

How Graffiti and Surroundings Shape Visitor's Perceived Safety: A Multiple Conjunctural Causation Analysis

Yue Mao^{a,1}, Xu Zhang^{a,1}, Lei Xiong^b, Bo-Wei Zhu^{a,*}, Guan-Qiang Wang^{a,*}, Zi-Jie Zou^a, Gwo-Hshiung Tzeng^c

^a Faculty of Humanities and Arts, Macau University of Science and Technology, Macau

^b Faculty of Innovation and Design, City University of Macau; Avenida Padre Tomás Pereira Taipa, Macau

^c Graduate Institute of Urban Planning, College of Public Affairs, National Taipei University, University Rd. 151, San Shia District, New Taipei City 23741, Taiwan

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ABSTRACT

Prior research has reported divergent findings regarding the relationship between the presence of graffiti and visitors' perceived safety in public open spaces. Subsequent research has re-examined this relationship by considering graffiti classification and perceivers' characteristics. Nevertheless, exploration of the conjunctural effects of graffiti's aesthetic and surrounding environmental signals on perceived safety remains limited. To address this gap, this research draws on Signalling theory and Gestalt perspectives to investigate how graffiti's visual elements and surrounding environmental conditions jointly influence perceived safety. Using 160 graffiti sites in Macau as case studies, a Rough Set Approach (RSA) was employed to establish five decision rules. The findings reveal that visual cues of graffiti and surrounding environmental cues interact conjuncturally to shape visitors' perceived safety. These results not only deepen understanding of the complex mechanisms linking graffiti and perceived safety, but also provide practical guidance for urban public space management particularly regarding rational resource allocation and the enhancement of safe and inclusive environments.

1. Introduction

Safety is a core dimension in the assessment of public open spaces (Mehta, 2014). Building safer urban public spaces requires attention to both objective safety and perceived safety (Grover, 2016). Yet, scholarly discussions of 'safe spaces' have tended to emphasize objective indicators, such as crime rates, traffic accidents, and urban-crime correlations (Cheong & Wu, 2015; Shi & Deng, 2019; Wang et al., 2020). Although reductions in crime contribute to improved perceived safety, perceived safety cannot be reduced to crime alone; it also derives from perceptions of the environmental, social, and other factors (Putrik et al., 2019). Among these, environmental factors play a crucial role (Harvey et al., 2015; Lee et al., 2024; Türtseven Doğrusoy & Zeynel, 2017), with vision constituting the primary channel through which such perceptions are shaped (Edensor & Sumartojo, 2015). Graffiti, as a salient visual stimulus, evokes emotional experiences and perceptions of urban environments (Wen & Peng, 2025).

Graffiti has long been contested due to its historical association with vandalism and crime (Szubielska & Ho, 2022). According to the Broken Windows theory (BWT), graffiti signals social disorder, suggests a lack of social control and reduces perceived safety and may trigger further disorderly behavior (Wilson & Kelling, 1982). Empirical studies have confirmed the correlations between the presence of graffiti and violent crime in urban public open spaces (He et al., 2017; Lee et al., 2023; Walker & Schuurman, 2015), reinforcing the perception that graffiti is a marker of disorder that provokes fear and undermines perceived safety (Austin & Sanders, 2007). Yet this perspective has been challenged: some studies found no significant relationship between graffiti and serious crime (Diniz & Stafford, 2021), while others report positive associations with perceived safety (Arroyo Moliner & Clavell, 2016).

These divergent findings suggest that important mediating variables have been overlooked. Subsequent research has incorporated factors such as graffiti classification (Vanderveen & Van Eijk, 2016) and perceiver gender (Navarrete-Hernandez et al., 2021). Yet other

* Corresponding authors.

E-mail addresses: 3250007463@student.must.edu.mo (Y. Mao), 2220018369@student.must.edu.mo (X. Zhang), leixiong@cityu.edu.mo (L. Xiong), bwzhu@must.edu.mo (B.-W. Zhu), gqwang@must.edu.mo (G.-Q. Wang), 2220025478@student.must.edu.mo (Z.-J. Zou), ghtzeng@gm.ntpu.edu.tw, ghtzeng@mail.knu.edu.tw (G.-H. Tzeng).

