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ORIGINAL CONTRIBUTION

Technology Readiness and Safety Outcomes in Construction: The Mediating Role of Worker Competence and Moderating Role of Top Management Support

Ishtiaq Ahmad *

Department of Business & Engineering, Universidad Isabel l, Spain

***Abstract*— Construction projects remain highly vulnerable to accidents due to dynamic workflows, hazardous environments, and limitations of conventional safety management approaches. With the growing adoption of Industry 4.0 technologies, construction organizations are increasingly investing in digital safety tools; however, their effectiveness depends on organizational readiness and workforce capability to implement them. Grounded in Socio-Technical Systems (STS) Theory, this study examines the impact of Technology Readiness (TR) on Safety Climate (SC) and Safety Performance (SP), while assessing the mediating role of Worker Competence (WC) and the moderating influence of Top Management Support (TMS). A quantitative cross-sectional survey was conducted using responses from 420 construction professionals drawn from both public (*n*=200) and private (*n*=220) sector organizations. An engineering-oriented predictive modeling approach was applied, and the model demonstrated strong predictive performance, explaining 62% of the variance in safety climate (R^2=0.62) and 58% in safety performance (R^2=0.58) with acceptable prediction error (SC: RMSE=0.41, MAE=0.32; SP: RMSE=0.45, MAE=0.35). Scenario analysis indicated that high technology readiness substantially improves predicted SC and SP, while competence improvement and strong management support generate similarly large gains in safety outcomes. Sensitivity analysis identified worker competence as the most influential predictor for both SC and SP, followed by technology readiness and top management support. Further, the sector-wise comparison revealed that private sector organizations demonstrated a stronger link between technology readiness and increases in worker competence, as well as greater improvements in safety outcomes associated with readiness, compared to public sector organizations. This suggests that private sector organizations were more effective at converting digital investments into competence and safety gains, possibly due to fewer institutional barriers or different organizational structures. The study concludes that sustainable safety improvement requires integrated strategies that enhance technology readiness, strengthen workforce competence, and reinforce leadership support to maximize the operational safety value of digital transformation in construction organizations.**

***Index Terms*— Technology readiness, Safety climate, Safety performance, Worker competence, Top management support**

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I. INTRODUCTION

The construction industry remains one of the most dangerous workplaces because it is dynamic, has temporary workforces, involves high exposure to heavy machinery, and operates in an ever-changing site environment [1]. These attributes form intricate risk paths in which unsafe actions, latent hazards, and operational uncertainties interrelate to cause accidents and near-misses [2]. Although the use of traditional safety management methods, which include compliance checks, toolbox talks, and supervision powered by rules, has been a long-standing tradition in the construction industry, most of the projects continue to record frequent safety failures, especially when the complexity involved in construction tasks is high, and the course of the schedule is stricter [3]. This fact has heightened the need for more active, technology-based safety systems that can enhance hazard detection, response speed, and the effectiveness of prevention.

As Industry 4.0 has taken hold, safety management in construction is gradually shifting toward digitally linked solutions rather than manual, reactive ones [4]. Current safety practices, developed by modern engineering, now use Building Information Modeling (BIM), the Internet of Things (IoT), wearable sensors, real-time site monitoring, robotics, and data-driven analytics to improve situational awareness and minimize exposure to hazardous environments [5]. The technologies can help safety managers and field engineers monitor high-risk operations, detect unsafe proximity incidents, generate automatic alerts, and improve consistency in safety decisions [6]. The advantages of such systems, however, do not come easily through the purchase or access to digital tools [7]. Technological investment across numerous construction organizations does not lead to the anticipated safety enhancement due to substantial variation in their willingness to adopt, implement, and operationalize technological innovations [8, 9].

Technology readiness, in this case, is also a vital organizational strength that will define the capacity to integrate digital safety innovations into routine construction activities. Technology readiness is a situational assessment of the psychological, technical, and operational preparedness of people and organizations to adopt new technologies and effectively utilize them to enhance performance outcomes [10]. A construction organization can also have access to IoT systems, safety dashboards, or BIM-based hazard visualization tools, yet the workforce is not ready to trust, learn,

*Corresponding author: Ishtiaq Ahmad
†Email: Ishtiaqarman@gmail.com

and regularly utilize them; the safety system will stay unutilized [11, 12, 8]. Technology readiness may therefore be considered an upstream engineering enabler that facilitates the effective operation of digital safety systems, thereby enhancing the safety climate and enabling measurable safety performance outcomes [13].

Available findings indicate that technology-based safety programs have the potential to enhance the safety climate, which is defined as employees' collective understanding of the organization's commitment to safety through policies, communication, top leadership actions, and the allocation of safety resources [14]. The more construction professionals view their organization as technologically progressive and active, the higher the chances of seeing digital investments in the form of smart PPE, real-time monitoring, and predictive warnings as evidence that management pays attention to the protection of the working force [15, 4, 16]. Equally, technology preparedness can be directly related to safety performance, as evidenced by improved compliance behavior, fewer unsafe acts and incidents, and increased hazard response [15]. However, these effects are not technical alone; they are based on the effectiveness of the interaction between workers and digital safety devices and on the ability to translate technological competence into safe working behaviors [17].

