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Determining factors affecting the perceived quality of fire safety signage icons: A structural equation modeling approach

Yogi Tri Prasetyo [a,b,*], Alif Bagas Adiutomo [c], Yoshiki B. Kurata [d,e], Retno Widyaningrum [c], Maela Madel L. Cahigas [f], Ardvin Kester S. Ong [f,g]

[a] International Bachelor Program in Engineering, Yuan Ze University, 135 Yuan-Tung Road, Chung-Li 32003, Taiwan
[b] Department of Industrial Engineering and Management, Yuan Ze University, 135 Yuan-Tung Road, Chung-Li 32003, Taiwan
[c] Department of Industrial and Systems Engineering, Institut Teknologi Sepuluh Nopember, Kampus ITS Sukolilo, Surabaya 60111, Indonesia
[d] Department of Industrial Engineering, Faculty of Engineering, University of Santo Tomas, Philippines. España Blvd, 1015 Manila, Philippines
[e] Research Center for Social Sciences and Education, University of Santo Tomas, Philippines, España Blvd, 1015 Manila, Philippines
[f] School of Industrial Engineering and Engineering Management, Mapúa University. 658 Muralla St., Intramuros, Manila 1002, Philippines
[g] E.T. Yuchengo School of Business, Mapúa University, 1191 Pablo Ocampo Sr. Ext., Makati, Metro Manila 1204, Philippines

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ABSTRACT

Fire safety signage icons have become extremely important in visual communication, conveying critical information with precision to prevent fire disasters. This study investigates the causal relationships among five cognitive constructs—semantic distance, communicativeness, complexity, layout, and perceived quality—of fire safety signage icons presented in four distinct formats: image-related, concept-related, semi-abstract (ISO 7010:2019), and combined. Two hundred fifty-one participants evaluated 12 pairs of semantic differential scales derived from these constructs. Structural equation modeling revealed that communicativeness exerted the most significant influence on perceived quality, followed by layout and semantic distance, while complexity indirectly affected perceived quality. This pioneering study is the first to uncover and analyze the causal relationships between cognitive factors and an icon's perceived quality. The proposed dimensions and semantic differential scales can also be applied and extended to evaluate other icons beyond fire safety signage.

1. Introduction

According to the World Health Organization (2018), it has been recorded globally that fire-related burns cause an estimated 180,000 deaths annually, with over 90 % occurring in low- and middle-income countries. In the United States alone, the economic cost of fires was estimated at $328.5 billion in 2014, which includes losses due to property damage, healthcare costs, and fire prevention efforts (Zhuang et al., 2017). Several factors contribute to casualties in building fires, highlighting the importance of knowledge and awareness of safety and the necessity for an effective safety management system (Kang et al., 2016). Visual reminders, such as fire safety signage, are effective ways to enhance understanding and compliance with safety protocols, which are crucial for minimizing injury risks (Pollack et al., 2017). Clear signages that mark exit routes and location indicators of fire safety equipment are essential for effective fire safety management, significantly impacting how quickly people can exit during emergencies and necessary for effective fire safety management (Jeon et al., 2019; Tharmarajan, 2007).

In these critical moments, such as fire disasters, every minute counts. These infographic materials become increasingly important for visual communication as they deliver crucial information effectively, efficiently, and accurately (Rotolo et al., 2022). Moreover, these icons are integral in cascading essential information to help people be safe or save themselves from life-threatening situations. Thoughtfully designed infographics, such as fire safety signage, enhance the visibility and impact of safety messages, encouraging appropriate actions during emergencies and bolstering overall safety management systems (Carolino, 2023). Several standards pertain to fire safety signage, including AS 1319, BS 5499, ANSI Z535.3, NFPA, and ISO 7010, with ISO 7010 being the most widely adopted standard for icon design.

Many studies classified icon formats into five (5): (1) Image-related, (2) Concept-related, (3) Semi-abstract, (4) Word, and (5) Combined. The

* Corresponding author at: International Bachelor Program in Engineering, Yuan Ze University, 135 Yuan-Tung Road, Chung-Li 32003, Taiwan.
E-mail addresses: yogi.tri.prasetyo@saturn.yzu.edu.tw (Y.T. Prasetyo), ybkurata@ust.edu.ph (Y.B. Kurata), widyaningrum@its.ac.id (R. Widyaningrum), mmlcahigas@mapua.edu.ph (M.M.L. Cahigas), aksong@mapua.edu.ph (A.K.S. Ong).

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first format, image-related, depicts specific details closely associated with the icon's intended meaning, as icon designers often prefer this format due to its simplicity and clarity (Chi & Dewi, 2014). The second format, concept-related, represents internal ideas rather than concrete objects or actions (Chi & Dewi, 2014). These icons can be ambiguous because the link between the abstract concept and the intended meaning may not always be clear. Semi-abstract icons are the third format, blending elements of image- and concept-related styles, thereby combining directness with some ambiguity (Chi & Dewi, 2014). Moreover, abbreviations or short phrases typically express a word-based icon format (Wiedenbeck, 1999). Abbreviations condense a longer phrase, while short phrases contain two or more words. Combined icons integrate images and text; some industries prefer this format as it enhances the clarity and understanding of the icon's message (Chi & Dewi, 2014; Collaud et al., 2022; Shao et al., 2024; Wiedenbeck, 1999).