¹ Yue Mao and Xu Zhang contributed equally to this work and should be considered co-first authors.

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potentially relevant variables remain underexplored. For instance, aesthetic qualities—such as perceived attractiveness—have been shown to shape safety perceptions (Zhou et al., 2022), but the role of graffiti's aesthetic characteristics in influencing perceived safety has not been systematically examined.

Gestalt theory emphasizes that individuals perceive environments as holistic configurations rather than isolated elements (Koffka, 1935; Kohler, 1929). Empirical evidence from studies of paintings, texts, and built environments confirms this holistic processing (Morin et al., 2007). Applied to urban graffiti, this perspective implies that urban graffiti is not evaluated in isolation but in relation to its surrounding context. Indeed, prior research demonstrates that environmental attributes such as street cleanliness and visibility significantly shape perceived safety (Bivina & Parida, 2019; Gharaveis et al., 2018). Consequently, perceptions of graffiti and its surrounding conditions interact to form an overall judgment of safety (Vanderveen & Van Eijk, 2016). It is necessary to explore the synergistic effect of the aesthetic elements of graffiti and the surrounding environmental elements on the perceived safety in urban public open spaces.

While theoretical models often assume that individuals make rational decisions based on complete knowledge of objective factors, in practice human perception is constrained by limited information acquisition and processing capabilities, thereby precluding fully rational judgments (Wang, Zhu, et al., 2025). Signalling theory posits that the judgments and perceptions are shaped by signals composed of perceptible elements. In the context of graffiti, identifying and verifying such signals that influence perceived safety is essential to understanding the mechanisms underlying perceived safety. Within the visual dimension, elements such as color, content, and structure can serve as signals related to aesthetic appeal (Chamberlain et al., 2022). Within the environmental dimension, maintenance and cleanliness cues, such as littering, broken windows, and vacant or abandoned buildings, have been shown to strongly affect perceptions of safety (Curl & Mason, 2019; Wilson & Kelling, 1982; Zhang et al., 2021), while spatial visibility has similarly been linked to perceived safety (Gharaveis et al., 2018). Accordingly, these variables can be conceptualized as potential signals influencing perceived safety.

The overall effectiveness of signals cannot be understood as the simple sum of their individual effects (Bove & Benoit, 2020). Rather, their impact often emerges from complex interactions, whereby signals in combination may exert greater—or lesser—effects than when operating in isolation. This indicates the presence of conjunctural causal configurations. Neglecting such complexity risks reinforcing biases in the literature regarding the positive or negative effects of graffiti, potentially leading to suboptimal allocation of public open space management resources. Systematically examining these conjunctural pathways is therefore crucial for decision-makers to optimize resource allocation and strategically strengthen safety-related signals in urban open space.

Addressing these gaps, this study aims to investigate how graffiti's visual elements and surrounding environmental conditions jointly influence visitors' perceived safety. The study was conducted across all identified graffiti sites within Macau's public open spaces. First, drawing on relevant theoretical frameworks, the study identified the potential graffiti visual elements and surrounding environmental elements that may shape perceived safety, along with their associated signal cues. Next, field surveys were conducted in which respondents evaluated perceived safety at graffiti sites (decision attributes), while researchers systematically audited graffiti characteristics and environmental conditions (conditional attributes). Finally, the Rough Set Approach (RSA) was applied to uncover multiple conjunctural causations between graffiti visual cues, environmental cues, and public perceptions of safety.

The remainder of this paper is structured as follows. Section 2 reviews the relevant theoretical frameworks. Section 3 details the research design and methods. Section 4 reports the empirical results, followed by a discussion in Section 5. Section 6 concludes with the theoretical and

practical implications, as well as limitations.