One of the main ways in which technology preparedness can improve safety outcomes is through workers' competence. Competence of workers encompasses knowledge, skills, and the ability to read risk information, adhere to safety measures, and apply technology-based systems in high-risk site conditions [18, 19, 20] . Digital safety technologies are part of the engineering vocabulary, meaning they are socio-technical systems that can be operated and used correctly by humans to minimize risks [21, 22]. Competence can be facilitated by technology preparedness through enhanced digital literacy, greater confidence in the use of monitoring tools, and the possibility of workers interacting with safety analytics and automated reporting systems [23]. Skilled employees are thus better placed to translate technological readiness into a greater perception of safety climate and enhanced safety behavior, which renders competence an acceptable mediating channel of the readiness-safety linkage.

Moreover, top management support plays a vital role in this equation, as it is an enabling factor that can make or break the process of translating technology readiness into workforce competence. Top management support includes leadership's dedication to implementing digital safety by allocating resources, providing training, supporting safety policies, and actively participating in the implementation of safety practices driven by innovation [24]. Although workers may show a formative willingness to technology, competency development might not be realized to its full potential unless leadership provides coordinated training, equipping, and institutional support for the new systems [25]. In turn, a high level of competence building can be accelerated by positive managerial support that endorses the use of technology as a safety measure and provides long-term organizational investment in the development of digital capabilities [26]. Consequently, top management support is expected to serve as a boundary condition that enhances the relationship between technology readiness and workers' competence [27]

Even though there is an increasing interest in the digital transformation in safety management, there are still significant gaps in the existing literature on construction safety. First, a lot of the research on construction technology and safety is devoted to the tools of adoption (e.g., BIM, IoT) without a sufficient description of the conditions of organizational readiness that predetermine the realization of the fact that these tools can enhance the climate of safety and safety outcomes [28, 29]. Second, there are very few studies that specifically test the internal transfer process in which technology readiness generates safety advantages, especially through competence-training processes among workers. Third, top management support is also commonly noted as a leadership factor, discussed as a general contextual factor, and less commonly as a moderator that alters the magnitude of readiness-to-competence pathways [30]. Lastly, there are differences in the sector. To fill these gaps, the research focuses on the role of technology readiness in safety climate and safety performance in construction organizations, and on the mediating role of worker competence and the moderating role of top management support. In addition, the paper compares public and private sector organizations using multigroup analysis to determine whether sector context affects the strength of the proposed relationships. This study is based on the Socio-Technical Systems (STS) Theory, which conceptualizes construction safety improvement as a result of the correspondence between technological readiness (technical subsystem) and competence and leadership support (social subsystem). The study is applicable to research on construction safety engineering because it integrates the notions of readiness, competence, leadership, and sector comparison within a single explanatory framework and clarifies how digital transformation generates safety value through human capability development and organizational enabling. action safety engineering because it integrates the notions of readiness, competence, leadership, and sector comparison within one explanatory framework and clarifies how digital transformation generates the safety value based on human capability development and organizational enabling.

II. LITERATURE REVIEW

Technology preparedness is an individual or organization's tendency to adopt and effectively use new technologies to achieve objectives. It reflects employees' confidence, competence, and optimism about using technological tools in their work [5]. Safety climate, in turn, is the overall perception people have of the organization's commitment to safety, as expressed through management practices, communication, and employee involvement [1]. Previous research has shown that a positive safety climate is not only dependent on managers' safety focus but also on organizational systems and tools that support safe behavior. In a company with a high technology preparedness, the company has more chances to integrate digital solutions like Building Information Modeling (BIM), Internet of Things (IoT) monitoring systems, and predictive safety analytics that enhance safety awareness and communication within the teams [3, 7]. Studies in the construction and manufacturing industries have revealed that technologically adaptive organizations exhibit a better safety culture because employees perceive safety technologies as a sign that management is concerned about their welfare [31, 2, 7].

The fact that the preparedness towards technology positively correlates with the extent of trust among employees in the digital systems and the fact that preparedness also reduces the extent of resistance to safety innovations, it can be concluded that the preparedness towards technology is playing a role in the emergence of the shared concept that safety is inherent in organizational practices [25, 8, 32]. Studies have established that firms that invest in data-driven, intelligent monitoring, data-driven wearable sensors, and data-driven safety systems demonstrate enhanced employee engagement and compliance with safety protocols [33, 5]. This sense that technology helps realize safety goals fosters greater openness, responsibility, and cross-reinforcement of safety values amongst teams [33]. This has led workers in technologically prepared organizations to view safety initiatives as achievable and credible, thereby boosting overall thinking regarding risk management and prevention [16]. Based on these empirical results, it can be hypothesized that the greater a construction company's technology readiness, the more positive its safety climate, as trust, communication, and collective responsibility for safety outcomes are facilitated [34]. Thus, technology preparedness will likely have positive effects on safety climate.

H1: Technology readiness positively influences safety climate.