Four cognitive factors are essential to evaluate the quality of icons: semantic distance, communicativeness, complexity, and layout. Semantic distance refers to how closely an icon's visual representation aligns with its intended meaning, which is critical for clarity in fire safety signage icons (McDougall et al., 2000). Additionally, communicativeness ensures the icon's distinctiveness and recognizability, highlighting unique meanings even within similar precaution concepts (Huang et al., 2002). Complexity involves the level of detail in an icon's design, ranging from intricate to simple (Ahmadi et al., 2021; Forsythe et al., 2008). Finally, layout concerns the spatial organization of elements, such as color and position, impacting icon recognition and understanding (Bañares et al., 2018). Thus, appropriate Kansei words are given to the four (4) cognitive factors indirectly linked to perceived quality. Kansei engineering has been widely applied to evaluate services in tourism, hospitality, and logistics (Chen et al., 2019; Jabreel et al., 2017).

This study seeks to identify how semantic distance, communicativeness, complexity, and layout impact the perceived quality of fire safety signage icons and provide detailed insights into how these cognitive factors affect icon quality, leading to practical recommendations for designing effective fire safety signage. This paper will utilize Structural Equation Modeling (SEM) to examine the differences between icon formats. Moreover, a semantic differential scale will gather insights into participants' perceptions. The findings of this study can be valuable to researchers and can support the government and related agencies in standardizing fire safety signage.

2. Theoretical research framework

The theoretical framework (illustrated in Fig. 1) depicts the factors derived from relevant studies that influence participants' perceptions of an icon's perceived quality. Five hypotheses were proposed to explore their varying impacts on the perceived quality of icon functions. The framework is grounded in the extended perceived quality model, which posits that perception is influenced by factors such as complexity, semantic distance, communicativeness, and layout.

The model constructs examined in this study include variables such as semantic distance, communicativeness, complexity, layout, and perceived quality, collectively the cognitive factors essential for evaluating an icon's effectiveness (Prasetyo et al., 2021). Previous research has recognized these cognitive factors as crucial for assessing readers' comprehensibility (Chi et al., 2017; Chi & Dewi, 2014; Huang et al., 2002; McDougall et al., 2000; Mu et al., 2022; Prasetyo et al., 2021; Stylidis et al., 2019). Since an icon's quality depends on multiple cognitive factors, understanding why some icons are easier to comprehend than others is essential (Blankenberger & Hahn, 1991; McDougall et al., 2000). A description of each cognitive factor examined in this study can be seen in Table 1. These cognitive factors are highlighted through Kansei words (measures) (see Table 2).

Icon complexity refers to the level of detail in an icon's graphic elements. While some icons require intricate designs to convey specific meanings, others benefit from simpler designs that allow quicker recognition. Typically, icon complexity is classified as either complex or

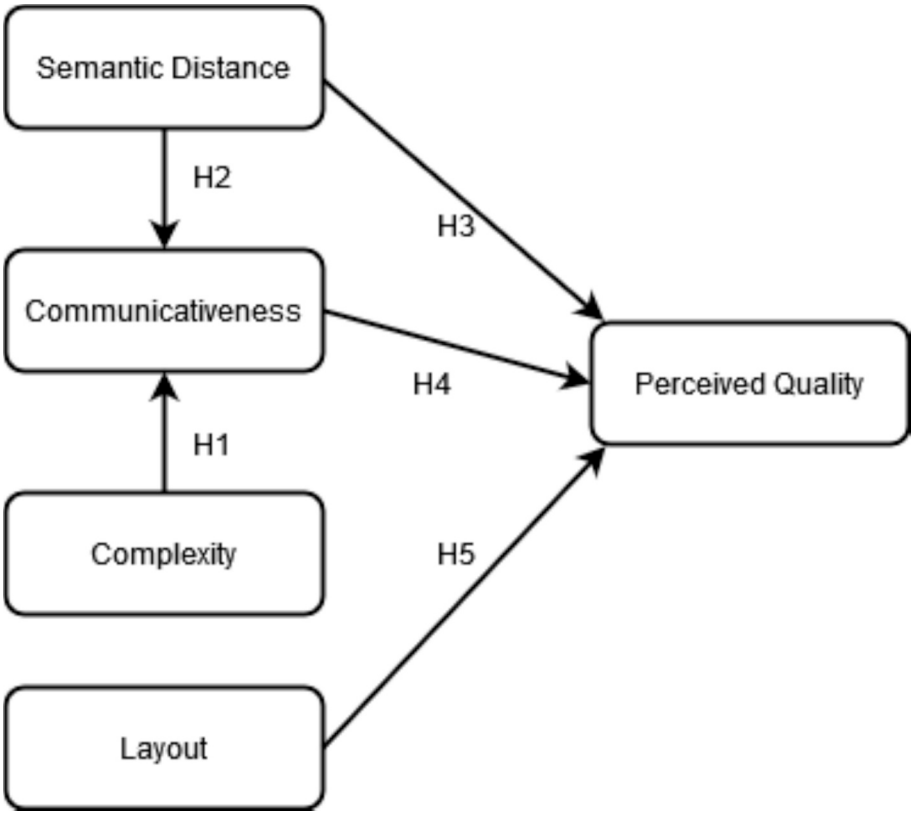


Fig. 1. Theoretical framework.

Table 1
Cognitive factors description.