2. Literature review

2.1. Signalling theory and synergistic effects

Human perception can be understood as a continuous process of interpreting signals embedded in the environment (Irwin, 1993). A signal functions as a medium that conveys perceptible indicators, enabling the receiver to derive meaning and make decisions under conditions of uncertainty (Bove & Benoit, 2020). Signalling theory, originally developed in the context of labor market (Stötzer et al., 2023), has since been extended to organizational studies to explain how firms communicate quality and reduce information asymmetry through observable behaviors and attributes (Drover et al., 2018; Spence, 1974). Early applications largely emphasized isolated or consistent signals before the introduction of the signal set concept; however, later work highlights that the process of individual perception is shaped by the interaction of multiple organizational signals (inconsistent signals), a complex cognitive process that does not depend on a single signal (Drover et al., 2018). This perspective resonates with the Gestalt theory, which posits that environmental cues are integrated into holistic perceptual configurations rather than being processed as isolated elements. Moreover, studies indicate that different types of signals exert dynamic and context-dependent effects; when multiple signals coexist, their interactions may generate complementary or synergistic outcomes, producing cumulative effects that exceed the influence of individual signals in isolation (Ko & McKelvie, 2018).

Although previous studies have demonstrated that graffiti affects perceived safety, the interaction between graffiti and other environmental factors remains underexplored from a systematic perspective. An increasing body of environmental research emphasizes the need to holistically examine how multiple contextual factors jointly shape visitors' perception (Li et al., 2025; Wang, Li, et al., 2025; Wang, Zhu, et al., 2025; Zheng et al., 2024; Zhu et al., 2025). Similarly, scholarship in criminology and service research has extensively highlighted the interactive effects of multiple signals (Bove & Benoit, 2020; Pyrooz & Densley, 2016). However, such integrative approaches have yet to be systematically applied to graffiti in public spaces, limiting the understanding of how multiple cues jointly shape perceptions of safety and constraining the development of context-sensitive urban design and management strategies.

2.2. Visual elements of graffiti

The identification of graffiti's visual elements in this study builds on the four main themes of color, content, production, and structure proposed in the study of graffiti and perceived attractiveness (Chamberlain et al., 2022). However, the keywords extracted in that work were insufficiently generalized and failed to adequately capture the complexity of graffiti's visual attributes, thereby limiting their utility for systematic coding and subsequent empirical analysis. To address this limitation, this study refines the categorization by incorporating more appropriate keywords and expanding the attribute set. As Chamberlain et al. (2022) note, additional attributes such as balance and rhythm provide greater analytical depth. Therefore, in order to enrich and harmonize the classification of graffiti's visual attributes, this study redefined and extended the criteria, drawing on both prior literature and domain-specific adjustments.

Previous research on visual attributes, particularly in the field of image feature recognition, has typically emphasized color, texture, and shape are considered as the most common image visual elements (Liu et al., 2007; Martínez-Jiménez et al., 2018). Within color dimensions, studies have focused on the discussion of hue, saturation, and lightness or brightness (Kim et al., 2020; Torres et al., 2020). Hue distinguishes different colors, each of which can evoke different emotional and

perceptual responses—for instance, excitement, danger—depending on individual and contextual factors (Kim et al., 2020; Takahashi & Kawabata, 2018; Yildirim et al., 2015). Empirical evidence further suggests that the psychological effects of colors often align with culturally and conceptually associated traits (e.g., white-purity, green-healthy, pink-feminine traits; Tham et al., 2020).

Given the complexity of color effects, many studies have reduced hues to broad categories of warm and cold (Kim et al., 2020; Linares et al., 2021; Roschk et al., 2017). According to the color ring, those close to blue (e.g., purples and greens) are cool tones and those close to red (e.g., yellows and oranges) are warm tones (Linares et al., 2021; Porter & Mikellides, 1976). Beyond hue, chroma or saturation—defined as vividness of a color—has also been widely employed, typically in terms of low versus high saturation, to examine impacts on people and products (Kunz et al., 2020; Pichierra & Pino, 2023).

Early studies selected roughness, contrast, directionality, regularity, and linearity to describe the characteristics of texture properties (Tamura et al., 1978). Among these, roughness, contrast, and regularity have been regarded as the most salient measures corresponding to visual perception (Fujii et al., 2003). More recent research in the context of graffiti distinguished textures as either smooth or rough (Zhang & Chan, 2022).