Safety performance refers to the actual results and behaviors that prevent accidents and reduce workplace injuries. It is a measure of the effectiveness of safety practices, procedures, and employees' compliance in reducing hazards [2]. Safety performance in construction environments, where operations are dynamic and complex, is highly reliant on human factors and technology-based interventions [26]. Technology preparedness helps organizations to introduce and use digital solutions that simplify safety processes, automate inspection, and better identify hazards in real time [35]. Past research has shown that when employees are psychologically and technically ready to adopt innovations, they tend to adopt technologies more readily to enhance safety-related activities [24]. To illustrate, it has been established that workers with greater readiness to technology are more compliant, have better situational awareness, and have a better perception of risks, thereby lowering the chances of accidents and incidents [36].

Empirical evidence indicates that technology readiness may support the shift to the proactive stage of safety management by enabling workers to predict threats and apply digital tools to promptly identify unsafe conditions. Indicatively, in construction companies where workers are eager to adopt automated warning systems or wearable safety goggles, near misses and occupational accidents are likely to decrease significantly [37, 38]. Workers who are technologically prepared not only use protection tools more effectively but also gain confidence in online procedures, resulting in improved reporting accuracy and protocol compliance [39]. This preparedness also enhances communication efficiency, enabling safety data to be shared and acted upon as soon as possible [14]. Consequently, technology preparedness directly influences safety performance improvement by aligning human abilities with digital innovation [23]. Based on empirical studies and logical arguments, one may suggest that the higher a construction company's level of technology preparedness, the better its safety performance, due to greater competence, responsiveness, and the way safety technologies are used [40].

H2: Technology readiness positively influences safety performance.

The concept of worker competence describes the knowledge, skills, and abilities of people to effectively perform safety-related duties, make informed decisions, and communicate closely with safety technologies and protocols [41]. High technology preparedness within organizations will result in investments in training, digital literacy development, and process adjustments that increase employees' competence in working with modern safety tools and procedures [42]. This is supported by past literature suggesting that a technology-driven environment is where the focus on skill development becomes more common, enabling workers to be better qualified to detect hazards, interpret safety data, and provide timely interventions [39]. Empirical studies in construction and industrial settings demonstrated that technological readiness has an indirect positive effect on safety perception by providing employees with the knowledge needed to navigate through the digital framework without any hesitation [10, 43]. Therefore, workers' competence emerges as a key channel through which technology preparedness can be translated into a collective conviction about the organization's safety priorities.

It is indicated that effective employees are more likely to take initiative in safety communication, adhere to digital procedures, and have a positive impact on safety perceptions at the group level [38]. The competence will instill confidence and trust in digital interventions and make employees see safety technologies not as a burden but as tools that enhance protection and efficiency [44]. It is through this positive perception that cohesiveness in the overall safety climate is established, reinforcing the collective sense of security and organizational responsibility [45]. With enhanced competence through technology-enabled learning and exposure, employees deepen their entrenchment in safety values and align their attitudes with organizational safety priorities [18]. Based on this empirical evidence, we can assume that workers' competence is a mediating variable that affects the relationship between technology preparedness and safety climate; therefore, technologically prepared companies can reinforce collective safety perceptions by increasing employees' competence.

H3: Worker competence mediates the relationship between technology readiness and safety climate.

Safety performance refers to the actual performance of safe behaviors and quantifiable results, such as fewer accidents, near misses, and risky practices [46]. The competence of workers is vital for mapping organizational preparedness into active safety outcomes, as it dictates the effectiveness with which they apply their knowledge in the immediate operational environment [47]. Technology preparedness fosters a learning-based approach in which employees are exposed to automated systems, simulation-based learning, and real-time feedback, thereby enhancing their competency in performing safety tasks [44]. Previous empirical studies show that effective employees pay close attention to hazards, respond more quickly to unsafe environments, and comply with safety measures using digital aids [41, 1, 2]. These competencies directly affect safety performance by ensuring proper risk reduction and the implementation of active safety measures.

It is also proven by such empirical studies that workers who are technologically capable use digital safety tools more efficiently, including those that are based on IoT and predictive analytics dashboards, as well as those that are supported by AI and allow workers to foresee and prevent incidents [35, 25, 48]. Increased competence translates to an increase in the capacity to make decisions in times of stress, improved adherence, and uniform implementation of safety protocols in dynamic construction scenarios [26]. By so doing, technology preparedness does not suffice unless employees are competent to utilize it. Thus, the competence of workers turns out to be the most important mediating variable that will convert the technological potential into the actual safety results [12]. According to the established empirical relationships, it can be concluded that the level of technology preparedness contributes to the level of safety performance indirectly by creating competent workers capable of using modern technologies to positively contribute and increase the amount of safety at the workplace.

H4: Worker competence mediates the relationship between technology readiness and safety performance.

