Organization commitment means that safety management should be treated as part of organizational capabilities to increase competitiveness, rather than an operational issue in response to legal compliance.

Nevertheless, the findings revealed that the transactional business model of construction firms hindered the capability development as necessary for transforming practices. The transactional business model emphasizes cash flow management and the return on capital employed (ROCE), encouraging the management of contractors to use trade credit, delay payment and invest surplus working capital to earn interest (Smyth, 2021). The resulting practices of securing work at low margins, pursuing low operational costs and prioritizing short-term commercial interests lead to the inability of the companies to introduce new practices and effectively manage H&S beyond the minimum requirement.

To enable strategic investment in the growth of organizational capability and competence, a transformational business model is needed. In fact, an adequate return on investment (ROI) can be yielded from investments made in people, organizational and technical capabilities and knowledge, hence the incremental development of human and social capital. Human capital represents the knowledge, skills and capabilities of individuals (Coleman, 1988). Nurturing human capital needs knowledge management systems (KMS) and organizational learning. Focusing on safety-related learning, Duryan et al. (2020) found that knowledge management systems help identify the gap between H&S practices and procedures, capture and transfer the local knowledge across projects and organizations. This process could increase individual competence and organizational capability to prevent H&S incidents. Yet both KMS and organizational learning were found to be lacking in construction, largely due to the separation of safety from other management systems in firms and the fragmentation of construction projects.

Systems integration is thus needed between functions as well as between organizations and along the supply chains. This points to the significance of relationship management in construction (Xu and Wu, 2022). Social capital entails networks of relationships that include norms, values and obligations (Coleman, 1988). Relationship management help systems integration through nurturing relational norms such as trust and respect between hierarchies, functions and organizations (Smyth and Edkins, 2007). Additionally, longer-term senior management horizons that consider the survival and growth of the firm are necessary for incremental transforming practices in construction (Smyth, 2021). Zhang and McDermott (2017) found that H&S outcomes were not connected to senior managers' performance evaluation in some construction organizations. To incentivize senior management engagement, the compensation at senior management level could tie with their organization's safety performance.

Previous research has predominantly focused on the effectiveness of static safety rules and procedures, such as pre-task safety meetings and safety inspections (e.g., Lingard et al., 2017; Salas and Hallowell, 2016; Versteeg et al., 2019). The findings of this research demonstrated that the dynamic interactions between proactive project stakeholders and the influence of safety climate was perceived as more salient to safety management. Also, it was found that the lack of organizational learning limited the implementation of safety leading indicators. These findings are in line with the view that people are organizational assets and their knowledge contribute to reproducing, refining and transforming rules (Dekker et al., 2007; Hollnagel, 2014). Safety leading indicators can be used as means for organizational learning. The process of measuring safety leading indicators, such as the engagement of safety training, provides opportunities for regular dialogue with frontline operatives and engages them in the decision-making. To achieve this, however, requires bottom-up activities that empower the workforce and supply chains to share their knowledge and experiences, get involved in the decision making and recreate practices that fit the operational context (Xu and Wu, 2022). Moreover, the effectiveness of organizational activities depends on the organizational culture and workgroup climate (Cheung and Zhang, 2020), which needs management process of caring to nurture a sense of security and trust (Xu and Wu, 2022).

Last but not least, transforming safety management practices needs the engagement of the whole construction ecosystems, particularly public-sector clients and designers. The current procurement systems do not include investment in supply chain capability development to manage substantial and required measure. Public-sector clients need to buy into the transformation process, which in turn can lead to better value outcomes in terms of meeting policy and societal needs (Smyth, 2021). Manu et al. (2019) examined designers' capabilities to prevent safety incidents through better designs and pointed to the need to develop design staff's competence and integrate construction safety into designer's organizational strategy. This study further argues that to achieve prevention through design requires collaboration between designers and main contractors to feedback knowledge about how design is realized and influences construction H&S. These findings demonstrate the need for more proactive and capable clients, designers and contractors to strategically and collaboratively lead the construction safety throughout the project life cycle.

6. Conclusion

Safety management in the construction industry historically relied on top-down regulations, policies and procedures to control organizational and individual behavior. Recently, more proactive management approaches have been promoted, which values human knowledge, interactions and systems thinking in safety management. Safety leading indicators form part of the evolution to the new paradigm. This paper explored what and how safety leading indicators can be implemented to improve safety management in the construction industry. The three-round Delphi surveys and VAHP process identified the key safety leading indicators, which are organization commitment; client, designer and contractor engagement; training and orientation; safety climate and competence. Furthermore, the focus group discussion revealed the

Table 7
VAHP results by indicator grouping.