Shape has been widely recognized as fundamental visual attribute in image studies (Liu et al., 2007). Psychological research has suggested that objects with curved factors in an image tend to elicit more positive evaluations compared to those with angularity factors (Silvia & Barona, 2009), a hypothesis subsequently confirmed in experimental image perception studies (Hübner & Fillinger, 2016). Accordingly, images can be broadly categorized as curved or angular, with each form eliciting distinct affective and perceptual responses.

Beyond the shape elements, this study extends the delineation of graffiti structure by incorporating additional visual characteristics such as balance and rhythm. Balance is a central feature in the organization of images (Wilson & Chatterjee, 2005). Perceived balance is a complex feature shaped by multiple factors, and computational approaches to predicting subjective balance have shown promise. For example, Hübner and Fillinger (2016) found that symmetry and balance were highly correlated in the aesthetic preference assessment. Earlier research applied the Assessment of Preference for Balance (APB), an objective symmetry-based measure (Wilson & Chatterjee, 2005), but these findings were limited to simple images, leaving its applicability to complex images uncertain. Accordingly, this study evaluates balance in graffiti by distinguishing between symmetric and asymmetric structures.

Rhythm, similarly, constitutes a pivotal factor of the visual art experience (Levin et al., 2019). Beyond its well-known role in music and poetry, rhythm also manifests in static art forms such as painting, sculpture, and architecture. In the context of painting, rhythm is understood as a structural property (Tosaki & Tosaki, 2017). Based on this point, this study categorizes the rhythm of graffiti as either rhythmic or non-rhythmic.

Beyond structural and compositional elements, this study further introduces the content attributes into the conditions of image visual elements. Figurative imagery is defined as the depiction of objects that closely resemble their real-world counterparts, representing them as they are conventionally perceived. By contrast, abstract imagery refers to the use of imaginative or symbolic factors to deliberately alter real-world appearances for artistic or expressive purposes (Naletelich et al., 2023).

In addition to examining the aforementioned visual attributes of graffiti, this study also considered the inclusion of visual environmental elements, i.e., elements of the surroundings.

2.3. Environmental elements

The negative impact of a chaotic physical environment on feelings of safety is particularly pronounced, as evidenced by graffiti, litter, and

abandoned buildings (Duchowny et al., 2020; Jeon & Kim, 2023). As emphasized by the Broken Windows Theory, disorderly environmental cues suggest a lack of social control, thereby reducing perceived safety and potentially triggering more disorderly behavior (Wilson & Kelling, 1982). Previous studies have emphasized that vacant and abandoned buildings pose a significant threat to safety (Kondo et al., 2015). Numerous studies have shown that abandoned buildings may serve as gathering places for criminals, linking them to criminal activities and significantly negatively impacting people's perceived safety (Deng et al., 2022; Garvin et al., 2013; Spelman, 1993).

A good physical environment can enhance people's perceived safety in a space. Existing research has found that well-maintained sidewalks are important environmental elements for pedestrians' perceived safety (Hong & Chen, 2014). Cleanliness, as a key component of sidewalk quality, is believed to have a direct impact on perceived safety. Studies have shown that people feel safer walking on clean and tidy sidewalks (Bivina & Parida, 2019; Ferrer et al., 2015). Additionally, the concept of 'Eyes on the Street' has been a central topic in research on the relationship between safety and the environment. The concept of 'eyes on the street' was first proposed by Jacobs (1961), who argued that increasing the 'eyes on the street' plays a central role in enhancing local safety. This concept emphasizes that certain environmental elements can increase natural surveillance on streets (Ceccato, 2019). Crime Prevention Through Environmental Design (CPTED) is widely used in the assessment and improvement of community environmental and safety issues (Lee et al., 2016; Lee et al., 2023). CPTED suggests that natural surveillance (e.g., visible windows and balconies) can serve as a form of surveillance, providing the possibility of being observed and thereby reducing crime (Glasson & Cozens, 2011). In addition to visible windows and balconies, environmental visibility is also a key design factor in addressing perceived safety issues (Gharaveis et al., 2018). Unlike natural surveillance, which emphasizes whether someone is watching, environmental visibility focuses more on the extent of physical visibility and unobstructedness. Environmental visibility elements are crucial to the study of perceived safety, as there is a strong positive correlation between the likelihood of being seen and perceived safety (Mahrous et al., 2018). Visibility is defined as the degree of visual accessibility; the higher the visibility, the lower the safety risk, and the safer the perceived environment. As Te Braak and van Tienen (2025) emphasize, low visibility has potential concealment, weakens people's ability to identify dangers, and is considered dangerous.

