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# Stakeholder perceptions of risk in construction

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ABSTRACT

Safety management in construction is an integral effort and its success requires inputs from all stakeholders across design and construction phases. Effective risk mitigation relies on the concordance of all stakeholders' risk perceptions. Many researchers have noticed the discordance of risk perceptions among critical stakeholders in safe construction work, however few have provided quantifiable evidence describing them. In an effort to fill this perception gap, this research performs an experiment that investigates stakeholder perceptions of risk in construction. Data analysis confirms the existence of such discordance, and indicates a trend in risk likelihood estimation. With risk perceptions from low to high, the stakeholders are architects, contractors/safety professionals, and engineers. Including prior studies, results also suggest that designers have improved their knowledge in building construction safety, but compared to builders they present more difficultly in reaching a consensus of perception. Findings of this research are intended to be used by risk management and decision makers to reassess stakeholders' varying judgments when considering injury prevention and hazard assessment.



## 1. Introduction

Despite advances in technology and implementation of robust safety management and risk mitigation techniques, occupational safety and health (OSH) incidents continue to cause persistent suffering to the construction industry and its workers. In the United States, 769 construction workers died in the workplace due to OSH incidents in 2013 (U.S. Bureau of Labor Statistics [BLS], 2014). This is unacceptable. These incidents have been shown to arise from well-known hazards, which could be controlled with the implementation of known risk mitigation and injury interventions (Kleiner et al., 2008).

Risk mitigation is an integral effort in construction and its success requires inputs from all stakeholders including owners, designers, builders, and suppliers (Floyd and Liggett, 2010). Such effort is difficult due to a construction project's fragmented nature with a variety of stakeholders across phases from design to construction (McCoy et al., 2009). Stakeholders in the construction phase are often targeted as the sole administrators for safety measures and implementation (Toole, 2002). For example, in the U.S., design professionals are not responsible for specifying means and methods of construction while the contractors need to take full responsibility to substantial safety risks on the jobsites. Designers always avoid to expose themselves to liability by involving in a construction issue for which they are not responsible under the contract. Standard contracts provided by industry authorities also recognize this principle and the terms usually include exemptions of designers' liability that associates with the supervision of construction means and methods. However, many injury cases in the workplace bring claims against the design. Recent studies (Fleming et al., 2007; Gambatese et al., 2008) have revealed that stakeholders in the design phase have great influence on OSH as well. High levels of design related concerns can also impact injury and fatalities. The design-related OSH in construction can be to as high as 43.9% of fatal injuries in construction (Driscoll et al., 2008) and therefore a significant contributor. Godfrey and Lindgard (2007) argued that effective safety management requires the risks arising as a result of design to be eliminated wherever possible. As a result, productive communication and collaboration (Migliaccio and Martinez, 2010) between designers and builders during pre-construction stages becomes vital for effective risk mitigation.

Effective risk management rests upon the consensus and collaboration of all stakeholders, but such integration is difficult to attain. Godfrey and Lindgard (2007) recognized this difficulty and questioned the existence of a unity of purpose with regard to OSH in the Architecture, Engineering and Construction (AEC) industry. Toole (2002) conducted a survey that has shown the lack of uniform agreement on site safety responsibilities among design

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engineers, general contractors, and subcontractors. Thekdi and Lambert (2014) demonstrated that consensus on risk mitigation is difficult to achieve among stakeholders within infrastructure projects due to discrepancies in perspective, expertise, and interests.

The authors posit one possible reason for this difficulty as an issue of risk perception from individuals or their corresponding roles. Most risk mitigation strategies assume that OSH risk is "objective" and can be impartially recognized and perceived (Arezes and Miguel, 2008), but this assumption can contain challenges. Flin et al. (1996) investigated the risk perceptions of offshore workers and found these perceptions are subjective and varied. Hallowell (2010) highlighted a significant difference in perceiving risk tolerance between construction workers and managers. Ouédraogo et al. (2011) observed that people react differently to the same consequences from different hazards and concluded that risk perception depends on fear, culture, education, society, and knowledge. However, little research has provided solid evidence to the discordance of stakeholder perceptions of risk in construction. The aim of this paper is to provide such evidence for AEC stakeholder perceptions.

Understanding risk perceptions in construction is critical, which necessitates research to investigate, compare, and contrast stakeholder judgment of risk. Risk perception is significantly related to risk behavior, providing an important insight to safety management (Rundmo, 1996). Risk analysis injects logic, reason, and scientific deliberation into risk management (Slovic and Peters, 2006), making it inappropriate to judge OSH from a simplistic and moralistic perspective (Toole and Gambatese, 2008). In the context of competing interests and goals, the determination of what OSH measure is acceptable, in terms of OSH outcomes, must involve an industry-wide conversation about risk and its acceptability from a range of diverse stakeholders (Saunders et al., 2012). As a result, every effort is needed to understand all stakeholders' OSH risk judgments and to develop strategies that encourage occupants of safety-critical roles.

This paper presents an experimental study that investigates AEC stakeholder perceptions of risk in construction. Specific objectives of the experiment are: (1) to verify whether safety-critical stakeholder groups have intragroup concordance in perceiving risk; (2) whether they have intergroup discordance in perceiving risk; and (3) to identify the discordance if it exists. Similar to other studies of risk perception (Slovic, 1987), this study examines the judgment made by construction stakeholders when they are asked to characterize hazardous conditions or technologies. Here, the writers define the risk as exposure to a hazardous condition which may cause work-related injuries, illnesses, and fatalities. The risk is measured in terms of the combination of (1) the likelihood of a hazardous event and (2) the severity of the hazard when it occurs (Chan et al., 2011; Fleming et al., 2007). Such setting is derived from the classic Risk formula: $Risk = P * D$, with $P$ being the probability of threat (i.e., the likelihood) and $D$ the expected damage (i.e., the severity), for quantitative risk assessment (Flammini et al., 2011). The experiment uses photographs to elicit responses in depicting hazards (Morgan, 2002) because it has been shown that the pictorial nature of a graphical risk display ignites stronger associations with risk outcomes (Chua et al., 2006).

