Framework for Measuring Resilient Safety Culture in Vietnam's Construction Environment

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Abstract: Resilient safety culture is characterized by continuous improvements to safety performance and the capacity to have foresight, recognizing and anticipating the changing shape of safety risks in complex sociotechnical systems. This study aims to conceptualize resilient safety culture in the construction environment by integrating resilience engineering principles into the concept of safety culture. To fulfill this research aim, a correlational research design was used. Data were collected using questionnaire surveys targeting construction project managers involved in the delivery of 78 recently completed building projects in Vietnam. The structural equation modeling (SEM) technique with partial least-squares estimation (PLS) was used to analyze the data. The results confirmed 3 dimensions (i.e., psychological resilience, behavioral resilience, and contextual resilience) with 24 measurable scale items to assess safety culture with respect to resilience. The study also revealed that psychological resilience has a weaker impact on accident prevention under higher contextual resilience and behavioral resilience levels. Theoretically, this study provides the theoretical development and empirical evidence to clarify the concept of resilient safety culture in terms of definition, purpose, and value in the context of construction projects. In practical terms, the study suggests that project hazards, unexpected events, and the risk tolerance of construction workers should be addressed to achieve consistently high safety performance. It also offers construction organizations a framework of safety practices to assess their capabilities in managing on-site safety risks. **DOI: 10.1061/(ASCE)CO.1943-7862.0001602.** *© 2018 American Society of Civil Engineers.*

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Introduction

In Vietnam, the annual number of injured workers and accidents at workplaces across all industries have shown an increasing trend in recent years (Department of Work Safety 2018). In addition, in the last 5 years construction, which contributes 20%–36% of work-related injuries and 20%–38% of work-related fatalities in Vietnam, has been recognized as the most dangerous industry (Department of Work Safety 2018). Therefore, various strategies for improving construction site safety performance need to be examined.

Construction organizations have traditionally adopted a holistic safety management strategy emphasizing two types of responses, prevention and protection, to reduce employee exposure to on-site hazards (Mitropoulos et al. 2005; Feng 2013). The effectiveness of traditional safety management approaches is largely dependent on the extent to which safety risks are known or can be made known (Hollnagel 2008). In recent years, the inherent complexity in technology, work tasks, and organizational structures of construction projects has led to the changing and unforeseen shape of safety risks and poses challenges for traditional safety management approaches (Dekker 2012). As traditional approaches tend to be institutionalized through policies, plans, procedures, and processes for safety management, they are not easily and readily adaptable to the natural and inevitable changes in work being conducted and the emerging and unforeseen safety risks being encountered (Wachter and Yorio 2014).

Developing and maintaining a positive safety culture is crucial for improving the safety performance of construction organizations (Fang and Wu 2013; Feng 2015). Safety culture aims to create a self-sustaining environment based on a comprehensive understanding of the causes of workplace safety performance or lack thereof (DeJoy 2005). A safety culture built upon traditional approaches helps an organization to improve safety performance by preventing the regular safety risks, which occur often enough to develop a standard response.

A resilience engineering approach has been recognized as a potential solution to the lack of effectiveness of traditional safety management and safety culture approaches in responding to the changing and unforeseen safety risks associated with the increasingly complex nature of sociotechnical systems (Pęciłło 2016). Proponents of resilience engineering recognize that many adverse events cannot be attributed to a breakdown or malfunctioning of components and normal system functions but must rather be understood as the result of unexpected combinations of normal performance variability (Hollnagel 2011). Accordingly, an accident does not represent a failure of systems in dealing with risks but rather implies that systems fail in adaptions necessary to cope with real-world complexity (Woods 2010). A resilience engineering approach proposes to develop an organization's capability to enable foresight and recognize and anticipate the changing shape of risks before adverse events occur (Woods and Hollnagel 2006).

To address the limitation of safety management and safety culture approaches in responding to the changing and unforeseen shape of safety risks, Akselsson et al. (2009) and Trinh et al. (2018) have discussed the notion of resilient safety culture and

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its application to the construction industry. Akselsson et al. (2009, p. 4) defined resilient safety culture as "an organizational culture that fosters safe practices for improved safety in an ultra-safe organization striving for cost-effective safety management by stressing resilience engineering, organizational learning and continuous improvements." In a recent publication, Trinh et al. (2018) defined resilient safety culture as an organization's psychological/cognitive, behavioral, and managerial/contextual capabilities to "anticipate, monitor, respond and learn" to manage safety risks and create an ultrasafe organization. Shirali et al. (2016) attempted to measure resilient safety culture in a petrochemical plant and identified 13 indicators representing a resilient safety culture. These indicators enable practitioners to identify inefficiencies in relating to their safety management. Although previous research made significant contributions in introducing resilience into workplace health and safety and developing the concept of resilient safety culture, it seems that no empirical research has been conducted to examine the dimensions of a resilient safety culture, which has been recognized as a multidimensional concept (Trinh et al. 2018). Against this background, this research aims to conceptualize resilient safety culture by integrating resilience engineering principles into the concept of safety culture in the context of the construction industry. To achieve the aim of this article, the following specific objectives were developed: (1) to identify the dimensions of a resilient safety culture and (2) to investigate the impacts of a resilient safety culture and its dimensions on the safety performance of construction projects.

The next section presents the theoretical basis for conceptualizing resilient safety culture, followed by the development of hypotheses and a conceptual model. The conceptual model is then tested with survey data using structural equation modeling (SEM) methods. The findings pertaining to the two objectives are then discussed to clarify the contribution to knowledge and practical implications. The article ends with a discussion of limitations and recommendations for future research.

Theoretical Foundation

Safety Culture Theory

Safety culture is often treated as a subset of organizational culture, where beliefs and values refer specifically to matters of health and safety (Clarke 1999). The most widely accepted definition of safety culture was proposed in the Safety of Nuclear Installations Report: "The safety culture of an organisation is the product of individual and group values, attitudes perceptions, competencies and patterns of behavior that determine the commitment to and the style and proficiency of an organisation's health and safety management characterized by communications founded on mutual trust, shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures" (ACSNI 1993, p. 23).