Although these environmental factors have been repeatedly confirmed in previous discussions on perceived safety, there is still a lack of relevant discussion in studies on graffiti and perceived safety. Based on this, this study selected street cleanliness, natural surveillance, the condition of abandoned buildings, and the visibility of graffiti as observable variables of the surrounding environment.

3. Materials and methods

3.1. Study design and methodology

This study aims to understand the multiple conjunctural causation between graffiti visual elements and their surrounding environmental elements (graffiti visibility and street cleanliness) and perceived safety from a comprehensive and systematic perspective. RSA is used to discover the logical rules between graffiti visual elements and their environmental elements and perceived safety. The Rough Set Approach (RSA) was first proposed by Pawlak in 1982 as a mathematical method for handling uncertainty (Pawlak & Skowron, 2007). Rough set analysis can objectively process and describe uncertain phenomena in observational data without requiring any prior information (such as membership functions or probability distribution forms) (Cheng et al., 2021). It can be applied to problems where classification data is imprecise, uncertain, or ambiguous (Guan & Bell, 1998; Lejeune et al., 2019; Peng et al., 2004). It has advantages in discovering data rules and addressing

intervention and counterfactual-related questions (Yao et al., 2019). Its mathematical foundation is based on the assumption that every object in the domain is associated with data and knowledge, and objects with the same information characteristics are indistinguishable (Greco et al.,

1999). Existing research applying RSA has focused on extracting sensory information from imprecise design information (Zhai et al., 2009), uncovering human emotional preferences from product morphological characteristics (Wang & Zhou, 2021; Zhai et al., 2009), and exploring