Top management support is the degree to which organizational leaders directly promote, invest in, and encourage the conduct of technological and safety-related projects ([10]. It includes managerial commitment, policy reinforcement, resource provision, and encouragement to adopt innovation [49]. While technology readiness indicates that employees are ready and mentally equipped to use digital systems, translating this readiness into actual competency is virtually impossible without managers' facilitation [50]. Past research in construction and industrial industries has shown that companies with strong managerial support offer formal training systems, lifelong learning opportunities, and access to advanced safety systems, which allow workers to acquire the required skills and confidence to use them [7]. Empirical research has consistently shown that leadership involvement is necessary to eliminate resistance and uncertainty and to create an innovation-driven learning environment [41].

There is also evidence that, without top management support, even technically prepared employees may not be optimally competent due to insufficient training, ambiguous policies, or a lack of motivation to use the new tools [8]. On the other hand, a leader who encourages technology adoption and promotes safety improvements will be able to get employees more willing to engage in skill development, demand clarity, and internalize digital safety measures [51]. Earlier studies have also emphasized the importance of top management support in enhancing employee motivation and accelerating capability-building processes by legitimizing technology adoption as an organizational priority [52, 53, 54]. Hence, the effect of technology preparedness on workers' competence is likely to be more pronounced in a high managerial support environment [54]. Based on these empirical findings, one may suggest that top management support positively moderates this relationship by underscoring the role of technology readiness in the development of worker competence.

H5: Top management support positively moderates the relationship between technology readiness and worker competence, such that the relationship is stronger when top management support is high.

Theoretical framework supporting the research

The theory underlying this study is Socio-Technical Systems (STS) Theory, which highlights the mutual dependence of organizational outcomes between technological infrastructure and human capabilities [28, 29]. According to STS, optimum performance is achieved when technological preparedness is well coordinated with human capability and is facilitated by organizational structures, such as leadership and safety climate. Technology readiness in a construction setting increases employees' willingness to embrace digital safety tools, but this is realised only when workers can operationalise the technologies in safety-related jobs. Previous research has confirmed that advanced technologies are associated with better safety performance and a better climate, mainly due to increased worker skills and a proactive safety policy [55]. Moreover, the mediating role of top management support aligns with the STS stream, which focuses on leadership as a structural facilitator of the successful adoption of technology-based practices [56]. When leadership actively supports technological innovation, workers are trained, inspired, and assured that their technological preparedness translates into competency, resulting in better safety performance and a stronger safety climate. Figure 1 is based on this theoretical premise and introduces technology readiness as an antecedent that has indirect effects on safety climate and safety performance, with worker competence as a mediating variable and top management support as a strengthener of the relationship between technology readiness and worker competence.

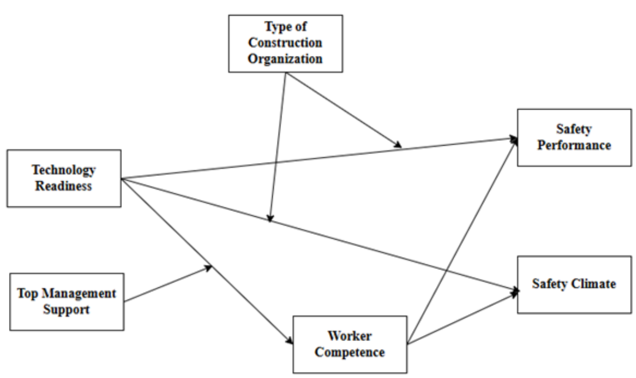

Fig. 1 *Conceptual framework*

III. RESEARCH METHODOLOGY

In this study, the research philosophy was positivism, and the research method was deductive, empirically testing the proposed socio-technical relationships among technology readiness and worker competence, safety climate, safety performance, and top management support in construction organizations. The quantitative, cross-sectional survey design was used due to its ability to systematically test hypothesis relationships and to examine large numbers of individuals in a large sample, and it is well accepted in research on engineering construction safety for testing factors related to organizational and human-technology interaction. The construction industry offers an appropriate empirical setting due to its risky work environment, extreme conditions, and increased reliance on digital safety systems, including monitoring tools, wearable devices, and data-driven safety management solutions. The individual construction professional was the unit of analysis because technology readiness, competence development, and safety-related perceptions and behaviors are experienced and acted upon at the individual level, though they are also influenced by organizational and sector-level factors. To explain institutional variation, the study included both public- and private-sector construction organizations, enabling comparisons of the proposed socio-technical relationship across sectors.

The construction professionals sampled comprised site engineers, project engineers, safety officers, supervisors, and skilled workers with first-hand experience in site operations and safety management. The primary data collection tool was a structured questionnaire, as survey techniques are effective for standardized evaluation of technology readiness, competence, leadership support, and safety outcomes in complex engineering settings. The measurement instrument was designed by modifying well-known, previously used scales in studies on construction safety and technology adoption, and the wording of items was adjusted to the specifics of construction site operational realities and digital safety applications. All constructs were measured using a Likert-type scale to assess the magnitude of respondents' perceptions. The data were screened before analysis for completeness, consistency, and outliers to ensure analytical robustness. The sampling strategy provided sufficient coverage not only of public organizations but also of private sector organizations and met the sample size criteria for the multivariate model, mediation, moderation, and comparative analysis by sector.