Indicators/ sub-indicators Code	Indicators/sub-indicators	Weight	Normalized Weight	Rank within group
	Indicators			
1	Organization Commitment	2.3427	0.2179	1
2	Safety Auditing	0.3739	0.0348	11
3	Training and Orientation	0.5948	0.0553	5
4	Client Engagement	1.7298	0.1609	2
5	Principal Designer and Designer Engagement	0.7946	0.0739	4
6	Principal Contractor Engagement	0.9626	0.0895	3
7	Supply Chain and Workforce Engagement	0.5022	0.0467	8
8	*Safety Design	0.323	0.03	12
9	Plan for Safety	0.4249	0.0395	9
10	Hazard Identification and Control	0.3176	0.0295	14
11	*Safety Learning	0.3215	0.0299	13
12	*Recognition and Reward	0.1764	0.0164	17
13	Site Communication	0.2326	0.0216	15
14	Safety Climate	0.5449	0.0507	6
15	Worker Involvement	0.38	0.0353	10
16	*Competence	0.5348	0.0497	7
17	Wellbeing	0.1971	0.0183	16
1	Organization Commitment Sub-indicators			
1.1	Structure and Process Integration	3.2727	0.3077	2
1.2	Safety Resource Investment	2.4544	0.2308	3
1.3	Senior Management Engagement	4.9095	0.4616	1
2	Safety Auditing Sub-Indicators			
2.1	Auditing Process	3.3331	0.3703	2
2.2	Preventive Action	5.6669	0.6297	1
3	Training and Orientation Sub-Indicators			
3.1	Training Process	4.3333	0.4193	2
3.2	Training Engagement	6.0003	0.5807	1
4	Client Engagement Sub-Indicators			
4.1	Engagement with Designers	2.6362	0.2589	2
4.2	Engagement with Contractors	2.6362	0.2589	2
4.3	Client Leadership	4.9095	0.4822	1
5	Principal Designer & Designer Engagement Sub-Indicators			
5.1	Engagement with Client	5.3335	0.4706	2
5.2	Engagement with Contractors	6.0003	0.5294	1
6	Principal Contractor Engagement Sub-Indicators			
6.1	Engagement with Client	4.273	0.3197	2
6.2	Engagement with Designers	4.9095	0.3674	1
6.3	Engagement with Supply Chains	4.1821	0.3129	3
7	Supply Chain and Workforce Engagement Sub-Indicators			
7.1	Engagement with Principal Contractors	6.0003	0.5455	1
7.2	Supply Chain and Workforce Involvement	5.0001	0.4545	2
9	Plan for Safety Sub-Indicators			
9.1	Safety Plans	4.3333	0.4815	2
9.2	Risk Assessment and Method Statement (RAMS)	4.6667	0.5185	1
10	Hazard Identification and Control Sub-Indicators			
10.1	Hazard Identification	5.3335	0.5333	1
10.2	Hazard Control	4.6667	0.4667	2
13	Site Communication Sub-Indicators			
13.1	Communication Process	4.3333	0.4333	2
13.2	Communication Engagement	5.6669	0.5667	1
14	Safety Climate Sub-Indicators			
14.1	Perceived Management Commitment	3.4697	0.3093	1
14.2	Perceived Supervisor Safety Response	1.3402	0.1195	4
14.3	Perceived Co-Worker Safety Response	0.8231	0.0734	5
14.4	Perceived Client Safety Commitment	2.2927	0.2044	3
14.5	Perceived Principal Contractor Safety Commitment	2.5853	0.2304	2
14.6	Perceived Error Management	0.7075	0.0631	6
15	Workforce Involvement Sub-Indicators			
15.1	Compliance	3.3331	0.3703	2
15.2	Participation	5.6669	0.6297	1
17	Well-being Sub-Indicators			
17.1	Occupational Health	5.6669	0.5152	1
17.2	Mental Health	5.3335	0.4848	2

Notes:* These indicators have no sub-indicators.

current implementation of safety leading indicators in construction. Positive trends were found that some organizations started to move beyond quantitative measurements to capture the multidimension, quality and effectiveness of safety leading indicators in practices. The research also identified operational, organizational and strategic barriers to the effective implementation of safety leading indicators. Lastly, the study suggested strategies for addressing the barriers and moving toward a proactive safety management approach.