To explain the concept of safety culture, many studies have attempted to develop a theoretical model of safety culture. There are two commonly used models of safety culture, which include (1) layer models (Guldenmund 2000; Reason 1997) and (2) triad models (Cooper 2000; Geller 1994). Layer models describe safety culture with the assumption that if the content of organizational culture is understood, it allows for analyzing and improving safety aspects of culture. However, layer models of safety culture are often criticized for lacking the means to objectively assess safety culture and disregarding the dynamic nature of culture (Choudhry et al. 2007; Cooper 2000). In contrast, triad models of safety culture focus on the interaction between psychological, behavioral, and situational elements in safety management (Cooper 2000; Geller 1994). The theoretical foundations for triad models of safety culture are (1) the presence of an interactive relationship between psychological, situational, and behavioral factors, which is recognized in various accident causation models, and (2) social learning theory (Bandura and McClelland 1977) and social cognitive theory (Bandura 1986). Based on the aforementioned theoretical foundations, Geller (1994) proposed a total safety culture model that recognizes the dynamic and interactive association between person, environment, and behavior. Cooper (2000) also developed a reciprocal model of safety culture that contains three elements: internal psychological factors (how people feel), safety-related behaviors (what people do), and objective situational features (what the organization has). Hence, triad models of safety culture provide a framework that could be used to measure and examine the reciprocal interactions between psychological, behavioral, and contextual safety-related factors in different settings.

Resilience Engineering Theory

The review by Righi et al. (2015) reveals that a considerable number of definitions of resilience exist in the literature. The common understandings within definitions of the term *resilience* are as follows: (1) resilience is an ability or the capability of an organization to "adapt/react, learn and anticipate" to withstand changes, pressures, disruptions, and so forth and to continue performing in times of adversity; (2) resilience is a property of organizations; and (3) the development of organizational resilience is a continuing process (Pęciłło 2016; Woods and Hollnagel 2006).

Organizational resilience is a multidimensional concept (Akgün and Keskin 2014; Lengnick-Hall et al. 2011). A review of the literature by Pillay et al. (2010) identified the three dimensions of organizational resilience, which include cognitive resilience, behavioral resilience, and contextual resilience. Cognitive resilience is a capability that enables an organization to interpret and analyze unfamiliar situations and figure out how to respond; behavioral resilience comprises the established routines that enable an organization to learn and implement new routines and fully use its resources; and contextual resilience comprises interpersonal connections, resource stocks, and supply lines that provide the foundation for quick actions under uncertain settings that pose potential risks to organizations (Lengnick-Hall et al. 2011).

Westrum (2006) identified three types of safety risk (i.e., regular threats, irregular threats, and unexpected threats) to the state of workplace safety that organizational resilience protects against. The fundamental idea behind resilience engineering is that, in a world of limited resources, irreducible unpredictability, and multiple conflicting goals, an organization manages safety risks proactively and creates safety via four resilience processes (or capabilities), which includes anticipating (knowing what to expect), monitoring (knowing what to look for), responding (knowing what to do), and learning (knowing what can happened) (Pęciłło 2016; Shirali et al. 2015).

Resilience engineering theory has some implications for safety management. First, because resilience engineering theory is based on four resilience processes, resilience processes (or capabilities) can serve as the theoretical basis for developing and implementing safety management practices for safety performance improvement in all workplace environments. Second, because a resilient organization is characterized by those four capabilities, the level of

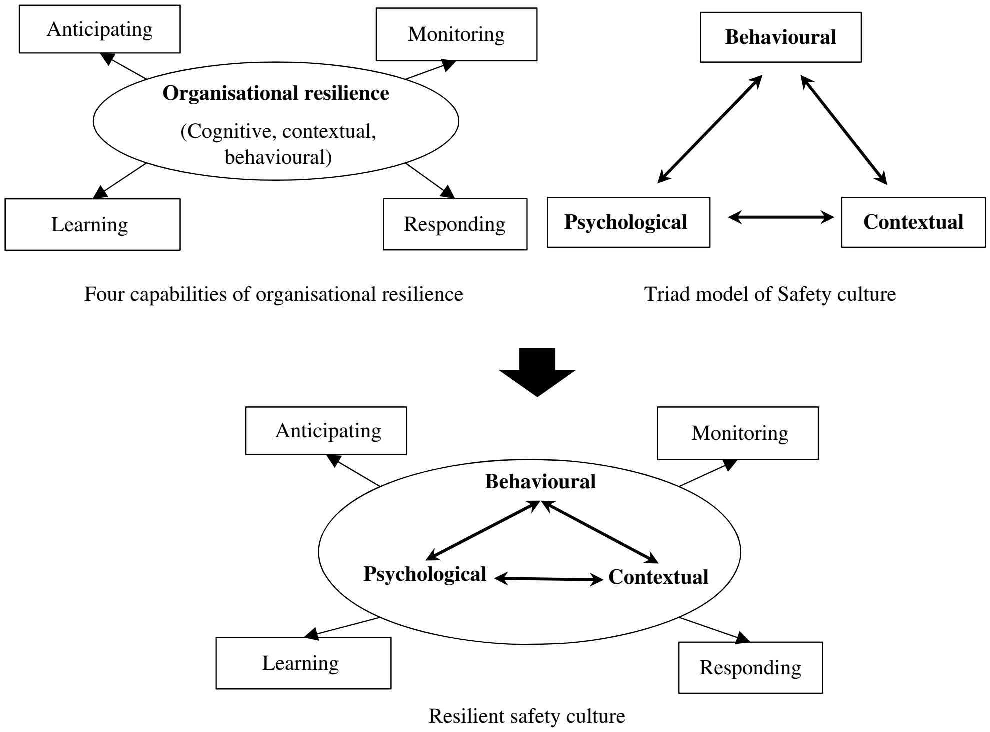

Fig. 1. Integration of resilience engineering principles and safety culture model.

organizational resilience can be determined based on the four resilience capabilities.

Hypotheses

As discussed earlier, a resilient safety culture aims to achieve consistently high safety performance, which is characterized by continuous improvements in safety performance and the capability to create foresight, recognizing and anticipating the changing shape of safety risks in complex sociotechnical systems. A comparison of safety culture dimensions and organizational resilience dimensions reveals a similar structure of both concepts (i.e., psychological/cognitive, behavioral, and managerial/contextual). In addition, resilience engineering theory enhances the concept of organizational safety culture by proposing four processes (i.e., anticipating, monitoring, responding, and learning) for safety management. Fig. 1 describes the integration of resilience engineering principles and safety culture models for conceptualizing a resilient safety culture. As shown in Fig. 1, a resilient safety culture reflects an organization's psychological, behavioral, and contextual capabilities to anticipate, monitor, respond, and learn in order to manage safety risks.

It is therefore inferred that the concept of resilient safety culture can be measured and examined under the same framework (i.e., psychological, behavioral, and contextual). The following hypotheses are set out:

Hypothesis 1: Resilient safety culture is measured by psychological resilience (PR), behavioral resilience (BR), and contextual resilience (MR).