The analysis was performed using Python (Anaconda distribution) as the main engineering analytics environment, with appropriate statistical and computational libraries to assess reliability, perform validity testing, and estimate multivariate models. The analysis was conducted through a systematic workflow that begins by evaluating the reliability and validity of the measurement instruments, followed by testing the direct, indirect, and conditional correlations between technology readiness and safety outcomes [57]. The concept of workers' competence as an intermediate between technology readiness and safety climate, versus safety performance, was studied based on a socio-technical principle: that technology enhances safety only when human capability is sufficiently developed [58]. Effects of top management support were also tested as a moderating variable to determine whether enabling leadership reinforces the readiness-to-competence pathway [59]. Moreover, the multigroup analysis was conducted to compare the organizations of the public and private sectors, enabling evaluation of differences in the functioning of digital safety systems across contexts. This research strategy offers a scientific and engineering-applicable framework for understanding how digital preparedness is translated into better construction safety outcomes through the development of competence and organizational support.

IV. RESULTS

Table 1 presents a summary of the respondent characteristics and ensures equal representation among respondents (n=200) and the private construction industry (n=220), allowing meaningful sector-wise comparisons. The sample is largely male (88.1%), consistent with the male-dominated nature of construction activities in both industries. The majority of respondents are aged 30-39 (41.4%) and have 5-10 years of experience (39.0%), indicating that the data set is composed mostly of mid-career professionals with sufficient experience in safety systems and site operations. The distribution of roles includes the high representation of site/project engineers (39.0%), safety officers (23.3%), and supervisors/foremen (22.6%), which is significant since these three segments are the primary subjects of the implementation of technology-enabled safety systems and the enforcement of safety measures on the site, contributing to the enhanced validity of the responses to the questions concerning the readiness, competence, and safety results.

TABLE I
RESPONDENTS PROFILE AND SECTOR DISTRIBUTION (*N*=420)

Characteristics	Category	Public (*n*=200)	Private (*n*=220)	Total (*N*=420)
Gender	Male	176 (88.0%)	194 (88.2%)	370 (88.1%)
	Female	24 (12.0%)	26 (11.8%)	50 (11.9%)
Age (years)	20–29	52 (26.0%)	71 (32.3%)	123 (29.3%)
	30–39	83 (41.5%)	91 (41.4%)	174 (41.4%)
	40–49	43 (21.5%)	38 (17.3%)	81 (19.3%)
	≥ 50	22 (11.0%)	20 (9.1%)	42 (10.0%)
Experience	< 5 years	44 (22.0%)	62 (28.2%)	106 (25.2%)
	5–10 years	78 (39.0%)	86 (39.1%)	164 (39.0%)
	11–15 years	45 (22.5%)	43 (19.5%)	88 (21.0%)
	> 15 years	33 (16.5%)	29 (13.2%)	62 (14.8%)
Job Role	Site/Project Engineer	74 (37.0%)	90 (40.9%)	164 (39.0%)
	Safety Officer	46 (23.0%)	52 (23.6%)	98 (23.3%)
	Supervisor/Foreman	51 (25.5%)	44 (20.0%)	95 (22.6%)
	Skilled Workforce	29 (14.5%)	34 (15.5%)	63 (15.0%)

Table 2 shows the descriptive statistics of all constructs and shows the consistently higher mean scores in the private sector than in the public sector in all variables, showing the existence of a stronger digital and safety maturity in the construction organizations that are privately situated. The level of Technology Readiness among private firms (M=3.62) is higher than among public firms (M=3.28), indicating that private firms are better prepared to adopt and use digital safety tools. The same tendency is observed for Worker Competence (Private M=3.70 vs Public M=3.35), suggesting greater competence development and readiness to operate on private projects. The private sector also has higher Safety Climate (3.58 vs 3.22) and Safety Performance (3.55 vs 3.18), indicating that perceptions of safety and its outcomes are better in sectors where digital readiness and competence are more apparent. Interestingly, the biggest gap is witnessed in Top Management Support (Private M=3.56 vs Public M=3.10) and leadership enablement is an essential contextual merit of the private sector in maintaining technology-driven implementation of safety.

TABLE II
DESCRIPTIVE STATISTICS (LIKERT 1–5)

Construct	Sector	Mean	SD	Min	Max
Technology Readiness (TR)	Public	3.28	0.71	1.70	4.80
	Private	3.62	0.69	1.90	4.90
	Overall	3.46	0.72	1.70	4.90
Worker Competence (WC)	Public	3.35	0.66	1.90	4.80
	Private	3.70	0.61	2.00	4.90
	Overall	3.53	0.66	1.90	4.90
Safety Climate (SC)	Public	3.22	0.67	1.80	4.70
	Private	3.58	0.63	2.00	4.90
	Overall	3.41	0.67	1.80	4.90
Safety Performance (SP)	Public	3.18	0.65	1.70	4.70
	Private	3.55	0.62	1.90	4.90
	Overall	3.37	0.66	1.70	4.90
Top Management Support (TMS)	Public	3.10	0.74	1.50	4.80
	Private	3.56	0.70	1.70	4.90
	Overall	3.34	0.75	1.50	4.90