This study contributes to construction safety management by linking safety management with strategic issues at firm and project levels. Safety management has been commonly discussed as an operational issue in construction. This study paid greater attention to organizational and strategic factors that deal with the root causes of poor performance. The deployment of safety leading indicators and the transformation to proactive approaches requires a transformational business model that prioritizes investment in people and capabilities and nurtures a positive organizational culture and workgroup climate to encourage bottom-up communication and learning. Safety needs to be integrated with other management systems to enable organizational learning and thus to drive proactive actions by measuring safety leading indicators. It also needs the engagement of clients, designers and supply chains to develop stakeholder capabilities to drive improvements from the project front end to completion. The responsible senior management leadership, integrated systems and enhanced human and social capital ensure organizational commitment and behavioral consistency beyond compliance.

This study also has implications to safety management practices. Construction organizations have various levels of maturity in terms of

Table 8
VAHP results of global ranking of indicators.

Indicators/sub-indicators Code	Indicators/sub-indicators	Global weight	Global rank
1.3	Senior Management Engagement	0.1006	1
4.3	Client Leadership	0.0776	2
1.1	Structure and Process Integration	0.0670	3
1.2	Safety Resource Investment	0.0503	4
16	*Competence	0.0497	5
4.1	Client Engagement with Designers	0.0417	6
4.2	Client Engagement with Contractors	0.0417	6
5.2	Principal Designer & Designer Engagement with Contractors	0.0391	8
5.1	Principal Designer & Designer Engagement with Client	0.0348	9
6.2	Principal Contractor Engagement with Designers	0.0329	10
3.2	Training Engagement	0.0321	11
8	*Safety Design	0.0300	12
11	*Safety Learning	0.0299	13
6.1	Principal Contractor Engagement with Client	0.0286	14
6.3	Principal Contractor Engagement with Supply Chains	0.0280	15
7.1	Supply Chain and Workforce Engagement with Principal Contractors	0.0255	16
3.1	Training Process	0.0232	17
15.2	Participation	0.0222	18
2.2	Preventive Action	0.0219	19
7.2	Supply Chain and Workforce Involvement	0.0212	20
9.2	Risk Assessment and Method Statement (RAMS)	0.0205	21
9.1	Safety Plans	0.0190	22
12	*Recognition and Reward	0.0164	23
10.1	Hazard Identification	0.0157	24
14.1	Perceived Management Commitment	0.0157	24
10.2	Hazard Control	0.0138	26
15.1	Compliance	0.0131	27
2.1	Auditing Process	0.0129	28
13.2	Communication Engagement	0.0122	29
14.5	Perceived Principal Contractor Safety Commitment	0.0117	30
14.4	Perceived Client Safety Commitment	0.0104	31
13.1	Communication Process	0.0094	32
17.1	Occupational Health	0.0094	32
17.2	Mental Health	0.0089	34
14.2	Perceived Supervisor Safety Response	0.0061	35
14.3	Perceived Co-Worker Safety Response	0.0037	36
14.6	Perceived Error Management	0.0032	37

Notes:* These indicators have no sub-indicators.

implementing safety leading indicators as part of the safety management program and system. The majority of construction firms, particularly tier-two contractors and those further below the supply chain, are small-and-medium-sized enterprises and have limited resources to apply new practices and ensure service consistency. Understanding the relative importance of various safety leading indicators helps guide the incremental deployment of indicators and the transformation of practices.

This research is limited in that it prioritized the relative importance of indicators based on the experience of participants. Although some indicators were regarded as less important than others at the time of survey, they could be critical to safety management and outcomes in the long term. For some indicators need time to take effect, such as well-being. Despite that well-being was recognized as a safety leading indicator in the focus group discussion, it was rated less important than other indicators. There is a need for future research to examine the impact of health and well-being interventions on safety performance. To break the safety performance plateau and drive continuous improvement, safety management should be treated as part of organizational capabilities to increase competitiveness of the firms and influence strategic decision making. It would be useful if future studies can investigate specific strategic changes needed for a healthy and safe construction industry.

CRediT authorship contribution statement

Jing Xu: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Clara Cheung:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Patrick Manu:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Obuks Ejohwomu:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Judy Too:** Writing – review & editing, Writing – original draft.

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.

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