- H1.1: Psychological resilience has a positive impact on resilient safety culture.
- H1.2: Behavioral resilience has a positive impact on resilient safety culture.
- H1.3: Contextual resilience has a positive impact on resilient safety culture.

Hypothesis 2: Resilient safety culture and its dimensions have a positive impact on safety performance.

- H2.1: Resilient safety culture has a positive impact on safety performance.
- H2.2: Psychological resilience has a positive impact on safety performance.
- H2.3: Contextual resilience has a positive impact on safety performance.
- H2.4: Behavioral resilience has a positive impact on safety performance.

Hypothesis 3: Safety performance is impacted by the interactions among psychological resilience, behavioral resilience, and contextual resilience.

- H3.1: Safety performance is impacted by the interaction between psychological resilience and contextual resilience.
- H3.2: Safety performance is impacted by the interaction between behavioral resilience and contextual resilience.
- H3.3: Safety performance is impacted by the interaction between behavioral resilience and psychological resilience.

Fig. 2 depicts the research hypotheses proposed in this study.

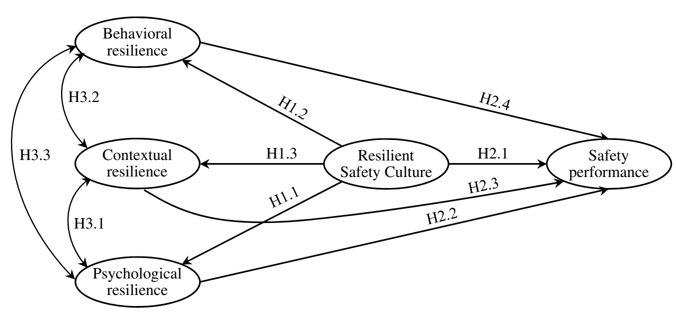

Fig. 2. Research hypotheses ($*p < 0.01$).

Research Methodology

Design

The objectives of this study indicate that this is a correlational research study, which seeks to discover or establish the existence of a relationship/association/interdependence between two or more aspects of a situation (Fellows and Liu 2015). This study adopted a quantitative approach to test the relationships between variables.

Data Collection Instrument

Resilient Safety Culture

A questionnaire survey was used to collect data regarding resilient safety culture because it offered the best opportunity to capture cross-sectional data on contextual, psychological, and behavioral safety-related factors in a timely and efficient manner (Chen and Jin 2013; McDonald et al. 2000). Based on a literature review, the concept of resilient safety culture can be explained by three dimensions: psychological resilience, contextual resilience, and behavioral resilience. In addition, because a resilient organization manages safety risks (i.e., regular threats, irregular threats, and unexpected events) via its four capabilities (i.e., anticipating, monitoring, responding, and learning), each dimension of a resilient safety culture can be evaluated using measurable scales, which are actual safety practices implemented at construction sites reflecting the following four resilience capabilities (Pęciłło 2016; Shirali et al. 2015):

- Anticipating: the capability of a construction project to identify the potential threats to the state of safety that should be prevented or avoided;
- Monitoring: the capability of a construction project to check the predefined indicators of regular threats to see whether they change and whether they require a readiness to respond;
- Responding: the capability of a construction project to respond to the regular and irregular threats by implementing a full and a ready set of responses or by adjusting normal functions;
- Learning: the capability of a construction project to take lessons from experiences, in particular how to learn useful lessons from the experiences of success and failure.

Based on previous studies (Azadeh et al. 2015; Pęciłło 2016; Shirali et al. 2013, 2015, 2016), 41 measurable scales for the three dimensions of resilient safety culture were developed. Psychological resilience was measured with 14 measurable scales, contextual resilience was measured with 14 measurable scales, and behavioral resilience was measured with 13 measurable scales.

Safety Performance

There are two types of measuring safety performance in construction projects: reactive measures (following an accident event) and proactive measures (before an accident event). The choice of safety performance measures or indicators depends on the purpose of the measurements and the resources available. In this study, a reactive measure of safety performance (i.e., accident rate) was chosen because (1) the objective and design of this research indicate that the accident rate enables a comparison of safety performance among construction projects and (2) reporting an accident is required by law in Vietnam, and records of injuries and accidents are available for all completed construction projects in Vietnam. Accordingly, to measure safety performance, the formula for calculating the recordable incident rate (IR) (Jaselskis et al. 1996) is given as follows:

$$\text{IR} = \frac{\text{Number of OSHA recordable cases} \times 200000}{\text{Number of employee labor hours worked}}$$

In the formula, the 200,000 employee hours worked reflects a 100-person crew working 40 h/week for 50 weeks.

Instrument

To validate the survey instrument and to determine how representative the items for a particular construct are, a content validity approach was adopted (Cooper and Emory 1995). The content validity of the instrument was theoretically supported because (1) the dimensions and their contents were derived from a comprehensive literature review and (2) multiple indicators and measurement scales that tap all of the parts of the definition were developed. The content validity and reliability of the instrument were further assured by a pilot study. In the pilot study, preliminary questionnaires were sent to six experts via email. The experts selected for the pilot study were experienced construction professionals involved in the site management of construction projects in Vietnam, which is consistent with the population in the actual data collection process. The six experts were recruited from the researchers' professional networks. It was noted that all the experts had more than 10 years' working experience in Vietnam's construction industry. The experts were required to read the questionnaire carefully and provide their feedback regarding (1) the comprehensibility and clarity of instructions, wording, questions, and statements; (2) the appropriateness of the questions to the context of the Vietnamese construction industry; (3) any other questions that might be added to the questionnaire; (4) the possibility of providing information pertaining to the questions; and (5) the time needed to complete the questionnaire. The main comments included, for example, revising some vague questions, reducing the length of the questionnaire, and explaining some terms. The questionnaire was then amended and finalized based on the experts' feedback.

The final questionnaire included four parts. The first part consisted of questions about the general characteristics of the construction project (e.g., location, duration, year of completion, total man-days worked for the project, project grade) and respondents (i.e., educational background, work experience). The second part required respondents to provide information about the safety performance of their project, as measured by the recordable IR. The third part consisted of questions relating to safety practices to measure resilient safety culture. Based on the actual safety practices implemented in their completed construction projects, respondents were required to indicate the level of their agreement on a five-point Likert scale (from 1 = strongly disagree to 5 = strongly agree) for each of the statements found in this part. The fourth part collected the "types of project positions" with whom the respondents consulted when they were completing the questionnaire (e.g., site manager, site safety manager, site supervisor, and site safety officer).