Table 3 indicate that the proposed engineering-oriented model has high predictive performance and good explanatory and predictive power for both safety outcomes. In the case of Safety Climate, the model had a reasonably small prediction error (RMSE=0.41; MAE=0.32) and a high explained variance (R^2 =0.62), indicating that technology readiness, competence, and management support are successively employed in explaining a significant range of variation in the safety climate in construction environments. Equally, in the case of Safety Performance, the model had acceptable prediction accuracy (RMSE=0.45; MAE=0.35) with high-rated explained variance (R^2=0.58), which indicates that the predictors have a significant meaning in explaining the result of safety performance in construction when the model is used as a practical decision-support model to predict construction safety performance improvements under varying levels of readiness and competence.

TABLE III
STANDARDIZED FACTOR LOADINGS

Target Variable	RMSE ↓	MAE ↓	R^2 ↑
Safety Climate (SC)	0.41	0.32	0.62
Safety Performance (SP)	0.45	0.35	0.58

Table 4 presents scenario-based forecasted results and proves that meaningful increases in the Safety Climate and Safety Performance result can be obtained through improvement in the technological readiness. The competence scenario also supports that the workforce competence improvement is a high-impact lever: workforce competence can be improved by +0.5 SD, which increases predicted safety climate and performance to 3.71 and 3.66, respectively, and does not increase these measures to 3.18 and 3.12, respectively. also supports the view that workforce competence improvement is a high-impact lever: workforce competence can be improved by +0.5 SD, which increases predicted safety climate and performance to 3.71 and 3.66, respectively, and does not increase these measures to 3.18 and 3.12, respectively. .

TABLE IV
SCENARIO COMPARISON RESULTS

Scenario	Condition	Predicted SC	Predicted SP
Scenario 1: Technology Readiness	Low TR (≤ 2.8)	3.05	3.02
	High TR (≥ 4.0)	3.78	3.72
Scenario 2: Competence Improvement	No WC improvement	3.18	3.12
	WC improved (+0.5 SD)	3.71	3.66
Scenario 3: Top Management Support	Low TMS (≤ 2.8)	3.12	3.08
	High TMS (≥ 4.0)	3.74	3.69

Table 5 shows the relative significance of the predictors and demonstrates that worker competence has the greatest effect on both safety climate and safety performance. Competence has the greatest significance, with the highest values for Safety Climate (0.41) and Safety Performance (0.44), which validates the notion that enhancing workforce skills and operational capability is the most powerful tool for improving safety. The second-best predictor (SC=0.33; SP=0.30) is technology readiness, which indicates that readiness enhances improvements in safety outcomes through the effective implementation of digital tools and safety technologies. The third-ranked support (SC=0.18; SP=0.16) is top management support, which implies that it primarily supports competence development and ongoing implementation. Control variables (age, experience, role) have weak effects (not exceeding 0.10), which again confirm that the outcomes of safety beliefs in this model are influenced by socio-technical readiness, competence, and leadership support rather than by demographic differences.

TABLE V
SENSITIVITY ANALYSIS

Predictor	Importance for SC	Rank	Importance for SP	Rank
Worker Competence (WC)	0.41	1	0.44	1
Technology Readiness (TR)	0.33	2	0.30	2
Top Management Support (TMS)	0.18	3	0.16	3
Control Variables (Age, Exp, Role)	0.08	4	0.10	4

Table 6 provides a comparison of the standardized effects of pathways by sector, and it is noted that the private sector's socio-technical conversion is more effective than the public sector's. The greatest discrepancy is in the readiness-to-competence correlation (TR->WC: Public 0.39 vs Private 0.55), indicating that the relationship between technology readiness and competence is stronger in private organizations, likely due to stronger training systems, faster implementation, and greater management flexibility. The predictive value of competence in both industries (WC→SC: 0.48 vs 0.51; WC→SP: 0.44 vs 0.50) proves its universal value. The direct impact on safety climate and safety performance is also more pronounced in private organizations (TR→SC: 0.26 vs 0.35; TR→SP: 0.21 vs 0.31), indicating that digital readiness gains yield greater benefits. In addition, the moderation effect is more pronounced in private firms (TR×TMS→WC: 0.12 vs 0.19), indicating that top management support is more effective in stimulating competence development in the private sector.