## 2. Method

### 2.1. Participants

Table 1 provides a summary of participant groups and descriptions. A total of 60 ($N = 60$) industry practitioners from four safety-critical AEC stakeholder groups participated in the experiment. The four stakeholder groups are architects, engineers, construction contractors, and safety professionals. These groupings include all dominant professions who direct or are largely engaged in a construction project and are the substantial decision-makers in OSH risk. Within the four groups, the architects and engineers are primarily involved in activities during the design stage and thus more likely to represent designers. In contrast, contractors and safety professionals are primarily involved during the construction stage and more likely to represent builders. All participants had more than three years of professional experience and were working in the architecture, engineering, and construction (AEC) industry at the time of experiment. Their workplaces were geographically varied throughout the United States.

**Table 1**
Participant summary.

| Code | Stakeholder group | Number | Description |
|---|---|---|---|
| *Arch* | Architects | 15 | Licensed architects, with at least five years of experience |
| *Engr* | Engineers | 15 | Structural engineers, mechanical engineers, electrical engineers, and other engineers, with at least three years of experience |
| *Cont* | Contractors | 15 | Principle contractors, trade contractors, project managers, site managers, and superintendents, with at least five years of experience |
| *Safe* | Safety professionals | 15 | OSHA safety experts, construction safety managers, safety officers, and safety consultants, with at least five years of experience |

The researchers adopted a respondent-driven-sampling (RDS) approach (Heckathorn, 1997) to recruit participants. RDS lends statistical rigor to conventional snowball sampling through longer recruitment chains and recruitment limits (Salganik, 2006). Scholars have criticized the snowball sampling approach due to its inherent biases that persons of similar characteristics are often networked and likely to recruit each other. In contrast, RDS allows researchers to make asymptotically unbiased estimates. Moreover, to ascertain confidentiality, the researchers provided participants with a unique code (e.g., *Arch01*, *Arch02*, or *Engr01*) for profession identity at invitation and they did not necessarily disclose their names nor affiliations during the experiment. The Virginia Tech Institutional Review Board (IRB) approved the RDS approach and inspected the process under IRB protocol #09-701 to ensure the safety of human subjects participating in this research.

### 2.2. Procedure

The experiment was based on a validated procedure to manipulate risk perceptions on building systems (Zhang et al., 2013). As illustrated in Fig. 1, the researchers asked a participant to complete the experiment through four steps: (1) log in the online experiment system using the given code (e.g., *Arch01*, *Arch02*, or *Engr01*) and then go through instructions; (2) sort four sets of total 32 photos (i.e., eight photos each set) based on the perceived risk likelihood in an ordinal scale of five categories (i.e., 1 = Rare, 2 = Unlikely, 3 = Moderate, 4 = Likely, and 5 = Almost certain); (3) sort the same four sets of total 32 photos based on the perceived risk severity in another ordinal scale of five categories (i.e., 1 = Insignificant, 2 = Minor, 3 = Moderate, 4 = Major, and 5 = Catastrophic); and (4) answer follow-up open-ended questions to expand on judgments in the two rounds of photo sorting. During the experiment process, a research assistant was available online to answer any instruction-related questions. The entire experiment

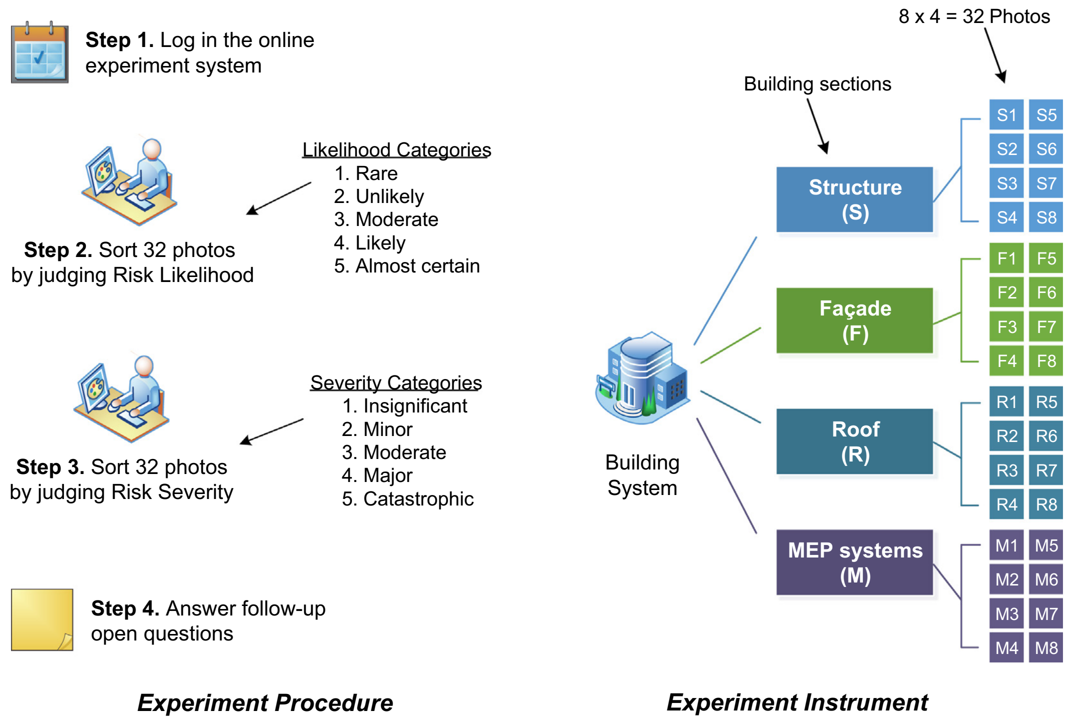


**Fig. 1.** Experiment procedure and instrument.

process was vetted under the IRB protocol to protect all participants' rights.