Sample and Data Collection

The research objectives suggest a contractor's project as the unit of analysis. In Vietnam, there are two categories of construction projects, building construction (e.g., civil and industrial buildings) and civil engineering construction (e.g., roads and bridges) (Ministry of Construction 2016). Building construction and civil engineering construction involve different types of technology and production processes. The focus of this research was on building projects in Vietnam. Hence, a list of building projects registered with the construction department of the five largest cities in Vietnam (i.e., Ha Noi, Hai Phong, Da Nang, Ho Chi Minh, and Can Tho) and completed within the last 3 years was drawn up and used as the sampling frame for this study. This is because (1) Vietnam can be

Table 1. Sample characteristics

Characteristic	Frequency	Percentage
Location		
Ha Noi	8	10.3
Hai Phong	1	1.3
Da Nang	5	6.4
Ho Chi Minh	63	80.8
Can Tho	1	1.3
Type of project		
Civil building	56	71.8
Industrial building	22	28.2
Project grade		
IV	5	6.4
III	7	9.0
II	20	25.6
I	32	41.0
Extraordinary	14	17.9
Contract size		
C	11	14.1
B	21	26.9
A	36	46.2
Nationally important project	10	12.8

divided into three regions (North, Central, and South). Each region has its largest cities, including North (e.g., Ha Noi City and Hai Phong City), Central (Da Nang City), and South (e.g., Ho Chi Minh City and Can Tho City); and (2) most Vietnamese building construction projects are located in these cities. Samples were then randomly selected from the list. For all randomly selected projects, project managers were contacted via telephone or email to request their participation in the study.

Of the 438 building project managers contacted, 115 responded to the questionnaire survey, representing a response rate of 26.2%. A number of invalid and unreliable questionnaires were identified and removed due to (1) the short response duration determined by Qualtrics survey software (5 responses), (2) incompleteness (6 responses), (3) the same choice for all required questions (8 responses), and (4) inconsistency in the answers on the duration of a project and total man-days worked on the project (18 responses). After excluding the invalid questionnaires, information from 78 projects was input into a database. The characteristics of the sample projects are shown in Table 1. The data of this study were mostly collected in Ho Chi Minh City (80.8%). This may be attributable to the fact that the majority of the projects in the sampling frame were located in Ho Chi Minh City (55%), which is the largest city in Vietnam. In terms of project type, most of the projects were from the civil sector (71.8%). It was noted that the majority (81%) of the projects were reported to be completed within 12 months from the date of completing the survey. The profile of respondents (Table 2) indicates that all respondents had at least 6 years of experience in the construction industry and held a bachelor's degree.

Table 2. Respondent demographics

Characteristic	Frequency	Percentage	Cumulative percentage
Educational background			
Bachelor's degree	63	80.8	80.8
Master's degree	15	19.2	100.0
Work experience			
6–10 years	50	64.1	64.1
11–15 years	12	15.4	79.5
16–20 years	8	10.3	89.7
>20 years	8	10.3	100.0

The sufficient working experience and knowledge of the respondents and their position as project manager might enhance the validity of this research.

Data Analysis Methods

Confirmatory factor analysis (CFA) and SEM were applied to test the hypotheses. The CFA method was used to confirm the reliability and fitness of the factor structure of resilient safety culture (i.e., psychological, behavioral, and contextual resilience), and SEM was used to test (1) the causal relationship between resilient safety culture and its dimensions and safety performance and (2) the interactive impacts among the dimensions of resilient safety culture on safety performance of construction projects. The SEM method has been widely used in safety management studies as an approach to analyzing the relationships among variables (Feng et al. 2017; Mohamed 2002). There are two types of SEM: covariance-based SEM (CB-SEM) and partial least-squares SEM (PLS-SEM), also called PLS path modeling (Hair et al. 2016). The PLS-SEM approach was considered more appropriate than the CB-SEM approach for this study because (1) PLS is distribution-free and, hence, suitable for data from unknown distributions (Falk and Miller 1992); and (2) PLS does not require a large sample size (Fornell and Bookstein 1982; Hair et al. 2016). A PLS-SEM is usually analyzed in two stages. The first stage involves the assessment of the reliability and validity of the measurement model. In the second stage, the structural model is assessed by examining its explanatory power and the path coefficients.

Results

Validity and Reliability Analysis

To evaluate individual item reliability, standardized loadings were assessed using SmartPLS software. As suggested by Hair et al. (2016), indicators with low loadings (below 0.4) should always be eliminated from the construct. The items used in the model testing after removal of an inconsistent item and their individual loadings are shown in Table 3. All the loadings are above 0.4, showing that the indicator reliability was acceptable.

Convergent validity is the extent to which a measure correlates positively with alternative measures of the same construct (Hair et al. 2016). The convergent validity of measured constructs was evaluated using composite reliability scores, Cronbach's alpha, and average variance extracted (AVE) tests (Fornell and Larcker 1981). The results of the convergent validity test are reported in Table 3. The results show that all of the calculated Cronbach's alpha and composite reliability scores exceeded 0.7, and AVE scores were higher than 0.5, as suggested by Hair et al. (2016). Thus, the measurement items were appropriate for their respective constructs.

Discriminant validity refers to the extent to which a construct is truly distinct from other constructs by empirical standards. It was evaluated using an analysis of cross loadings (Chin 1998). The results of the discriminant validity test are reported in Table 4. The results show that all items loaded higher on the construct they were theoretically specified to measure when compared to other constructs in the model, demonstrating the discriminant validity of the constructs. In addition, the discriminant validity of constructs was further ascertained by comparing the square root of AVE scores and correlation coefficients between the latent constructs. The square root of the AVE of each construct should be higher than its highest correlation with any other construct (Hair et al. 2016). Accordingly, the results shown in Table 5 indicate that discriminant validity is