TABLE VI
SECTOR-WISE MODEL PATH COMPARISON

Relationship (Path)	Public (β)	Private (β)	Difference	Interpretation
TR → WC	0.39	0.55	+0.16	Stronger readiness-to-competence conversion in private sector
WC → SC	0.48	0.51	+0.03	Competence strongly shapes safety climate in both sectors
WC → SP	0.44	0.50	+0.06	Competence improves safety performance more in private
TR → SC	0.26	0.35	+0.09	Private sector benefits more from readiness
TR → SP	0.21	0.31	+0.10	Readiness improves safety outcomes more in private
TR×TMS → WC	0.12	0.19	+0.07	TMS moderating role stronger in private sector

V. DISCUSSION

Digital readiness gains have more benefits. In addition, this research will provide a powerful empirical foundation for the socio-technical argument, according to which safety outcomes in construction are increasingly predetermined by an organization's digital preparedness and its capacity to translate technology-facilitated potential into safe working practices. The profile of the respondents suggests that the dataset represents the important players in construction execution and safety control systems, specifically engineers on sites/projects, safety officers, and supervisors (Table

1). The validity of the findings is reinforced by this vocation structure, as these functions are the direct ones in the application of safety systems, compliance, and the coordination of hazard controls at the field level [4]. The descriptive findings also reveal a sector-based pattern: organizations in the private sector have higher readiness to technology, worker competency, safety climate, safety performance, and top management support than those in the public sector (Table 2). Regarding the engineering implementation, this implies that non-governmental organizations can have greater system readiness to implement the digital safety solutions, including mobile safety reporting, sensor-based monitoring, and data-driven hazard analysis, and governmental organizations can be constrained in their infrastructure, training practices, or consistency of implementation [21]. Notably, the identified difference between constructs shows that digital safety effectiveness cannot be considered to be an identical phenomenon in all construction systems; instead, organizational setting, maturity of readiness, and leadership facilitate safety competency.

One of the technical contributions of the study is that an engineering-based predictive framework is implemented to explain the safety climate and safety performance, and the identification of results indicates that the model has good accuracy and explanatory power (Table 3). The model accounts for 62% and 58% of the variation in safety climate (R^2 = 0.62) and safety performance (R^2 = 0.58), respectively, with small prediction errors on a scale of 1 to 5. These results indicate that preparedness, competence, and management support, when combined, create a stable analytical framework that can forecast the safety situation at construction sites [23]. The fact that the safety climate is slightly more predicted than safety performance can be explained by the engineering logic as well: climate is a set of shared perceptions highly dependent on organizational systems, methods of leadership, and visibility of technology, whereas safety performance is also affected by other sources of uncertainty related to the operations, including task complexity, environmental hazards, pressure of schedules, and intensity of exposure, which may decrease the levels of predictability [13]. However, the high predictability of both results supports the idea that digital readiness is not just an organizational concept that exists in the abstract; it functions as a system-level capability that can be measured and is capable of affecting reliability of safety, prevention behavior, and handling of hazards when incorporated into the construction operations.

The results obtained using scenarios give a more engineering insight through illustration of how safety outcomes may change with varying socio-technical settings (Table 4). The technology readiness situation indicates that increasing the readiness level from low to medium results in significant changes in the safety climate and safety performance, as predicted. This means that high-readiness environments would be better placed to operationalize technology into daily routine, thereby enhancing hazard identification and collective commitment to safety [4]. Simultaneously, the competence improvement scenario demonstrates that workers' competence improvement by +0.5 SD results in robust improvements in both outcomes, which is why it is assumed that competence is the most operational lever in the system. Safety engineering tools are not enough; there must also be appropriate human interaction, proper use of monitoring systems, and adherence to technology-assisted decision-making. Likewise, the top management support scenario shows that leadership-driven enablement is an essential control condition, and high support results in significantly improved safety outcomes compared with poor support [41]. It means that managerial interventions, including training budget allocation, ensuring device presence, implementing digital safety measures, and maintaining accountability, are necessary to maintain implementation fidelity. Thus, the scenario evidence confirms a key finding: the best safety benefits of digital safety systems occur when technology preparedness is followed by workforce skills and reinforced by leadership enablement.

The sensitivity analysis provides additional value, as the relative importance of predictors is determined, with workers' competence being the most important for safety climate and safety performance (Table 5). This is consistent with the engineering aspects of system reliability and the human-technology interface, where competence reduces operational errors, enhances compliance accuracy, and improves safety control and effective utilization. Both outcomes rank technology readiness as the second most important, indicating that readiness is a precondition that facilitates the adoption and continued use of safety technology tools [25]. The third in ranking is top management support, which means its impact is large but mainly enabling, facilitating training, enforcement, and the provision of resources that convert competence and readiness into outcomes. The insignificance of control influences (age, experience, and role) indicates that the digital transformation of safety is not driven by demographic factors, but by the design and maturity of the socio-technical safety systems. In practice, it implies that organizations will be able to enhance safety performance without basing it on the age structure of the workforce or its tenure, but rather they need to focus on competence-building interventions and readiness development that cut across roles and levels of experience [39]. This finding also adds weight to the overall implication that capability development and system integration are more effective at improving engineering safety performance than isolated compliance control systems.