The experiment instrument totaled 32 photos in four sets. Each photo depicted a common construction method and its related work condition, in which inherent OSH hazards may exist. The participants sorted a photo's likelihood of being hazards by judging the possibility of potential OSH accident in the provided work condition; and also sorted the severity of the hazards by judging the consequences of potential OSH accident in the presented work condition. To provide a holistic view of possible hazards (see Fig. 1), the researchers first broke down a building system into four major sections: Structure, Façade, Roof, and MEP systems; and then selected eight photos to represent hazards in the construction of each building section. Table 2 summarizes the 32 photos and their descriptions. The instrument quality was first validated in a pilot study (Zhang et al., 2013) to maximally retain the photos' representativeness and heterogeneity; its reliability is further measured in the following analysis of this study.

Fig. 2 demonstrates the interface of the online experiment system. The researchers designed the system using Qualtrics software. In each sorting (a set of eight photos), participants needed to carefully observe each image in the photo area and drag it into a perceived risk category in the judgment area. With internet connection, participants were able to complete the experiment through a choice of multiple devices such as desktops, laptops, tablets, or smart phones. Such an online system offers great convenience for participants who were geographically located in various places in the United States.

### 2.3. Measures

To achieve the research objectives, the authors adopted various measures to analyze the collected experiment data. These measures examined both the rating and ranking of photos. The measures consisted of three parts: (1) instrument reliability test, (2)

**Table 2**
Instrumental photos' IDs and descriptions.

| ID | Description | ID | Description |
|---|---|---|---|
| S1 | Cast-in-place concrete column placement | R1 | Metal roof canopies |
| S2 | Steel framed structural system | R2 | Flat cast-in-place reinforced concrete roof with bitumen membrane water proofing |
| S3 | Precast reinforced concrete tilt-up system | R3 | Steel roof sheeting system to a frame building |
| S4 | Precast reinforced concrete columns, beams, and slab panels | R4 | Timber rafter system for curved roof panels |
| S5 | Reinforced concrete structural frame with post-tensioned slabs | R5 | Tiled roof on timber rafters |
| S6 | Steel structural frame with precast concrete decking (Hoisting) | R6 | Plywood sheathings installed to roof trusses |
| S7 | Steel structural frame with steel decking to receive concrete cover | R7 | Pre-assembled timber roof canopy system |
| S8 | Reinforcement fixing for cast-in-place concrete slab and columns | R8 | Prefabricated roof systems for offsite built classrooms |
| F1 | Precast concrete panel system for housing | M1 | MEP suspended from steel roof structure |
| F2 | Precast concrete panel system for parking garage | M2 | MEP suspended from concrete structure |
| F3 | Concrete and window panel facade system | M3 | MEP suspended from concrete structure |
| F4 | Full story prefabricated facade system | M4 | MEP suspended from steel structure with spray-on fire retardant |
| F5 | Glazed panel facade system | M5 | MEP suspended from concrete structure |
| F6 | Mixed glass and concrete panel facade system | M6 | MEP suspended from steel panel |
| F7 | Cast-in-place reinforced concrete walling | M7 | Electrical wiring systems |
| F8 | Concrete block wall facade system | M8 | Pre-assembled building service modular installed offsite |

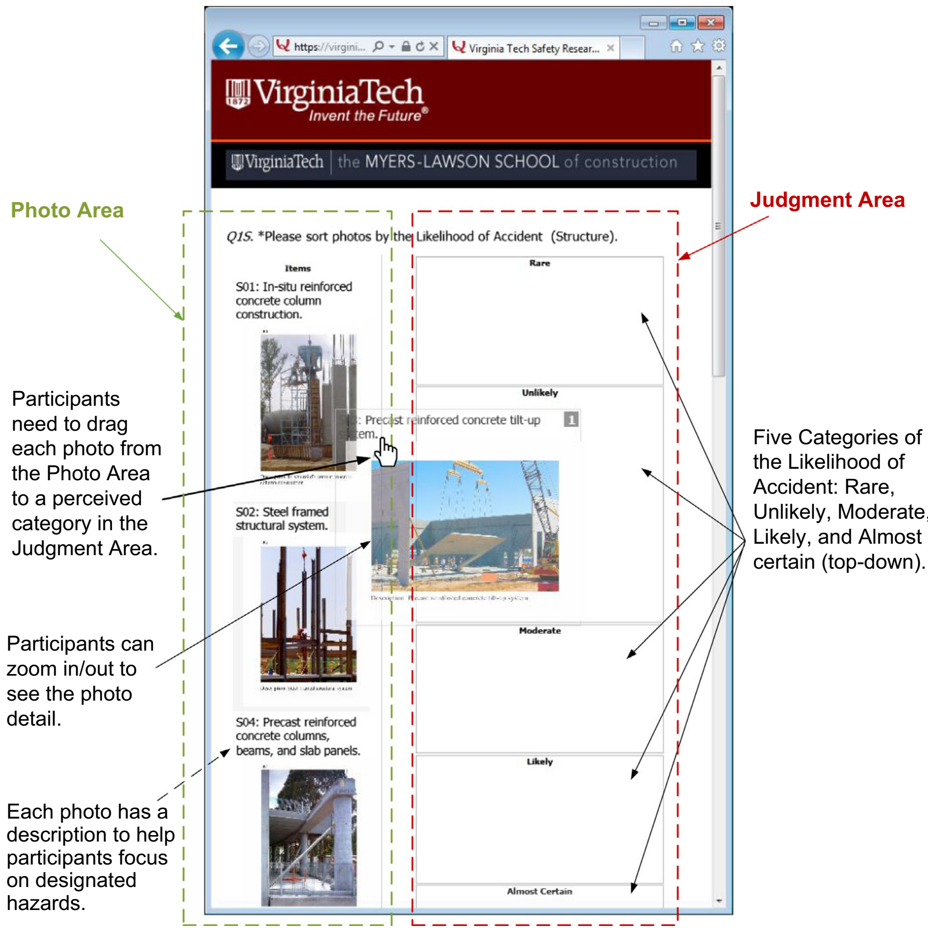


**Fig. 2.** Interface example of the online experiment system.

intragroup comparison, and (3) intergroup comparison. The researchers used SAS software to perform all analysis.