Cognitive Factor	Description	References
Perceived Quality	It is one of the essential aspects of icon development that defines design effectiveness.	Prasetyo et al., 2021 Stylidis et al., 2019 Chi et al., 2017
Communicativeness	Describes how a symbol conveys its intended message	Huang et al., 2002
Complexity	Pertains to the complexity level within the icon's details	Ibrahim El-bayoumy Ali et al., 2021; Shao et al., 2023
Layout	Describes the accuracy involved in assembling the components of an icon	Huang et al., 2002
Semantic distance	Describes the measure of how intuitively the icon's design aligns with the user's understanding of its intended meaning.	He et al., 2023; Jin et al., 2023; Shen et al., 2024

Table 2
Subjective features and its corresponding semantic scale.

Cognitive Factor	Description	References
Perceived Icon Quality	1. Unlikeable – Likeable	Prasetyo et al. (2021)
	2. Ugly – Beautiful	Chi et al. (2017)
	3. Ineffective – Effective	Prasetyo et al. (2021)
	4. Vague – Clear	Prasetyo et al. (2021)
Communicativeness	5. Weak – Strong	Prasetyo et al. (2021)
	6. Unfamiliar – Familiar	Ibrahim El-bayoumy Ali et al. (2021)
Complexity	7. Complex – Simple	Ibrahim El-bayoumy Ali et al. (2021)
	8. Disorganized – Organized	Prasetyo et al. (2021)
Layout	9. Cluttered – Uncluttered	Ibrahim El-bayoumy Ali et al. (2021)
	10. Unrecognizable – Recognizable	Ibrahim El-bayoumy Ali et al. (2021)
Semantic Distance	11. Abstract – Concrete	
	12. Incompative – Compatible	Prasetyo et al. (2021)

simple. This paper adopts the complex-simple dichotomy, a method utilized by Prasetyo et al. (2021); Shen et al. (2018); Shen et al. (2020); Zhang et al. (2016).

Complex icons are characterized by their detailed and dense designs and are distinct from simple icons, which are known to be minimalist and straightforward. These icons reduce cognitive task efficiency, especially if users are unfamiliar with the icon. It is recommended that icons be paired with familiar elements or simple text to enhance usability and mental performance, particularly in contexts where quick recognition is crucial (Shen et al., 2020).

Fire safety signage is essential for conveying critical safety information rapidly and effectively. These signs typically combine icons and text to deliver vital instructions during emergencies. In the current landscape, fire safety organizations and government bodies increasingly utilize digital and physical media to educate the public about fire safety protocols, particularly in urban areas with higher fire disaster risks. Since fire safety instructions involve complex information, studies recommend that the complexity of fire safety icons should match their communicative effectiveness (Ganor, & Te'eni, D., 2016; Smythwood et al., 2019). Moreover, well-designed fire safety icons significantly improve emergency comprehension and response times (Ghayas et al., 2013). McDougall et al. (2016) found that complexity is a crucial cognitive factor in determining how effectively users can identify and understand icon formats and concepts. Thus, this study hypothesizes the following:

Hypothesis 1. *Complexity positively influences communicativeness.*

Semantic distance refers to the degree of similarity between an icon's visual representation and its intended meaning. When the semantic distance is small, icons closely resemble objects or actions they represent, making them easier to understand. Moreover, as safety icons are easily understood, users perceive the overall safety system as high quality and more likely to be accurate. Ganor, and Te'eni, D. (2016) found icons with a smaller semantic distance, especially in interfaces designed for older users. It was also determined that these icons effectively ensured accurate and quick comprehension. Chi and Dewi (2014) mentioned that semantic distance significantly affects icon matching accuracy, representing the icon's quality and communicativeness. Furthermore, familiarity with icons substantially improves cognitive performance, mainly when the icons are simple and concrete (Shen et al., 2018). Other studies also showed that semantic distance has an association with communicativeness, as evident in the studies of Huang et al. (2002) and McDougall et al. (2000). Thus, it was hypothesized that:

Hypothesis 2. *Semantic distance positively influences communicativeness.*

Hypothesis 3. *Semantic distance positively influences perceived quality.*

Clear and communicative design significantly increases the perceived effectiveness of icons. User-friendly behavior improves satisfaction, perceived quality, and effectiveness (Heard et al., 2020). Hu et al. (2020) stated that well-designed safety icons have decreased reaction times and minimized errors during emergencies, enhancing workplace safety and perceived system quality. Additionally, the communicativeness of an icon, which refers to its ability to convey intended information accurately, is considerably critical. Several studies have shown that clear, familiar, and appropriately dimensional icons are more effective in communicating safety messages than vague or unfamiliar ones (Chi et al., 2017; Chi et al., 2019; Chi & Dewi, 2014; Huang et al., 2002; McDougall et al., 2000). These findings emphasize the importance of using well-designed functional and aesthetically pleasing icons, enhancing safety systems' overall quality and effectiveness. Thus, it was hypothesized that:

Hypothesis 4. *Communicativeness positively influences perceived quality.*

To effectively convey safety information, the icon design should have an appropriate layout for arranging lines, shapes, and texts. Studies have shown that a well-organized layout significantly enhances user comprehension and trust in safety systems (Prasetyo et al., 2021). Consistent with this notion, neat and orderly layouts of elements that make up designs indicate the quality and reliability of icons (Bañares et al., 2018; Huang et al., 2002; Prasetyo et al., 2021). Such effective organization reduces cognitive overload, facilitating faster recognition and response – key facets in emergency cases (Prasetyo et al., 2021; Zeng et al., 2023). Similarly, predictable and familiar standardized layouts of icons also build trust among users who rely on them for safety (Park et al., 2017; Shen et al., 2021). High-quality icons are explicitly designed to support rapid decisions during crises but also boost long-term memory recall when applying safety procedures (Bovea et al., 2018). Consequently, space must be strategically considered when creating safety icons, and the layout must be carefully reviewed. Therefore, it was hypothesized that:

Hypothesis 5. *Layout positively influences perceived quality.*

Perceived quality is considered a critical cognitive factor that assesses the effectiveness of an icon's design in conveying the intended message accurately. This concept emphasizes the ability of icons to resonate with their audience, ensuring that the communication with their users is clear and compelling (Chi et al., 2017; Lin et al., 2019; Stylidis et al., 2019). According to Bovea et al. (2018), successful communication is achieved if recipients can correctly interpret the message conveyed by the icon. Thus, an icon's perceived quality measures aesthetic appeal, including functional clarity and communicative effectiveness. This study formulated five (5) hypotheses interrelated to

perceived quality (see Fig. 2).

3. Methodology

3.1. Participants

A total of 251 participants were recruited to participate in this study (Table 3). This study considered participants who are university students taking bachelor's degrees, master's degrees, and doctorates who understand the English language. This paper was distributed and surveyed using Google Forms and was administered right after the experiment from February 2024 to April 2024, capturing valuable insights from the demographic characteristics of the students.

3.2. Icon collection

ISO 7010:2019 was selected as the design basis. Since all icons in ISO 7010:2019 can be categorized as semi-abstract, the combined icon was created by adding a word function beneath the original ISO 7010:2019 icon (Table 4). For the image-related icon, a visual representation of the function was created—such as depicting someone capturing the function with a camera—while the concept-related icon primarily emphasized the icon's function. These two formats were created manually while remaining comparable to ISO 7010:2019.

This study did not use icon formats such as abbreviations, words, or arbitrary symbols. The arbitrary format was excluded because it is not universally understood; to grasp its meaning, participants would need an explanation of each icon before the experiment. Furthermore, the word and abbreviation formats were excluded because they rely solely on text labels, which may not be understood by individuals unfamiliar with a particular language, potentially leading to misunderstandings during emergencies. Icons not found in the standard or online were created by the authors following the classification principles established by Chi and Dewi (2014).

Table 3
Participants' demographic profile ($n = 251$).

Characteristics	Category	N	%
Nationality	Indonesia	12	40.00
	Philippines	10	33.33
	India	5	16.67
	Somaliland	2	6.67
	Pakistan	1	3.33
Gender	Male	19	63.33
	Female	11	36.67
Age	18–25 years old	20	66.67
	26–33 years old	10	33.33
Educational Background	Bachelor Student	13	43.33
	Master Student	16	46.67
	PhD Student	1	3.33
Visual Acuity	Need Corrective Lenses	6	20.00
	Do not need Corrective Lenses	24	80.00

*All participants were thoroughly informed about the study's objectives and experimental procedures.

3.3. Subjective rating test

Previous research has demonstrated that evaluating symbol attributes such as familiarity, concreteness, simplicity, meaningfulness, and accuracy in semantic representation is effective (Ibrahim El-bayoumy Ali et al., 2021). The data gathered from subjective ratings reflect participants' perspectives, as evidenced by their choices and preferences, and this approach is considered valid to the extent that it shows predictive accuracy (Rajavi et al., 2021). In this study, participants rated the icon styles based on their preferences, with a scale ranging from 1 (least preferred) to 7 (most preferred). The scale included 12 pairs of