Lastly, the sector-wise comparison of paths provides solid evidence that private-sector organizations better translate technology readiness into competence and safety outcomes than public-sector organizations (Table 6). The greatest discrepancy is found in the readiness-to-competence pathway, suggesting that the mechanisms for implementing readiness-to-competence may be more flexible within private organizations, their access to training resources may be more robust, and the conversion of readiness to operational capability may be accelerated. Further, the direct impacts of readiness on the safety climate and safety performance are higher in private organizations, demonstrating that the same level of readiness yields greater returns in performance in the private context [60]. Also, the moderation effect is more pronounced in the private sector, indicating that management support there has greater functional efficacy, which could be attributed to faster decision-making, a stronger system of accountability, and fewer accountability constraints. Nevertheless, competence is an effective predictor of success in both industries, providing a practical guideline for the work of governmental organizations: despite the relative deficiencies in readiness and leadership support, competence development programs can still lead to substantial improvements in the safety climate and performance. Regarding engineering, public-sector construction systems must focus on a competence enhancement system structured around digital training, the normalization of safety technology workflows, and systems to reinforce leadership to enhance the efficiency of readiness conversion. In engineering, public-sector construction systems must focus on a competence enhancement system structured around digital training, the normalization of safety technology workflows, and systems to reinforce leadership to enhance the efficiency of readiness conversion.

Implications

The results of the current research are useful operationally to construction organizations that want to improve safety outcomes by going digital. In terms of engineering, enhancing worker competence should be regarded as the most influential intervention since it turned out to be the most significant contributor to safety climate and safety performance, i.e., organizations should prioritize well-organized training initiatives aimed at teaching employees how to use digital tools, i.e. mobile reporting systems, sensor alerts, and safety dashboards, safely. Simultaneously, organizations ought to enhance technology preparedness by making systems user-friendly, accessible on the level of the location, and integrated into the daily operations (i.e. digital inspections, real-time monitoring, incident tracking), which is to be implemented as a series of technologies that are not operated by anyone. In management terms, the high impact of top management support is pointing to the leaders that they have to leave the symbolic commitment and supply viable implementation tools, such as budget to support safety technology, ongoing training of skills, regular maintenance of the digital safety equipment, and the regular adoption of safety protocols supported by technology. Furthermore, the differences in the sectors imply that organizations in the public sector need to implement specific ability-enhancing approaches to bridge the readiness competence gap, like regularized digital safety practices, require compulsory competence qualification, and system-driven implementation must address the lag in the implementation timeline, whereas organizations in the private sector need to maintain the lead by expanding competency courses and strengthening leadership-based adoption to realize optimal safety payoffs of digital investments. All these implications show that the socio-technical approach to technology-facilitated safety improvement should be a coordinated effort that involves preparedness, capacity, and managerial empowerment which will act as a dependable system of minimizing the operational risk and enhancing the construction safety performance.

VI. CONCLUSION

This paper illustrates that the digital transformation of construction safety improvement is essentially a socio-technical engineering process, in which technology readiness enhances the greatest safety performance when it is converted into workforce ability and facilitated by enabling leadership. The findings demonstrate that technology readiness has a positive impact on safety climate and safety performance, whereas competence of the workforce can be considered the most effective factor of safety improvement, which proves that safety technologies bring value only under the condition of the workforce that can successfully interpret and use it in the field. The results of the scenario based analysis also suggest that the shift in readiness between low and high, enhancing competence and reinforcing the support of the top management can significantly increase the forecasted levels of safety, indicating these variables as the safety improvement levers in practice. Also, comparisons at the sector level indicate that the readiness-to-competence conversion is stronger in private construction organizations rather than in public organizations, as well as safety returns on digital readiness, indicating that contextual constraints may also contribute to the level of efficiency of the operationalization of safety innovations. On the whole, the research demonstrates that to realize any quantifiable safety benefits, it is not only necessary to invest in digital technology, but also to develop an integrated implementation plan that would ensure the coordination of technology preparedness, development of competence, and managerial support as a single safety system.

Limitations and Future Work

The study has limitations although its contributions may be taken into consideration when the study is interpreted. First, the study employed the cross-sectional type of design, which restricts the ability to draw a strong causal conclusion and exhaustive levels of how technology preparation and adequacy improve over time during safety system delivery. The future research and studies should be longitudinal or time-lagged designs to investigate the development of readiness and competence during various phases of the projects and to test whether the positive change in readiness results in the long-term decrease in incidents and cases of unsafe behaviors. Second, the paper was based on self-reported measures, which can result in the presence of perception bias and common method variance despite the popularity of such measures in assessing the safety climate and readiness; hence, future studies need to integrate survey data with objective safety indicators near-miss logs, recordable incident rates, safety audit reports, wearable sensors data, or digital records of utilizing a reporting system. Third, although the predictive framework demonstrated a high level of explanatory power, other operational variables (such as project complexity, intensity of hazard exposure, work scheduling pressure, subcontracting structure, and technology availability) were not represented explicitly; future studies need to incorporate them into the predictive model through hybrid engineering methods, including BIM-based risk modelling, digital twin simulation, or IoT-based safety analytics, to make them more realistic and provide improved predictions. Last but not least, the greater effects of the private sector indicate that there could be institutional constraints that undermine the implementation success in the state-level organizations; the following work should focus on exploring sector-specific barriers by using mixed-method research and develop implementation roadmaps based on the specifics of the governance of the public sector, the procurement process, and the training capacity so that the digital safety transformation can offer the same benefits regardless of the construction setting.

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