The researchers calculated the Cronbach's Alpha statistic to measure the instrument's reliability (i.e., the internal consistency). An Alpha value of greater than 0.6 indicates acceptable reliability and that of greater than 0.7 indicates good reliability (Cronbach and Shavelson, 2004).

The researchers calculated the Kendall's coefficient of concordance for ranks ($W$) and Friedman's $\chi^2$ to measure intragroup concordance. The statistic $W$ describes the degree of intragroup agreement among the 15 participants within a stakeholder group when they judge risk, in terms of likelihood and severity. When $\chi^2$ is significant at a 95% confidence level it indicates the existence of intragroup concordance. The statistic $W$ ranges from 0 to 1, representing the extent from no agreement to complete agreement.

The researchers performed Wilcoxon Signed-Rank test, Kruskal–Wallis test, and Jonckheere–Terpstra Trend test (short as *J–T* Trend test) to measure the intergroup discordance. The Wilcoxon Signed-Rank test determines whether the pairwise stakeholder groups have statistically significant discordance of risk perceptions; the Kruskal–Wallis test determines whether all the four stakeholder groups as a whole have discordance of risk perceptions; and the *J–T* Trend test investigates how different the perceptions are by testing whether an order of perceived risk levels exists among the four stakeholder groups (e.g., $\theta_1 \leqslant \theta_2 \leqslant \cdots \leqslant \theta_k$; $\theta$ = perceived risk level).

## 3. Results

### 3.1. Reliability test

Table 3 lists the results of instrument's reliability tests. All the Cronbach's Alpha values for testing perceptions on risk likelihood were above 0.7, indicating very good internal consistency. The Cronbach's Alpha values for testing perceived risk severity on Façade, Roof, and MEP systems were greater than 0.8, also indicating very good internal consistency. Only the photos for testing

**Table 3**
Results of the Cronbach's Alpha test of reliability.

| Building section | Likelihood | | | Severity | | |
|---|---|---|---|---|---|---|
| | Cronbach's Alpha | Std. deviation | *N* of photos | Cronbach's Alpha | Std. deviation | *N* of photos |
| Structure | 0.795 | 5.146 | 8 | 0.695 | 4.545 | 8 |
| Facade | 0.827 | 4.985 | 8 | 0.848 | 5.193 | 8 |
| Roof | 0.824 | 4.736 | 8 | 0.833 | 5.586 | 8 |
| MEP | 0.878 | 5.680 | 8 | 0.904 | 5.655 | 8 |

perceived risk severity on Structure was lower (but also at an acceptable level) with an Alpha of 0.695. Overall, the results from the Cronbach's Alpha test indicate high reliability of the experiment setting.

### 3.2. Intragroup comparison

Table 4 lists the results of Kendall's $W$ value calculations. The results indicate that all the four stakeholder groups have overall intragroup concordance at 99% confidence level ($p < 0.001$). When looking at the coefficients, not all degrees of agreement were high-ranging between 0.15 and 0.45. Comparatively, architects had the greatest concordance when perceiving risk severity ($W = 0.418$, $p < 0.001$); and in contrast, contractors contained the least concordance when judging the risk likelihood ($W = 0.154$, $p < 0.001$). Combining results suggests that each stakeholder group has demonstrated homogeneous within-group risk perceptions based on professional characteristics, while the degree of such homogeneity is low due to individual differences.

Results in Table 2 also indicate interesting findings when examining the frequency that each group achieved agreement. The authors define concordance rate as the count of obtaining significant agreement out of the total eight rounds of sorting (i.e., four sections times likelihood/severity). In this way, the architects had a high concordance rate of 87.5% (i.e., seven in eight sorts); the engineers had a medium concordance rate at 50.0%; the contractors had a low concordance rate at 12.5%; and the safety professionals had a fair concordance rate at 75.0%. These findings are consistent with their overall intragroup judgment performance as discussed in the previous section. Additionally, Roof scenes result in the highest concordance rate when its inherent hazards are being judged, while the Façade section result in the lowest.

Moreover, the participants reflect a low degree of intragroup concordance and even discordance when judging hazards in a few building sections; which the researchers interpret as individual differences. As Motowildo et al. (1997) underlined, individual differences lead to variability in knowledge, skills, and work habits, which may mediate effects of cognitive ability on professional performance.

### 3.3. Intergroup comparison

Table 5 presents results of pairwise intergroup comparisons from the Wilcoxon Signed-Rank test. When judging the likelihood of potential condition-related injuries, architects demonstrated highly significant discordance with all other three stakeholders: the engineers ($Z = 6.025$, $p < 0.001$), contractors ($Z = 5.268$, $p < 0.001$), and safety professionals ($Z = 3.592$, $p < 0.001$). Another observed significant discordance was the pairwise between the engineers and contractors ($Z = 2.568$, $p = 0.010$). Combining the findings, it suggests that designers (i.e., *Arch* and *Engr*) and builders (i.e., *Cont* and *Safe*) largely differ on the likelihood judgment of