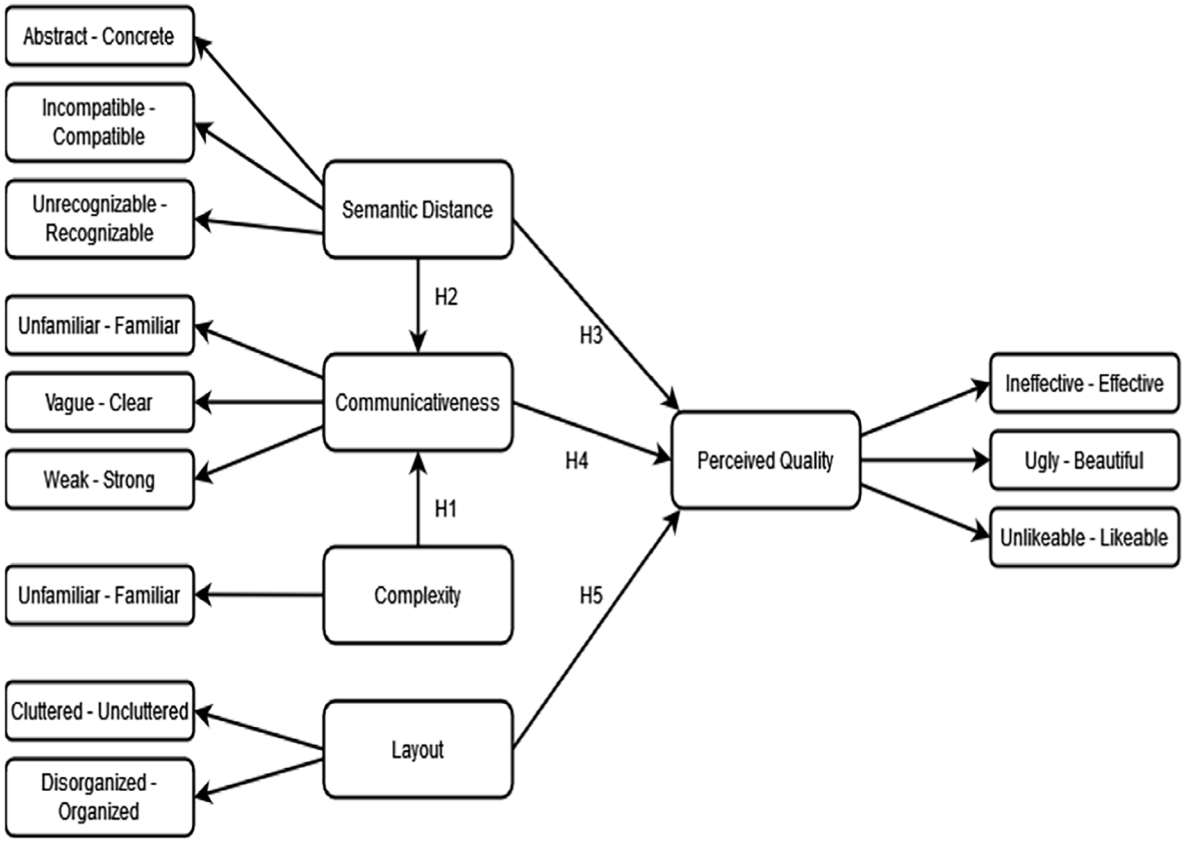


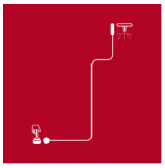
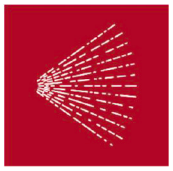
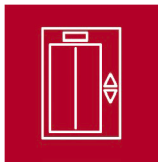
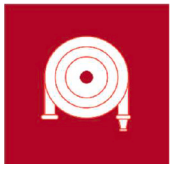
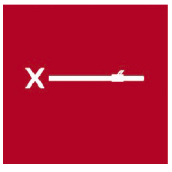
Fig. 2. The proposed SEM.

Table 4
Icons and formats classifications.

Number	Function	Icon Format			
		Image Related	Concept Related	Semiabstract (ISO)	Combined
1	Fire Extinguisher				
2	Fire Hose Reel				
3	Fire Ladder				
4	Fire Alarm				
5	Fire Emergency Telephone				
6	Fire Protection Door				
7	Fixed Fire Extinguishing Battery				
8	Wheeled Fire Extinguisher				
9	Portable Foam Applicator Unit				

(*continued on next page*)

Table 4 (*continued*)

Number	Function	Icon Format			
		Image Related	Concept Related	Semiabstract (ISO)	Combined
10	Water Fog Applicator Unit				
11	Fixed Fire Extinguishing Installation				
12	Fixed Fire Extinguishing Bottle				
13	Remote Release Station				
14	Fire Monitor				
15	Fire Blanket				
16	Firefighters' Lift				
17	Fire Alarm Flashing Light				
18	Unconnected Fire Hose				

semantic scales derived from the SEM framework: unrecognizable-recognizable, abstract-concrete, incompatible-compatible, vague-clear, weak-strong, unfamiliar-familiar, complex-simple, disorganized-organized, cluttered-uncluttered, unlikable-likable, ugly-beautiful, and ineffective-effective. Each icon was displayed one at a time to avoid bias, and participants were encouraged to answer this in their free time without time pressure to prevent fatigue. Fig. 3 shows the user interface, where the icon and its meaning appeared on the left, and the semantic differential scale was in the center. After evaluating an icon, participants should click "Next" to proceed to the next one.

3.4. Structural equation modeling

Structural equation modeling (SEM) is a multivariate data analysis technique utilized to analyze and prove complex relationships among multiple variables (Kurata et al., 2022; Kurata, Ong, Cunanan, et al., 2023; Kurata, Ong, Prasetyo, et al., 2023). The framework developed in this study comprises three exogenous variables (Semantic distance, Complexity, and Layout) and two endogenous variables (Communicativeness and Perceived quality). This research used SEM to estimate the strength and significance of each variable relationship, providing insights into how these variables contribute to Perceived Quality.

4. Results

The subjective rating test experiment assessed how participants perceived the icons using twelve semantic scales. Two hundred fifty-one (251) participants evaluated 40 workplace safety conditions and first aid icons, which were presented in four formats. A seven-point scale was used to identify each icon's most suitable semantic scale. The study then analyzed the data using structural equation modeling (SEM), which helped interpret the data framework created.

This study investigated the causal relationship between five (5) constructs or cognitive factors (semantic distance, communicativeness, complexity, layout, and perceived quality) through structural equation modeling. The SEM analysis employed a bootstrapping process, a robust statistical resampling technique, to assess the significance of these relationships and validate the hypothesized paths (Preacher & Hayes, 2008). The hypotheses test involved relationships between critical constructs such as Complexity, Communicativeness, Semantic distance, Layout, and Perceived quality. Each hypothesis aimed to explore how these constructs influence one another within the model, and the result of the bootstrapping process determined whether each hypothesis was accepted or rejected. The result of the bootstrapping process is shown in Table 5.