Table 3. Measurement model evaluation

Construct	Measurement item	Loading	Cronbach's alpha	Composite reliability	AVE
Behavioral resilience	Beh10: Listen to feedback from workers	0.815	0.890	0.914	0.605
	Beh12: Draw conclusions when any dangerous events occur	0.807			
	Beh13: In incident investigations, aim to prevent similar accidents in the future rather than blame workers for such events	0.745			
	Beh3: Conduct site inspections to check changes in work conditions (e.g., safety hazards and preventive safety measures).	0.821			
	Beh6: Pay attention to not sending people to work sites where safety risks are not clearly defined	0.81			
	Beh7: Act decisively when faced with regular and irregular safety issues	0.743			
	Beh9: React quickly to emergencies	0.695			
Contextual resilience	Man1: Analyze potential safety risks	0.839	0.930	0.943	0.674
	Man11: Implement preventive safety measures following changes to work conditions	0.759			
	Man13: Collect and distribute feedback or revisions on safety issues	0.81			
	Man2: Assess needed safety resources	0.863			
	Man4: Assess potential changes in work conditions that might present an accident risk	0.856			
	Man6: Provide up-to-date information about safety risks	0.873			
	Man7: Monitor work conditions	0.811			
	Man9: Provide safety resources related to observed hazards	0.746			
Psychological resilience	Psy10: Tendency to refuse to work when appropriate preventive and protective measures are not provided	0.813	0.925	0.938	0.628
	Psy11: Tendency to refuse to work when it is not clear how to execute the work task	0.829			
	Psy2: Awareness of negative consequences resulting from noncompliance with health and safety rules	0.753			
	Psy3: Acknowledgement of unexpected hazardous events	0.746			
	Psy4: Mindfulness of project hazards even when they are recognized and controlled with preventive measures	0.805			
	Psy5: Knowledge and procedure level for identifying potential hazards regarding work tasks	0.858			
	Psy6: Heedfulness of coworkers' activities	0.775			
	Psy7: Awareness of major safety concerns on sites.	0.856			
	Psy9: Tendency to refuse to work when hazards and safety risks related to work task are not clear	0.68			

Table 4. Analysis of cross loadings

Item	Behavioral resilience	Contextual resilience	Psychological resilience
Beh10	0.815	0.599	0.428
Beh12	0.807	0.566	0.467
Beh13	0.745	0.453	0.33
Beh3	0.821	0.63	0.534
Beh6	0.81	0.526	0.394
Beh7	0.743	0.559	0.425
Beh9	0.695	0.535	0.537
Man1	0.564	0.839	0.641
Man11	0.479	0.759	0.621
Man13	0.588	0.81	0.643
Man2	0.63	0.863	0.62
Man4	0.604	0.856	0.603
Man6	0.606	0.873	0.681
Man7	0.617	0.811	0.708
Man9	0.597	0.746	0.617
Psy10	0.487	0.639	0.813
Psy11	0.363	0.566	0.829
Psy2	0.458	0.628	0.753
Psy3	0.433	0.607	0.746
Psy4	0.513	0.678	0.805
Psy5	0.561	0.72	0.858
Psy6	0.417	0.586	0.775
Psy7	0.442	0.673	0.856
Psy9	0.428	0.442	0.68

Table 5. Comparison of square-rooted AVEs and correlation coefficient between constructs

Construct	Behavioral resilience	Contextual resilience	Psychological resilience
Behavioral resilience	0.778	—	—
Contextual resilience	0.715	0.821	—
Psychological resilience	0.578	0.783	0.792

satisfactory and that the three dimensions of resilient safety culture are different from each other.

Structural Model Analysis

Relationship between Resilient Safety Culture and Safety Performance

The relationship between resilient safety culture and safety performance was tested using SEM. The three dimensions of a resilient safety culture are the latent variables in the SEM model, whereas the measurement items of each latent variable were derived from validity and reliability analysis in the validity and reliability analysis section. To test the relationship between resilient safety culture and safety performance, the number of bootstrap samples was set to 5,000, as recommended by Hair et al. (2016). The structural model

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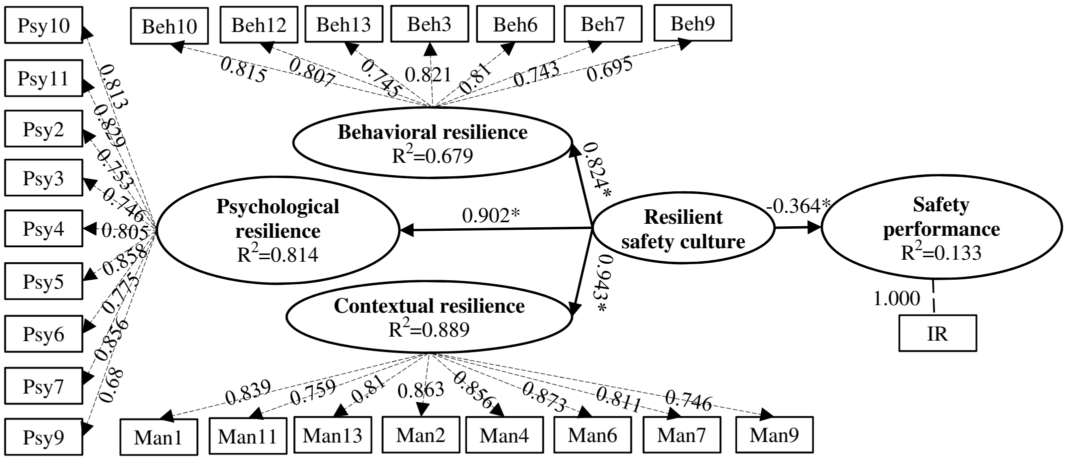

Fig. 3. Resilient safety culture and safety performance.

was assessed by examining its explanatory power and the path coefficients (Chin 1998). The path coefficients were estimated using SmartPLS software, and the model fit was assessed by the level of variance (i.e., R^2 values – squared multiple correlations explained each predicted construct) and its significance level (Hair et al. 2016). The testing result of the model is shown in Fig. 3. The result shows that resilient safety culture has a significant negative correlation with recordable IR ($\beta = -0.364$, t-value $= 3.572$, $p < 0.01$). The paths from resilient safety culture to behavioral resilience, contextual resilience, and psychological resilience are 0.824, 0.943, and 0.902, respectively ($p < 0.01$). The R^2 values for behavioral resilience, contextual resilience, psychological resilience, and safety performance are 0.679, 0.889, 0.814, and 0.133, respectively ($p < 0.05$), suggesting a satisfactory level of explanatory power of the structural model. Therefore, H1.1, H1.2, H1.3, and H2.1 are confirmed.

Relationships between Dimensions of Resilient Safety Culture and Safety Performance

The relationships between each dimension of resilient safety culture and safety performance were tested using SEM models. The results show that there are significant and negative correlations between (1) psychological resilience and IR ($\beta = -0.351$, $p < 0.01$) (Model 1 in Table 6), (2) behavioral resilience and IR ($\beta = -0.296$, $p < 0.01$) (Model 2 in Table 6), and (3) contextual resilience and IR ($\beta = -0.351$, $p < 0.01$) (Model 3 in Table 6). The results provide evidence to support Hypotheses H2.2, H2.3, and H2.4.