**Table 4**
Results of the Kendall's coefficient of concordance by comparing participants within each stakeholder group.

| Building section | Statistic | *Arch* | | *Engr* | | *Cont* | | *Safe* | |
|---|---|---|---|---|---|---|---|---|---|
| | | Likelihood | Severity | Likelihood | Severity | Likelihood | Severity | Likelihood | Severity |
| Overall | Kendall's $W$ | 0.209** | 0.418** | 0.227** | 0.339** | 0.154** | 0.252** | 0.319** | 0.289** |
| | Friedman's $\chi^2$ | 97.399 | 194.344 | 105.675 | 157.461 | 71.836 | 117.251 | 148.500 | 134.359 |
| | *Sig.* ($p$) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Structure | Kendall's $W$ | 0.155* | 0.264** | 0.264 | 0.444 | 0.075 | 0.215 | 0.160 | 0.373* |
| | Friedman's $\chi^2$ | 8.181 | 29.721 | 5.368 | 9.381 | 8.631 | 6.024 | 12.020 | 15.673 |
| | *Sig.* ($p$) | 0.023 | <0.001 | 0.615 | 0.226 | 0.280 | 0.537 | 0.100 | 0.028 |
| Façade | Kendall's $W$ | 0.078 | 0.283** | 0.051 | 0.089 | 0.082 | 0.057 | 0.114 | 0.149* |
| | Friedman's $\chi^2$ | 8.181 | 29.721 | 5.368 | 9.381 | 8.631 | 6.024 | 12.020 | 15.673 |
| | *Sig.* ($p$) | 0.317 | <0.001 | 0.615 | 0.226 | 0.280 | 0.537 | 0.100 | 0.028 |
| Roof | Kendall's $W$ | 0.391** | 0.377** | 0.332** | 0.274** | 0.379** | 0.112 | 0.528** | 0.254** |
| | Friedman's $\chi^2$ | 41.064 | 39.550 | 34.809 | 28.721 | 39.782 | 11.747 | 55.432 | 26.639 |
| | *Sig.* ($p$) | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.109 | <0.001 | <0.001 |
| MEP | Kendall's $W$ | 0.296** | 0.216** | 0.398** | 0.212** | 0.045 | 0.037 | 0.213** | 0.202** |
| | Friedman's $\chi^2$ | 31.105 | 22.699 | 41.818 | 22.233 | 4.676 | 3.840 | 22.356 | 21.181 |
| | *Sig.* ($p$) | <0.001 | 0.002 | <0.001 | 0.002 | 0.699 | 0.798 | 0.002 | 0.004 |

* Significance at 95% confidence level.
** Significance at 99% confidence level; *Arch* = Architects, *Engr* = Engineers, *Cont* = Contractors, and *Safe* = Safety professionals.

**Table 5**
Results of the Wilcoxon Signed-Rank test by comparing pairwise stakeholder groups.

| Risk | Pairwise | $Z$ | Mean difference | S.E. difference | *Sig.* ($p$) | Lower CL | Upper CL |
|---|---|---|---|---|---|---|---|
| Likelihood | Arch–Engr | 6.025 | 27.969 | 4.642 | <0.001** | 0.530 | 0.800 |
| | Arch–Cont | 5.268 | 24.438 | 4.639 | <0.001** | 0.330 | 0.660 |
| | Arch–Safe | 3.592 | 16.688 | 4.646 | <0.001** | 0.260 | 0.740 |
| | Engr–Cont | 2.568 | 11.875 | 4.624 | 0.010** | 0.060 | 0.330 |
| | Engr–Safe | −1.239 | −5.750 | 4.640 | 0.215 | −0.400 | 0.070 |
| | Cont–Safe | 0.000 | 0.000 | 4.645 | 1.000 | −0.260 | 0.260 |
| Severity | Arch–Engr | −0.181 | −0.844 | 4.649 | 0.856 | −0.330 | 0.330 |
| | Arch–Cont | −0.941 | −4.375 | 4.651 | 0.347 | −0.460 | 0.160 |
| | Arch–Safe | −1.196 | −5.563 | 4.650 | 0.232 | −0.460 | 0.130 |
| | Engr–Cont | 1.009 | 4.688 | 4.647 | 0.313 | −0.130 | 0.400 |
| | Engr–Safe | −1.137 | −5.281 | 4.646 | 0.256 | −0.400 | 0.130 |
| | Cont–Safe | 0.020 | 0.094 | 4.646 | 0.983 | −0.260 | 0.200 |

** Significance at 99% confidence level; *Arch* = Architects, *Engr* = Engineers, *Cont* = Contractors, and *Safe* = Safety professionals.

**Table 6**
Results of the Kruskal–Wallis test by comparing four stakeholder groups.

| Risk | *K* | *Sig.* (*p*) | Stakeholder | *N* | Rank sum | Expected rank | Rank mean | Order |
|---|---|---|---|---|---|---|---|---|
| Likelihood | 41.768 | <0.001** | Arch | 32 | 957.00 | 2064.00 | 29.906 | 1 |
| | | | Engr | 32 | 2795.00 | 2064.00 | 87.344 | 4 |
| | | | Cont | 32 | 2265.00 | 2064.00 | 70.781 | 3 |
| | | | Safe | 32 | 2239.00 | 2064.00 | 69.969 | 2 |
| Severity | 2.353 | 0.503 | Arch | 32 | 2238.00 | 2064.00 | 69.938 | 4 |
| | | | Engr | 32 | 2210.50 | 2064.00 | 69.078 | 3 |
| | | | Cont | 32 | 1916.00 | 2064.00 | 59.875 | 2 |
| | | | Safe | 32 | 1891.50 | 2064.00 | 59.109 | 1 |

** Significance at 99% confidence level; *Arch* = Architects, *Engr* = Engineers, *Cont* = Contractors, and *Safe* = Safety professionals.