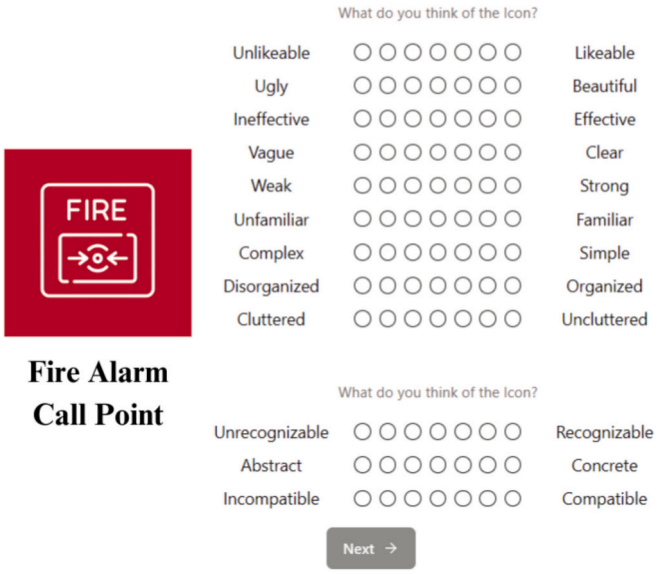


Fig. 3. Example of preference evaluation test screen.

The bootstrapping results from the SEM analysis strongly support all the tested hypotheses. The *p*-value results were <0.001, indicating significant relationships among the constructs within the study, which led to the acceptance of all hypotheses in this study. Fig. 4 shows the final model. H1 implied that complexity positively communicativeness (β:0.199; p-value = 0.000). Next, H2 proved that semantic distance positively influenced communicativeness (β:0.762; p-value = 0.000). H3 verified that semantic distance positively influenced perceived quality (β:0.158; p-value = 0.000). Furthermore, H4 verified that communicativeness positively influenced perceived quality (β:0.581; p-value = 0.000). Lastly, H5 verified that layout positively influenced perceived quality (β:0.215; p-value = 0.000).

Moreover, the factor loadings (FL) for each measure were also calculated, as shown in Table 6. Based on the results, all factor loadings were at least 0.70, indicating a strong construct validity. Therefore, these measures effectively represent each identified construct.

Table 7 displays the composite reliability (CR) and average variance extracted (AVE) metrics alongside Cronbach's alpha to assess convergent validity. The data confirms that all constructs in the model meet the necessary standards for validity and reliability (Sarstedt et al., 2019).

The analysis of model fit indices shown in Table 8 between the saturated and estimated models reveals a close congruence, affirming a satisfactory model fit. Both models show an SRMR of 0.033, indicating excellent replication of the observed covariance matrix. The d_ULS value stands consistently at 0.086 for both, underscoring their effective data approximation. A minor variation in the Geodesic Discrepancy (d_G) from 0.252 to 0.251 between the saturated and estimated models suggests robust model estimation. Additionally, the Chi-square improvement from 3390.519 in the saturated model to 3351.784 in the estimated model and a slight increase in the NFI from 0.910 to 0.911 further validate the estimated model's ability to accurately capture the underlying data structure. These metrics collectively demonstrate the estimated model's reliability and validity in fitting the hypothesized relationships within the study.

The Heterotrait-Monotrait Ratio (HTMT) table provides insights into the discriminant validity of the analyzed constructs (see Table 9). Generally, HTMT values below 0.90 indicate good discriminant validity, meaning that the constructs are sufficiently distinct. Results show that the HTMT values between Communicativeness and Complexity (0.844) and between Complexity and Layout (0.886) suggest that these constructs are distinguishable, supporting discriminant validity. However, the HTMT values between Communicativeness and Layout (0.904) and between Layout and Perceived Quality (0.913) are slightly above the 0.90 threshold, indicating a potential overlap that could challenge the distinctiveness of these constructs. Thus, a more concerning results reveal higher HTMT values observed between Communicativeness and Perceived Quality (0.968), Communicativeness and Semantic Distance (0.975), Layout and Semantic Distance (0.926), and Perceived Quality and Semantic Distance (0.938). These elevated values suggest significant overlap, indicating that these constructs may not be distinct from one another and could pose issues with discriminant validity.

Table 5
Bootstrapping results.

Hypothesis	Relationship	*P*-value	Decision
H1	Complexity → Communicativeness	< 0.001	Accepted
H2	Semantic Distance → Communicativeness	< 0.001	Accepted
H3	Semantic Distance → Perceived Quality	< 0.001	Accepted
H4	Communicativeness → Perceived Quality	< 0.001	Accepted
H5	Layout → Perceived Quality	< 0.001	Accepted