Moderated Effects between Different Dimensions of Resilient Safety Culture on Safety Performance

The moderated effects between dimensions of resilient safety culture on safety performance were tested using SEM models. The results show that there are significant and positive correlations between (1) Moderating Effect 1 and IR (H3.1) ($\beta = 0.282$, $p < 0.01$) (Model 4 in Table 6) and (2) Moderating Effect 3 and IR (H3.3) ($\beta = 0.268$, $p < 0.05$) (Model 6 in Table 6). However, no significant relationship was found between Moderating Effect 2 and IR (H3.2) ($\beta = 0.180$, $p > 0.05$) (Model 5 in Table 6).

The results of moderation analysis indicate that the relationship between psychological resilience and IR does not remain constant under different contextual resilience and behavioral resilience levels (Models 4 and 6 in Table 6). Fig. 4 shows the variance of the simple slope for IR on psychological resilience at different levels of contextual resilience. The three lines represent the relationships between psychological resilience (x-axis) and IR (y-axis) under different levels of contextual resilience. The middle line represents the

Table 6. Results of SEM analysis

	Hypotheses					
	H2.2	H2.3	H3.4	H3.1	H3.2	H3.3
	PR→IR	BR→IR	MR→IR	(PR*MR)→IR	(BR*MR)→IR	(PR*BR)→IR
Results	Model 1	Model 2	Model 3	Model 4: Moderating effect 1	Model 5: Moderating effect 2	Model 6: Moderating effect 3
Dependent variable	IR	IR	IR	IR	IR	IR
Independent variable	PR	BR	MR	PR	BR	PR
Moderator variable	—	—	—	MR	MR	BR
Calculation method	—	—	—	Two stage	Two stage	Two stage
Product term generation	—	—	—	Standardized	Standardized	Standardized
Coefficient	−0.351[a]	−0.296[a]	−0.351[a]	0.282[a]	0.180	0.268[b]
t value	4.183	2.857	4.105	2.900	1.312	2.118
R^2	0.124	0.087	0.123	0.244	0.174	0.240
R^2 adjusted	0.112	0.075	0.112	0.213	0.141	0.209
f^2	0.141	0.096	0.141	0.138	0.056	0.136

[a]$p < 0.01$ (two-tailed).
[b]$p < 0.05$ (two-tailed).

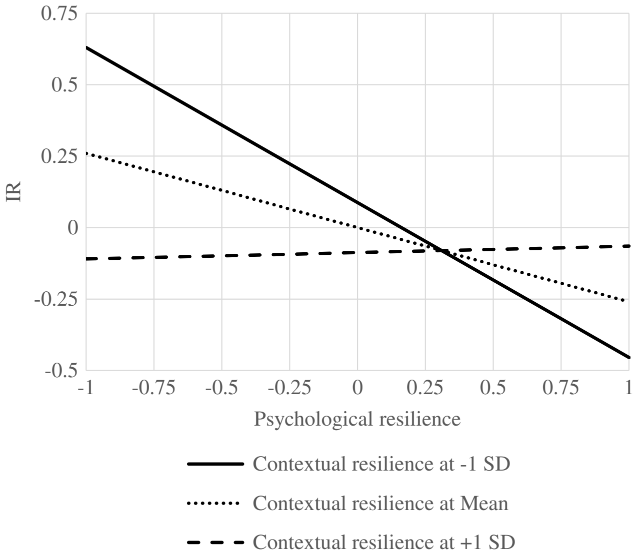

Fig. 4. Simple slope for IR on centered psychological resilience at three typical values of contextual resilience.

relationship between psychological resilience and IR when there is an average level of contextual resilience. The other two lines represent the relationships between psychological resilience and IR under higher (i.e., +1 standard deviation) and lower (i.e., −1 standard deviation) levels of contextual resilience. Thus, a higher contextual resilience level entails a weaker correlation between psychological resilience and IR. This provides empirical evidence to support Hypothesis H3.1.

Fig. 5 shows the variance of the simple slope for IR on psychological resilience at different levels of behavioral resilience. The variance of the simple slope indicates that there is a stronger relationship between psychological resilience and IR under lower behavioral resilience levels. This provides empirical evidence to support Hypothesis H3.3. The statistical results and their implications are discussed in the next section.

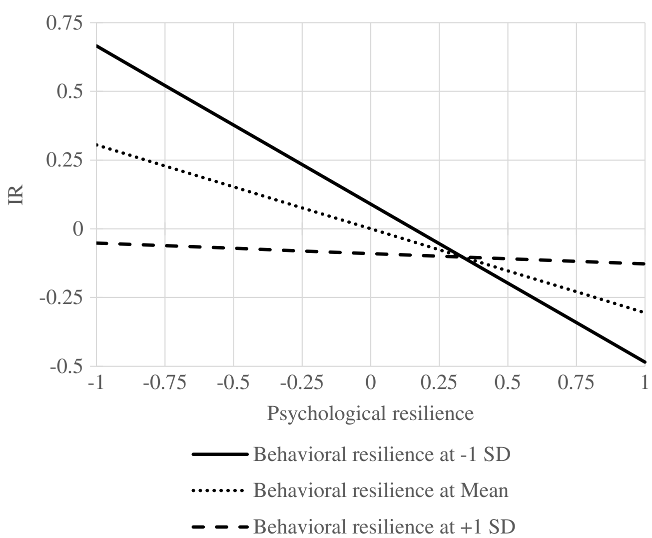

Fig. 5. Simple slope for IR on centered psychological resilience at three typical values of behavioral resilience.

Discussion

Dimensions of Resilient Safety Culture

The results of confirmatory factor analysis provide empirical support to the proposed factor structure of a resilient safety culture (Fig. 3). Accordingly, resilient safety culture is considered to be a latent construct underlying three dimensions, which are also latent and measured using different measurable scales. The dimensions behaved well in the statistical analyses carried out to check for the internal consistency reliability and convergent and discriminant validity.