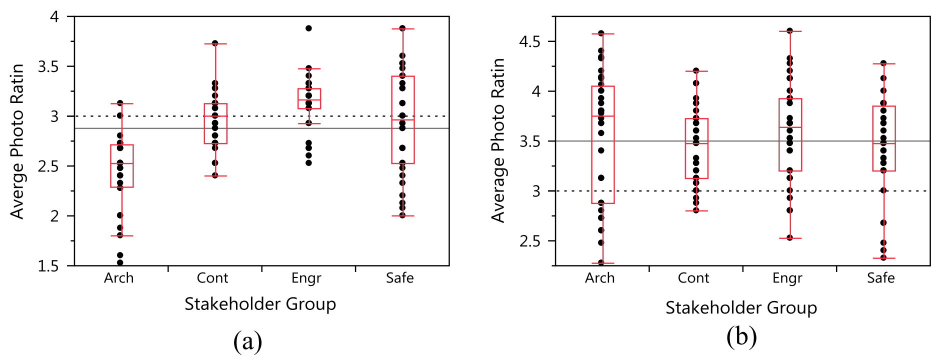


**Fig. 3.** Quantile box plots of average photo rating on (a) risk likelihood and (b) risk severity by stakeholder group.

accidental injuries. In contrast, the tests did not identify any significant differences on the severity judgment of accidental injuries from any pairwise stakeholder groups. In summary, the findings indicate that the designers and builders judge injury probability for a work condition differently, while judge the impact of the injury similarly.

Table 6 lists the results of intergroup comparison from the Kruskal–Wallis test. The results identified a significant discordance on likelihood perceptions ($K = 41.768$, $p < 0.001$) among the four stakeholder groups, suggesting they judge OSH risk probability in construction differently. In contrast, the results did not identify any significant discordance on severity perceptions among the four, suggesting the groups judge OSH risk consequences similarly. Such findings are highly consistent with findings from the pairwise intergroup comparisons, and further confirm the existence of intergroup discordance on risk likelihood perceptions.

In Table 6, the four stakeholder groups' rank sum values also indicate the order of perceived risk. Based on these rank sum values, the researchers assigned an order number to each group (see the Order column in Table 6). A larger order number represents a greater rank sum value and indicates a higher level of risk perception, and vice versa. As a result, findings imply an ascending trend of likelihood perceptions from the stakeholders which are the architects (lowest with order 1), safety professionals (lower with order 2), contractors (higher with order 3), and engineers (highest with order 4). In addition, the authors do not consider the trend of severity perceptions in Table 6 since previous findings did not identify significant intergroup discordance.

To visualize how the four stakeholder groups are judging risks, the authors plotted all participants' average rating scores in Fig. 3. The quantile box plot (Fig. 3a) confirms the previously identified trend and illustrates how the trend of likelihood perceptions performed. Accordingly, the architects tended to perceive OSH injuries as unlikely to occur, because they contained the lowest median rating score (around 2.5 in a scale of 1–5); the engineers tended to judge OSH injuries as likely to happen, because their median rating score was slightly above 3.0; and the contractors and safety professionals tended to view risk likelihood as moderate, because their median scores were extremely close to 3.0. On the other hand, the four stakeholder groups exhibited a tendency of perceiving injury severity as moderate to major, because all their median scores were around 3.5 (see Fig. 3b). Such a result suggests two interesting findings: (1) it offers an interpretation as to why stakeholder groups do not judge risk severity differently; and (2) it validates the experiment quality by indicating that all stakeholders (including architects) recognize hazards from the photos and are aware of the consequences of possible injuries.

To further verify the trend of likelihood perceptions among the four stakeholder groups, the authors performed two rounds of *J–T* Trend tests. The first test was to determine whether the ascending order of architects, safety professionals, contractors, and engineers was significant (i.e., $Arch \leqslant Safe \leqslant Cont \leqslant Engr$); and the second test was to determine whether the ascending order of architects, contractors, safety professionals, and engineers was significant (i.e., $Arch \leqslant Cont \leqslant Safe \leqslant Engr$). The first preset order results from the previous intergroup comparison. The second preset order results from an observation that the contractors and safety professionals contained extremely close values in both ranking mean (see

**Table 7**
Results of the *J–T* Trend test on likelihood perceptions with order of $Arch \leqslant Safe \leqslant Cont \leqslant Engr$.

| | *N* | *J–T* Value | Mean *J–T* value | Std. De. *J–T* value | Std. *J–T* value | *Sig* (2-tailed) |
|---|---|---|---|---|---|---|
| Overall | 60 | 846.00 | 675.00 | 65.539 | 2.609 | 0.009** |
| Structure | 60 | 764.00 | 675.00 | 64.995 | 1.369 | 0.171 |
| Facade | 60 | 803.00 | 675.00 | 58.769 | 2.178 | 0.029* |
| Roof | 60 | 780.50 | 675.00 | 64.010 | 1.648 | 0.099 |
| MEP | 60 | 881.50 | 675.00 | 68.645 | 3.008 | 0.003** |

* Significance at 95% confidence level.
** Significance at 99% confidence level.

**Table 8**
Results of the *J–T* Trend test on likelihood perceptions with order of *Arch* ⩽ *Cont* ⩽ *Safe* ⩽ *Engr*.

| | *N* | *J–T* value | Mean *J–T* value | Std. De. *J–T* value | Std. *J–T* value | *Sig.* (2-tailed) |
|---|---|---|---|---|---|---|
| Overall | 60 | 845.00 | 675.00 | 65.539 | 2.594 | 0.009** |
| Structure | 60 | 780.00 | 675.00 | 64.995 | 1.615 | 0.106 |
| Facade | 60 | 783.00 | 675.00 | 58.769 | 1.838 | 0.066 |
| Roof | 60 | 795.50 | 675.00 | 64.010 | 1.838 | 0.060 |
| MEP | 60 | 861.50 | 675.00 | 68.645 | 2.717 | 0.007** |

** Significance at 99% confidence level.

Table 6) and rating score. Hence, the researchers also decided to switch orders and examine the post-switched order. Tables 7 and 8 present the results of the two rounds of *J–T* Trend tests, respectively.