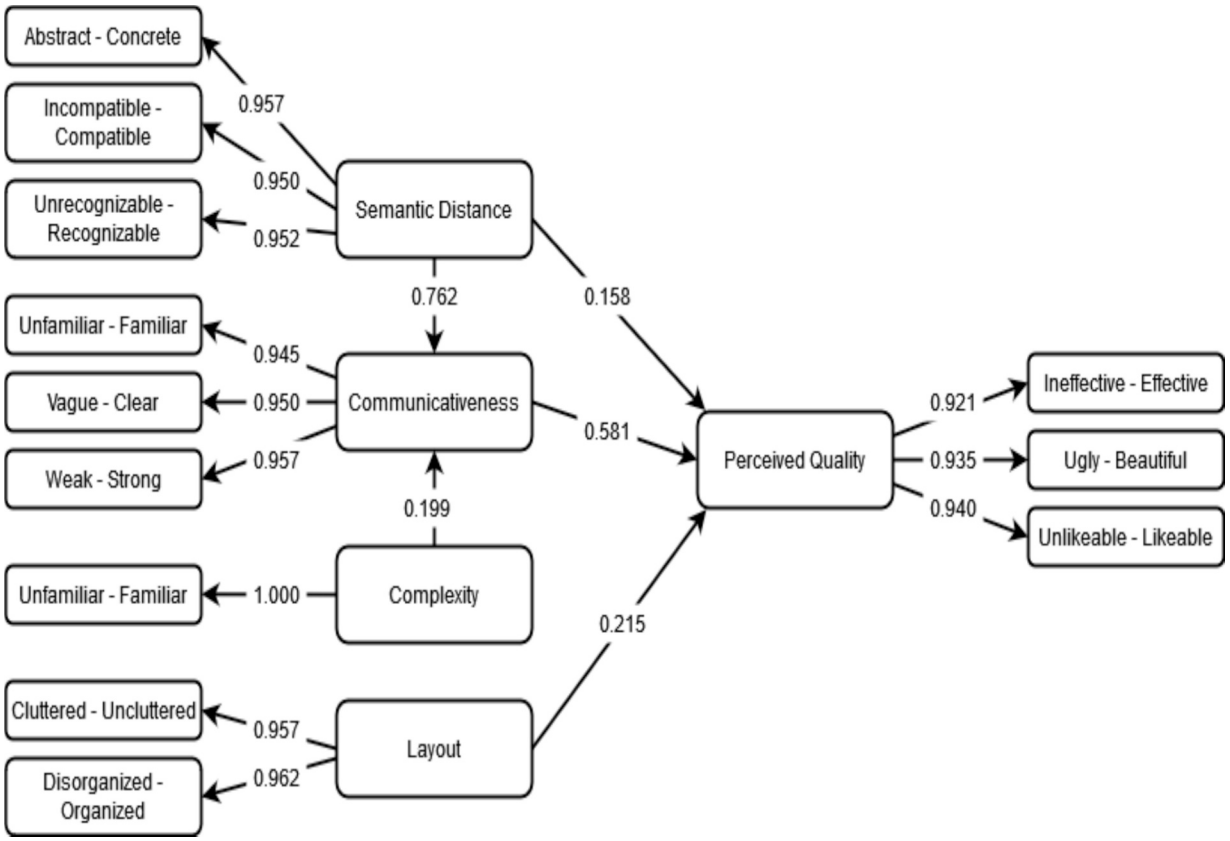


Fig. 4. The final model.

Table 6
Semantic scale statistics result.

Cognitive Factor	Semantic Scale	Mean	StDev	Final Model Factor Loading
Semantic Distance	Unrecognizable – Recognizable	4.6307	1.7592	0.952
	Abstract – Concrete	4.6083	1.6952	0.957
	Incompatible – Compatible	4.6877	1.7692	0.950
Communicativeness	Unfamiliar – Familiar	4.6535	1.7748	0.945
	Vague – Clear	4.6912	1.7630	0.950
	Weak – Strong	4.6496	1.7706	0.957
Complexity	Complex – Simple	4.7478	1.6963	1.000
Layout	Cluttered – Uncluttered	4.8202	1.6834	0.957
	Disorganized – Organized	4.8096	1.6773	0.962
Perceived Quality	Ineffective – Effective	4.789	1.6984	0.921
	Ugly – Beautiful	4.7237	1.7304	0.935
	Unlikeable – Likeable	4.7728	1.7325	0.940

Table 7
Convergent validity.

Cognitive Factor	Cronbach's Alpha	Composite Reliability (rho_a)	Composite Reliability (rho_c)	Average Variance Extracted (AVE)
Communicativeness	0.947	0.947	0.966	0.904
Layout	0.914	0.917	0.959	0.921
Perceived Quality	0.924	0.925	0.952	0.868
Semantic Distance	0.949	0.949	0.967	0.908

Table 8
Model fit.

Parameter	Saturated Model	Estimated Model
SRMR	0.033	0.033
d_ULS	0.086	0.086
d_G	0.252	0.251
Chi-square	3390.519	3351.784
NFI	0.910	0.911

5. Discussion

The study intends to determine how latent variables such as semantic distance, communicativeness, complexity, and layout influence the perceived quality of fire safety signage icons using structural equation modeling (SEM). Two hundred fifty-one (251) participants participated by answering the self-administered questionnaire distributed through Google Forms administered right after the conducted experiment from February 2024 to April 2024.

As determined from the results, Complexity indicated a positively significant relationship with Communicativeness ($\beta = 0.199, p < 0.001$). Shen et al. (2020) highlighted that icons with a good level of complexity but not too simple or too detailed effectively convey their intended message. 66.67 % of the respondents aged 18–25 years old, which pose a lesser chance of incorrect understanding among users; however, according to the study of Wu et al. (2022), older adults are more likely to incur errors and long reaction times with high visual complexity icons. Moreover, although complexity may make something poorly understood, a well-balanced design adds to communicativeness and provides enough detail to be informative but not so much as to overwhelm the user (McDougall et al., 2016). Visually appealing representations affect

Table 9
Heterotrait-Monotrait ratio.

Latent Variables	Communicativeness	Complexity	Layout	Perceived Quality	Semantic Distance
Communicativeness					
Complexity	0.844				
Layout	0.904	0.886			
Perceived Quality	0.968	0.831	0.913		
Semantic Distance	0.975	0.837	0.926	0.938	

an icon's complexity; however, the study's result contradicts that aesthetic icons do not show easier comprehension among users, as evident in the study of Collaud et al. (2022).