Psychological Resilience

Psychological resilience was characterized by nine measurable scales: health and safety awareness (Psy2), consciousness of health and safety issues on sites (Psy7), hazard identification ability (Psy5), decision-making with respect to safety risks (i.e., Psy9, Psy10, Psy11), acknowledgement of the occurrence of unexpected hazardous events (Psy3), heedfulness of coworker activities (Psy6), and mindfulness of the changing shape of safety risks pertaining to project hazards (Psy4). These measurable scales indicated employee perceptions of safety practices, which address (1) project hazards (i.e., Psy2, Psy7, Psy5, Psy9, Psy10, Psy11) and (2) the unexpected (i.e., Psy3, Psy6, Psy4). The former finding is supported by many researchers on the importance of safety knowledge and experience, hazard recognition ability, risk perception, and decision-making with respect to safety risks and safety improvement (Choudhry and Fang 2008; Guo et al. 2012; Wilson 1989). If workers are not knowledgeable or their experience is limited, then they may be at greater risk (Choudhry and Fang 2008). Thus, it is vital to increase a person's knowledge of associated hazards and how to avoid them (Wilson 1989). Perceptions of risk are important since injured workers who are accident victims perceive risks as low and underestimate risks in some cases (Choudhry and Fang 2008). The finding of a study by Guo et al. (2012) revealed that workers' safety attitude toward risk-taking could effectively influence the rate of death related to crane/heavy plant/equipment operation. In addition, the latter of the aforementioned results can be supported by those studies (Cigularov et al. 2010; Mitropoulos et al. 2005) whose findings revealed the existence of the unexpected (i.e., human error, unpredictable hazards) and the importance of corresponding safety practices. In a model of construction accident causation, Mitropoulos et al. (2005) pointed out that, in the construction environment, there are many circumstances in which actual conditions are different than expected or resources (e.g., information, tools, material) are missing. Construction worker errors are also inevitable due to time pressures, mental pressures, fatigue, newness of a task, distractions, and overconfidence, and these also generate unpredictable hazardous situations (Cigularov et al. 2010; Mitropoulos et al. 2005).

Contextual Resilience

Contextual resilience was characterized by eight measurable scales: analysis of project hazards and risk assessment (Man1), appropriate safety plans (Man2), provision of up-to-date information on work tasks (Man6), provision of resources to achieve health and safety targets (Man9), assessment of potential changes in working conditions (Man4), monitoring changes in working conditions (Man7), rapid collection, collation, and distribution of feedback or responses on health and safety issues (Man13), and provision of preventive measures following any changes to working conditions (Man11). These measurable scales indicate a safety management system implemented by project contractors, which address (1) identified project hazards as planned (i.e., Man1, Man2, Man6, Man9) and (2) the unexpected (i.e., Man4, Man7, Man13, Man11). The former are supported by many studies (e.g., Aksorn and Hadikusumo 2008; Hinze 2002). Hinze's (2002) study revealed that safety preproject/pretask planning is one of nine specific areas that are vital for the improvement of safety performance. The relationship between information management and safety management is consistent with accident causation theory, which proposes that an increase in unpredictability in tasks and the related working conditions can generate hazardous work situations (Mitropoulos et al. 2005). The findings by Tam et al. (2004) and Aksorn and Hadikusumo (2008) indicated that sufficient resource allocation to safety has a critical effect on safety performance improvement. In addition, the latter of the aforementioned results can find support in several studies (Radujković and Burcar 2005; Zou et al. 2009), which revealed the changing shape of safety risks and their impacts associated with the unique and complex nature of construction projects. In the construction environment, safety risks can emanate from changes in legislation, effects of related authorities, adoption of nonstandard building contracts, and uncertain site conditions (Zou et al. 2009). The nature of safety risks and their impacts alter over the duration of a construction project (Radujković and Burcar 2005).

Behavioral Resilience

Behavioral resilience was characterized by seven measurable scales: conducting site inspections (Beh3), making the effort not to send people to work sites posing threats of physical or mental harm (Beh6), acting decisively in the face of health and safety issues (Beh7), reacting quickly to emergency situations (Beh9), and gathering records of safety experiences through feedback from workers and accident investigations (i.e., Beh10, Beh12, Beh13). These measurable scales indicate the behavioral safety of project site management and supervisors, which address (1) project hazards (i.e., Beh3, Beh7, Beh6) and (2) the unexpected (i.e., Beh9, Beh10, Beh12, Beh13). This finding is supported by many studies (e.g., Aksorn and Hadikusumo 2008; Fernández-Muñiz et al. 2007) that examined the role of project site management and supervisors in safety improvements.

In light of the foregoing discussion, psychological resilience, behavioral resilience, and contextual resilience constituted a framework for defining, measuring, and improving a resilient safety culture. It was found that psychological resilience could be measured through employees' perceptions of safety, contextual resilience could be measured through the implementation of a safety management system, and behavioral resilience could be measured through the behavioral safety of site management. The measurable scales of the three dimensions of a resilient safety culture indicated that, to achieve consistently high safety performance, on-site safety practices should address not only project hazards and safety risks but also unexpected events (e.g., human error and unpredictable hazardous situations).

Impacts of Resilient Safety Culture and Its Different Dimensions on Safety Performance

As anticipated in Hypothesis H2.1, the results confirmed that resilient safety culture is negatively correlated to the recordable IR of construction projects ($\beta = -0.364$, $p < 0.01$) (Fig. 3). Close examination of the causal relationships between the dimensions of resilient safety culture and IR indicated that there exist significant negative correlations between (1) psychological resilience and IR ($\beta = -0.351$, $p < 0.01$), (2) behavioral resilience and IR ($\beta = -0.296$, $p < 0.01$), and (3) contextual resilience and IR ($\beta = -0.351$, $p < 0.01$) (Table 6). This result indicates that an improvement in all aspects of the behavioral safety of project site management and supervisors, employees' perceptions of safety, and the implementation of a safety management system could produce safety performance improvement in construction projects as measured through a decreased IR value. This finding can be explained by Wachter and Yorio's (2014) study, where it was indicated that the engagement of employees on sites who come into daily contact with hazards and hazardous situations and who are at the cutting edge of accidents appear to play a role equally important to that of the specific system of safety management practices in reducing and preventing accidents. This is because employees interact necessarily with the safety management system and keep the safety management system effective (Wachter and Yorio 2014). Based on this finding, it is implied that the assessment of resilient safety culture and its dimensions could provide a basis for reliable prediction of the safety performance of construction projects.

Moderated Effects of Psychological Resilience on Safety Performance

As discussed earlier, the results of studies show that the effect of psychological resilience on recordable incident rate does not remain constant under different contextual resilience level and behavioral resilience level. Psychological resilience has a weaker impact on accident prevention under a higher level of contextual resilience and a higher level of behavioral resilience. These findings indicate that (1) for those building projects with contractors having a better safety management system, the impact of workers' perceptions of safety on accident prevention is less significant, and (2) for those building projects with site management and supervisors who engage in better behavioral safety, the impact of workers' perceptions of safety on accident prevention is less significant.