Results from Table 7 verified the existence of the first preset order at a 99% confidence level ($J–T = 846.00$, $p = 0.009$). This trend was particularly significant when the four groups judged building sections of Façade ($J–T = 803.00$, $p = 0.029$) and MEP systems ($J–T = 881.00$, $p = 0.003$). Results from Table 8 also verified the existence of the second preset order at a 99% confidence level ($J–T = 845.00$, $p = 0.009$). This trend was particularly significant when they judged MEP systems ($J–T = 861.50$, $p = 0.007$). Coupling the results, it presents solid evidence on the trend of risk likelihood perceptions, suggesting the following: (1) architects tend to perceive lower likelihood; (2) engineers tend to perceive higher likelihood; (3) contractors and safety professionals tend to perceive similarly medium likelihood. It is noteworthy that this study cannot identify which stakeholder group's perception is more accurate or closer to the risk, though.

## 4. Discussion

Data analysis confirmed the intragroup concordance and intergroup discordance of risk perceptions from construction stakeholders. The results indicate that OSH risks also contain "social attributes" in lieu of technological and engineering attributes only. In other words, the risks may be perceived subjectively due to the itinerary of interests, roles, opportunities, or power differentials, which is interpreted as "social structures" in social science (Archer, 1995). Social structures together with cultural systems (sets of ideas about what is true or false) shape people's perceptions, actions, their attempts to influence others (Friedman and Miles, 2002). People with shared social structures and cultural systems group into stakeholders; and hence stakeholders' perceptions represent their social roles, though they can remain independent and subjective. Noteworthy is that social structures are formed and transformed within a context of social interaction between people and society, whereby individuals are affected by each other (Barge and Luckmcmn, 1967). The findings suggest project managers include the social attributes of OSH risks into their considerations when make OSH-related decisions.

Findings identified the gaps of risk perception between designers (i.e., architects and engineers) and builders (i.e., contractors and safety professionals). The results shown that designers have difficulty achieving consensus in safety-related perceptions while builders are likely to reach such an agreement. The authors interpret that designers are lack of hazards awareness during the construction phase and unfamiliar with OSH control measures (Mills, 2009). From a systems perspective, the OSH risks in the construction phase can often be traced back to decisions made by persons who are organizationally and spatially removed from the productive work, such as clients, cost planners, suppliers, and design contributors. These decisions are often made before construction works have commenced. In this work system it is difficult for decision makers to 'take the perspective' of persons whose OSH could be affected by their decisions. The identified gaps of perception indicate the gaps between work system and environmental expectations (Kleiner, 2006; Zhao et al., 2015c); and therefore communication interfaces need to be developed between sub-environment personnel and the organization. As a result, alignment of objectives and effective communication at the interface between subsystems of complex (i.e., differentiated and decentralized) project organizations (Du, 2014) are essential to the OSH optimization.

Findings provided quantifiable evidence to the extent of alignment and heterogeneity among stakeholders' understandings of OSH risk and risk control. The builders' risk assessment seems comparatively accurate assuming they thoroughly understand construction means and methods. The architects' risk assessment is low since they often allocate OSH responsibility to other stakeholders due to liability exposure (El-Sayegh, 2008; Gambatese et al., 2005). The engineers' risk assessment is comparatively high because they are obligated to ensure satisfactory building performance in their design and calculation and hence prone to be sensitive to uncertainties. Such evidence facilitates the development of shared mental models of OSH (Lingard et al., 2015; Prussia et al., 2003). Shared mental models are acknowledged to be a critical determinant of OSH performance and culture but is particularly problematic for the fragmented construction industry. Fragmentation and a lack of consistency in the technical roles and contractual responsibilities of construction industry participants create differences in orientation and diverse working styles and processes, including those related to OSH within the industry. Construction projects are characterized by high levels of organizational and cultural differentiation, militating against the development of shared mental models and a unity of purpose with regard to OSH risk reduction. The identified differentiation among stakeholders helps to establish a "common purpose" within organizations and achieve the effective interface of communication.

Findings have practical implications to injury intervention strategy: the prevention through design (PtD). Many scholars and practitioners (Toole and Gambatese, 2008; Zhao et al., 2012, 2014) have advocated PtD as a successful strategy in mitigating OSH hazards. PtD adopts approaches of "designing hazards out" at the early design/planning stage to eliminate/reduce the workers' exposure at the construction stage (Weinstein et al., 2005). The "informational difficulties" (Driscoll et al., 2008) identified from the present work may hinder the PtD's implementation if overlooked. Effective OSH risk management relies upon decision makers' capability of recognizing hazards, assessing the implication of these hazards, and determining appropriate interventions. The effectiveness can be seriously hindered when decision makers differ significantly in their understandings of the nature of an OSH hazard and/or opportunities for its control (Zhao et al., 2015a,b). The findings contribute to such decision making process by not only alerting the discordance of perception but also providing baseline information for decision makers to adjust their risk judgments.

Findings also have practical implications to improving construction risk management technology. The methodology reported in this work can be developed into a tool that measures degree of congruence in OSH attitudes for project team members. The tool can also be used in the evaluation of industry efforts to increase the extent to which stakeholders take the perspective of others when making safety-critical decisions; for example, when assessing the extent to which virtual reality models of the construction process enable construction designers to take the perspective of construction workers. The tool also provides a useful means for project risk management to review OSH risks during the conceptual and detailed design stages.

The researchers acknowledge two specific limitations of the research. One limitation is that the researchers did not account for owners' risk perceptions although they are a key stakeholder. Owners are not a profession in the AEC industry and do not necessarily contain building construction skills, though. As a result, their backgrounds and corresponding judgments may be largely varying and the comparison of their perceptions may be less meaningful. Another limitation goes to the experimental instrument. All the photographs used in this research pertain to building construction projects and the findings resulting from this instrument may be less applicable when referring to other types of construction projects (e.g., infrastructure construction).