Second, Semantic distance showed a significant relationship with Communicativeness ($\beta = 0.762$, $p < 0.001$) and Perceived quality ($\beta = 0.158$, $p < 0.001$). Icons with closer semantic distances closely resembling things they represent are more effective (Chi & Dewi, 2014). Moreover, to ensure that users do not experience confusion when understanding icons, these should be abstractly different for quick recognition and to be more perceptive (Silvennoinen et al., 2017). Users who find icons that are easy to recognize and understand are more likely to perceive them as high-quality designs (Ganor, & Te'eni, D., 2016). Meanwhile, a study done by Zhang et al. (2024) indicated that an icon's semantic distance substantially affects people's cognitive performance, and better captures people's vigilance.

Third, Communicativeness positively influences Perceived quality ($\beta = 0.581$, $p < 0.001$). Among other evaluated constructs, communicativeness had the most substantial direct effect on perceived quality. Thus, clear communication plays a vital role in the icon design process: if the icon provides its message, a user is more predisposed to rank it as of good quality (McDougall et al., 2000). It was also found that through communicativeness, complexity has indirect effects on perceived quality through their positive influence on communicativeness. This indicates that while users may not prefer overly complex icons, a certain level of complexity and aesthetics is necessary to ensure that the icon communicates effectively, enhancing perceived quality (Ibrahim El-bayoumy Ali et al., 2021; Jylhä & Hamari, 2022).

Finally, Layout positively influences Perceived quality ($\beta = 0.215$, $p < 0.001$). Results suggest that a well-organized and uncluttered layout significantly contributes to users' perceptions of an icon's quality. Participants in the study favored fire safety icons with a clear and systematic arrangement of elements, which aligns with previous research emphasizing the importance of layout in visual design (Bañares et al., 2018). In addition, demographic factors such as age, gender, and nationality may have little impact on how icons are perceived based on aesthetics (Jylhä & Hamari, 2022).

5.1. Limitations and future research

The study acknowledges several limitations. One fundamental limitation is related to the participant's demographics, as the research primarily focuses on international university students. The experiment commenced in February 2024, and due to time constraints, the number of participants was limited to 251 respondents. Future studies may increase the number of participants to enhance the robustness of the findings further. Furthermore, as the study solely considered a homogenous sample group of international university students from Indonesia, the Philippines, India, Somaliland, and Pakistan, the perceptions of quality across different cultures and demographics may provide a more in-depth result that can be weighed in future studies. These considerations may examine a more diverse sample, which includes participants from different age groups, varied cultural backgrounds, and occupations. Another limitation is that the icons used in the study were uniformly designed with a green square background and a white symbol to minimize potential biases. Exploring the impact of different design elements (e.g., color schemes, icon shapes, etc.) on perceived quality may contribute to a different perspective of people towards the icons, which may influence its results.

This study analyzes the icons' format rather than exploring individual iconography. Future studies can examine specific characteristics of individual icons and other factors, such as situational factors (e.g. different types of buildings, emergency scenarios), users' technological familiarity, aesthetics, usability, and emotional response, and how these variables influence perceived quality. Lastly, recorded values from the Heterotrait-Monotrait (HTMT) indicate potential issues with the discriminant validity results, particularly between the constructs Communicativeness - Perceived quality, and Semantic distance - Perceived quality. Future studies could address these overlaps and ensure clear distinction between these constructs.

6. Conclusions

This study seeks to identify how semantic distance, communicativeness, complexity, and layout impact the perceived quality of fire safety signage icons. A total of 251 participants evaluated 76 icons categorized between 19 functions and four icon formats (Image-related, concept-related, semi-abstract, and combined). Furthermore, the study identified twelve pairs of semantic scale words that best describe the corresponding cognitive factors (semantic distance, communicativeness, complexity, layout, and perceived quality). The structural equation modeling (SEM) revealed that the combined icon format, which integrates image icons and text labels, is the most effective in conveying safety information. This format was consistently preferred across various semantic scales, particularly regarding perceived quality, communicativeness, complexity, and layout. The study confirms that icons with a smaller semantic distance closely resembling the objects or actions they represent are more easily understood and perceived as higher in quality.

The SEM analysis further highlighted that communicativeness had the most significant factor influencing perceived quality, with complexity and layout also playing crucial roles. While complexity can sometimes hinder understanding, a balanced level of complexity that is not overwhelming can enhance communicativeness, leading to a higher perception of quality. A well-organized layout also significantly contributes to the perceived quality of icons. These findings provide valuable insights for designers and relevant agencies in creating and standardizing fire safety signage. By focusing on communicativeness, semantic distance, layout, and complexity in this order, designers and related agencies can develop practical fire safety signage standards that enhance safety and awareness, making it easier for individuals to respond appropriately in emergencies.

CRediT authorship contribution statement

Yogi Tri Prasetyo: Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Alif Bagas Adiutomo:** Writing – original draft, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yoshiki B. Kurata:** Writing – review & editing, Validation, Supervision, Formal analysis. **Retno Widyaningrum:** Writing – review & editing, Validation, Supervision. **Maela Madel L. Cahigas:** Writing – review &

editing, Validation, Supervision, Funding acquisition. **Ardvin Kester S. Ong:** Writing – review & editing, Visualization, Validation, Funding acquisition.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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