The preceding results are inconsistent with the commonly held assumption that organizational and supervisory factors have positive influences on employees' motivation and knowledge with regard to safety, thereby reducing accidents in the workplace (Fernández-Muñiz et al. 2007; Vinodkumar and Bhasi 2010; Wachter and Yorio 2014). Nonetheless, the differences between the findings of this study and earlier studies could be explained by risk compensation theory as developed by Peltzman (1975), who found that, in a safer environment, drivers tend to increase their speed rather than enjoy the increased safety associated with driving at the same speed. Risk compensation theory postulates that individuals tend to adjust their behaviors in response to perceived changes in risk. They will behave less cautiously in situations where they feel "safer" or more protected. Clearly, individuals will tend to behave more cautiously if their perception of risk or danger increases (Peltzman 1975). This theory is also supported by several researchers (Huang et al. 2013; Vernero and Montanari 2007). Huang et al.'s (2013) study found that participants with a perceived higher knowledge of ecological hazards tend to have a higher risk tolerance for those hazards than those who profess to have little to no knowledge of ecological hazards. Workers in a chemical plant were loath to wear personal protective equipment because they believed they already had an appropriate perception of risk (Vernero and Montanari 2007). The feeling of personal control over a situation can lessen anxiety and cause a worker to become more relaxed when it comes to engaging in unsafe behaviors (Weyman and Kelly 1999). In the context of this study, contextual resilience and behavioral resilience involve safety practices that provide construction workers with the information pertaining to work tasks and safety risks and appropriate preventive measures to perform their jobs safely. Therefore, when contractors have a better safety management system and site management and supervisors demonstrate better behavioral safety, workers tend to believe that they are more

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fully informed of work tasks and their related safety risks and more protected. Consequently, workers are more likely to have higher levels of risk tolerance.

Limitations and Implications for Future Research

This research has several limitations. The first limitation relates to the use of a self-reporting survey method to collect data. By adopting a survey method, this study quantitatively evaluated resilient safety culture. Nonetheless, the response biases can have a large impact on the validity of survey research. In this study, the impact of response biases was minimized by the following factors: (1) a careful selection of appropriate respondents; (2) respondents were encouraged to consult other project management staff when completing the questionnaire; (3) the data collection procedure ensured the voluntary nature of participation in the questionnaire, anonymity of respondents, and confidentiality of respondents' responses; (4) assuring the comprehensiveness and clarity of the questionnaire to avoid unintended error made by respondents through a pilot study; (5) respondents were encouraged to review and revise their responses; and (6) invalid and unreliable responses were identified and removed from the database. Moreover, the extensive working experience, high education level of the respondents, and their position as project managers could enhance the quality and reliability of the data collected. In addition, the validity of the research findings can be assured by (1) confirming the reliability and validity of constructs before performing any substantive analyses and (2) interpreting the statistical results within an extensive review of the pertinent literature.

Second, R^2 is a measure of a model's predictive power and is calculated as the squared correlation between a specific endogenous construct's actual and predicted values (Hair et al. 2016). In the analysis of the relationship between overall resilient safety culture and safety performance (Fig. 3), the R^2 for safety performance is 0.133. This result indicates that the inclusion of all three predictors (i.e., three dimensions of resilient safety culture) explained 13.3% of safety performance variance. In addition, in the analysis of the relationship between the dimensions of resilient safety culture and safety performance (Table 6), the largest R^2 for safety performance is 0.24, which was found in Moderating Effects 1 and 3. Thus, the variance in safety performance is better explained by the inclusion of the interaction between either psychological resilience and contextual resilience or psychological resilience and behavioral resilience. Nonetheless, because low R^2 values represent the relatively weak predictive power of those models, safety performance may be explained by other factors. Additionally, as discussed earlier, resilient safety culture aims to achieve consistently high safety performance by responding to the changing and unforeseen safety risks associated with the unique and complex nature of construction projects. It is acknowledged that all construction projects are unique in terms of their complex nature. However, the impact of project complexity on the safety performance of construction projects remains unclear. It is also not known whether a construction organization with a high level of resilient safety culture sustains its safety performance improvement under a changing complexity level of construction projects. Therefore, it would be worthwhile for future researchers to investigate the interactive effects of resilient safety culture and project complexity on safety performance.

The last limitation concerns the generalizability of the findings. The findings were reached based on the data collected from 78 building projects located in the 5 largest cities in Vietnam. Thus, the findings of this research should be interpreted in the context of the Vietnamese construction industry. In addition, owing to the low response rate in the construction industry, the sample size (N = 78) is not too large. Nonetheless, the use of the PLS-SEM approach and bootstrapping technique with 5,000 resamples reduced the potential problem caused by the relatively small sample size.

Conclusions

This study conceptualized resilient safety culture in the context of construction projects by integrating resilience processes into an existing safety culture model. The research confirmed 24 measurable safety practices comprising 3 dimensions (i.e., psychological resilience, behavioral resilience, and contextual resilience) to define, assess, and improve resilient safety culture. The results of this study also indicated that resilient safety culture and its dimensions have a positive impact on the safety performance of construction projects. The effect of psychological resilience on the recordable incident rate does not remain constant under different contextual resilience and behavioral resilience levels. Psychological resilience has a weaker impact on accident prevention under a higher level of contextual resilience and a higher level of behavioral resilience. The implication of the findings is that, to achieve a consistently high safety performance, project hazards, the unexpected, and the risk tolerance of construction workers should be addressed. The study also provides construction organizations with a framework of safety practices to assess their capabilities to manage on-site safety risks, thereby helping decision makers to integrate appropriate safety management efforts in their portfolio.

The findings of this study may contribute to the knowledge of construction safety management by providing a theoretical development and empirical evidence to clarify the definition, purpose, and value of the concept of resilient safety culture in the context of construction projects. The innovations of this study lie in (1) developing and validating the instrument in the form of a questionnaire for measuring resilient safety culture of construction projects; (2) recognizing that employees' perception of safety, the implementation of a safety management system, and the behavioral safety of site management are three aspects for assessing and improving resilient safety culture of construction projects; (3) recognizing the role of a resilient safety culture in addressing project hazards and the unexpected for creating ultrasafe construction organizations; (4) recognizing that a resilient safety culture and its dimensions can serve as predictors of safety performance of construction projects; and (5) recognizing the settings from which the risk tolerance of construction workers could emerge when examining interactive impacts among the dimensions of resilient safety culture on the safety performance of construction projects.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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