## 5. Conclusions

The paper reports on an experimental study that investigates stakeholder perceptions of risk in construction. The study analyzed and collected data from 60 participants in the AEC industry, including stakeholder groups of architects, engineers, contractors, and safety professionals. Findings reveal that these safety-critical roles in construction projects have demonstrated certain degrees of intragroup consensus concerning OSH risk. The resulting consensus is consistent with sociological theories and reflects the social structure of stakeholders. Findings also reveal that all the stakeholders are able to recognize OSH hazards in construction processes yet they have different estimations of risk likelihood. Specifically, architects tend to perceive lower probability of incidents, engineers perceive higher probability, and contractors and safety professionals contain similar medium perceptions. Additionally, findings indicate that designers have improved their knowledge of risk in building construction, which is different from prior research.

This work contributes to the body of safety knowledge by providing convincing evidence as to discrepancies in stakeholder perceptions. One resulting implication is the acceptance of risk's social attributes which are shaped by multiple influences and inevitably perceived differently by occupants of disparate sociotechnical roles. Another implication goes to the effective risk management practice in construction. Findings suggest that decision makers recognize the risk judgment gaps between designers and builders and appropriately adjust them based on the quantifiable evidence identified by this study. Furthermore, the methods used in this work contribute to the scientific body of knowledge by introducing an innovative research tool for investigating risk attitudes and judgements.

Extending this work could take the form of an investigation into reasons why stakeholders perceive risk likelihood differently. The present work has revealed differences in risk perceptions yet has not answered the question of why. Future research should also analyze the participants' responses to the follow-up questions of the experiment using techniques such as text analysis and factor analysis. As a result, research could explain why risk perceptions are different and which whose judgment is more accurate. Results could also be used to generate a decision support tool that would help stakeholders assess risk perception across teams and stakeholders and help decision makers evaluate the appropriateness of design and interventions for risk mitigation.

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## Appendix A. Algorithms of measures

### A.1. Cronbach's Alpha statistic

The Cronbach's Alpha statistic estimates the proportion of variance in the test scores that could be attributed to true score variance. It is defined in Eq. (A.1).

$$Alpha = \left(\frac{m}{m-1}\right)\left(1 - \frac{\sum_{i=1}^{m} var(S_i)}{var(\sum_{i=1}^{m} S_i)}\right) \tag{A.1}$$

where $m$ = number of photos in the instrument ($i$ = 1, 2, ..., $m$); and $S_i$ = the rating score of the $i$th photo. Mathematically, the statistic estimates the proportion of variance in the test scores that could be attributed to true score variance. Cronbach's Alpha ranges from 0 to 1, representing a degree from complete inconsistency to complete consistency.

### A.2. Kendall's coefficient

The Kendall's coefficient of concordance for ranks ($W$) is defined in Eq. (A.2). The statistic $W$ ranges from 0 to 1, representing the extent from no agreement to complete agreement

$$\text{Kendall's } W = \frac{12\sum_{i=1}^{m}\left(R_i - \overline{R}\right)^2}{n^2(m^3 - m)} \tag{A.2}$$

where $m$ = number of photos ($i$ = 1, 2, ..., $m$); $n$ = number of participants within a stakeholder group ($j$ = 1, 2, ..., $n$); $R_i$ = the average rank given to the $i$th photo from all participants; and $\overline{R}$ = the average rank of all photos signed across all participants.

### A.3. Friedman's $\chi^2$

The Friedman's $\chi^2$ statistic is defined in Eq. (A.3). It is used to determine the significance of Kendall's coefficient of concordance ($W$).

$$\text{Friedman's } \chi^2 = W(m-1)n \tag{A.3}$$

where $m$ = number of photos ($i$ = 1, 2, ..., $m$); $n$ = number of participants within a stakeholder group ($j$ = 1, 2, ..., $n$); $W$ = Kendall's coefficient of concordance. Kendall's $W$ is the normalization of Friedman's $\chi^2$ and describes the degree of intragroup concordance.

### A.4. Wilcoxon Signed-Rank (Z)

The Wilcoxon Signed-Rank statistic $W$ is defined in Eq. (A.4), and its corresponding $Z$ value is defined in Eq. (A.5). The statistics are calculated by comparing the mean of signed ranks.

$$\text{Wilcoxon's } W = \sum_{i=1}^{n'} R_i^{+} \tag{A.4}$$

$$Z = \frac{W - \frac{n'(n'+1)}{4}}{\sqrt{\frac{n'(n'+1)(2n'+1)}{24}}} \tag{A.5}$$

where $R_i^{+}$ = the $i$th signed positive rank; $n'$ = the largest number of signed rank.

*A.5. Kruskal–Wallis (K)*

The Kruskal–Wallis statistic $K$ is defined in Eq. (A.6). It is calculated by comparing the summation of ranks.

$$K = \frac{12}{m(m+1)} \sum_{l=1}^{k} \frac{R_l^2}{m_l} - 3(m+1) \quad (A.6)$$

where $k$ = number of stakeholder groups ($l = 1, 2, \ldots, k$); $m$ = total number of photos; $m_l$ = the number of photos in the $l$th stakeholder group; and $R_l$ = the rank sum from all photos by the $l$th stakeholder group.

*A.6. Jonckheere–Terpstra Trend (J–T)*

The Jonckheere–Terpstra statistic $J$–$T$ is defined in Eq. (A.7).

$$J\text{–}T = \sum_{l_1=1}^{k-1} \sum_{l_2=l_{1+1}}^{k} U_{l_1 l_2} \quad (A.7)$$

where $k$ = total number of stakeholder groups ($l = 1, 2, \ldots, k$; $k > 2$); and $U_{l1l2}$ = the Mann–Whitney $U$ count (Lehmann and D'Abrera, 2006) between the $l_1$th and $l_2$th stakeholder groups.

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