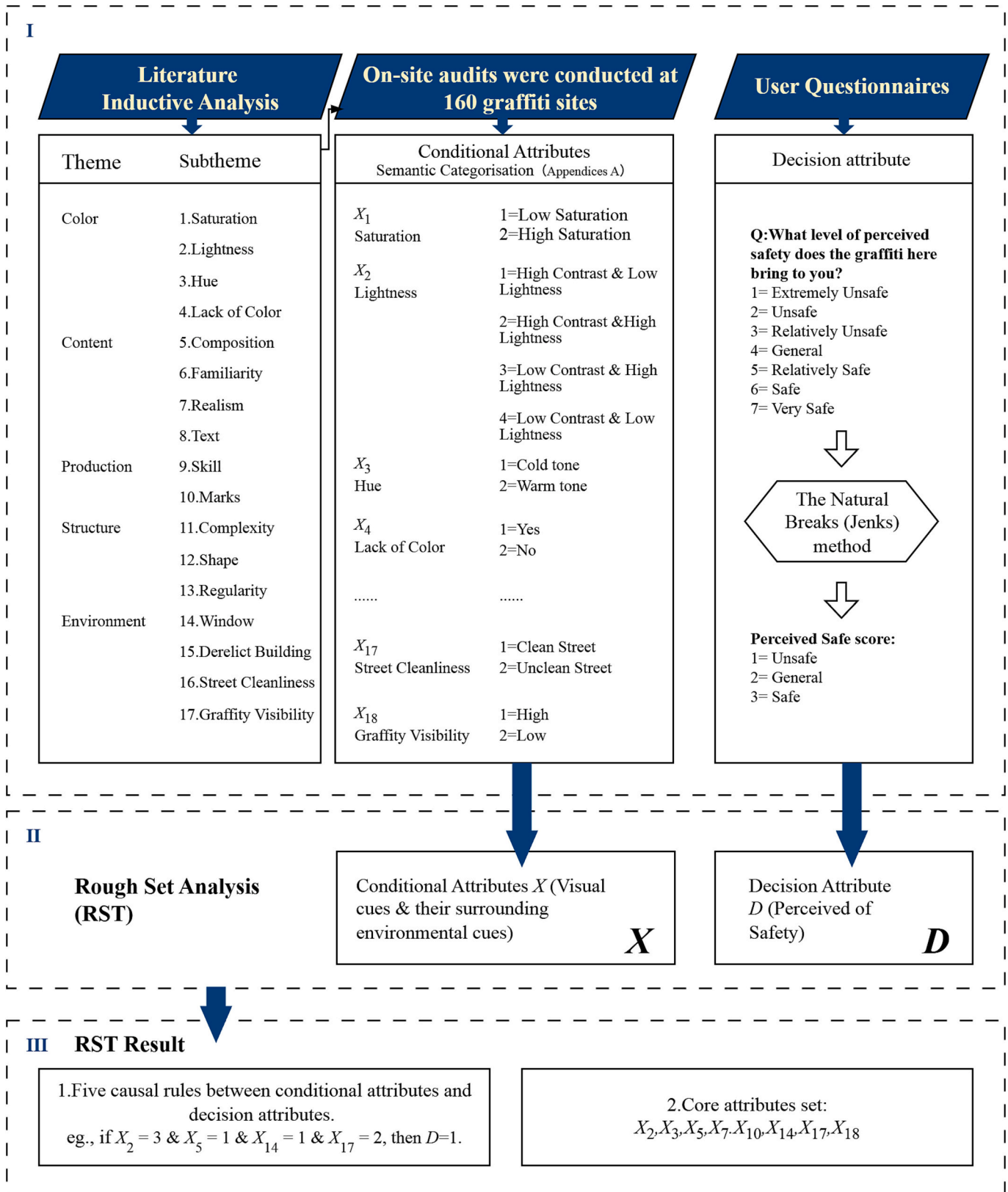


Fig. 1. Research flowchart.

comprehensive causal relationships between the environment and human attitudes (Fan et al., 2023; Mei et al., 2022; Wang, Li, et al., 2025; Zhu et al., 2025). Therefore, RSA is more effective in identifying the core elements that influence perceived safety from a large amount of attribute information (visual elements and their corresponding environmental elements) and in revealing easy-to-understand logical rules between attributes and decisions (perceived safety).

The entire research process, including the methods and steps at each stage, is shown in Fig. 1. First, this study identified the visual elements of graffiti and the environmental elements that influence perceived safety through a literature review, forming a preliminary assessment framework. Based on preliminary investigations and expert experience, this framework was refined into the final assessment framework, which was used to audit 160 graffiti sites in Macau. Next, the study collected pedestrians' perceptions of graffiti-related perceived safety at each graffiti site as decision attributes. Finally, the study employed RSA to extract decision rules from the combination of conditional attributes and decision attributes in the attribute value table, presenting the causal relationships between graffiti, its surrounding environment, and perceived safety in the form of if-then rules. This study followed the RSA data analysis method described by Fan et al. (2023). Detailed steps of the RSA are provided in the supplementary file.

3.2. Study areas

This study uses graffiti in public spaces throughout the Macau urban area as a case study (Fig. 2). The Macau urban area consists of two parts: the peninsula and the island. The Macau Peninsula is a densely populated urban area and a historic district, home to 84.88% of Macau's population. The public spaces in this area are planned and constructed in a compact layout, while the island section is a newly developed urban area. Compared to the peninsula, the public spaces in this area exhibit significant differences in scale and form (Ye et al., 2018). Land reclamation and planning initiatives carried out at different times have created diverse urban spaces, providing a rich variety of venues for graffiti art and opening up more possibilities for the expression of graffiti art forms and themes. In addition, the fusion of diverse cultures in Macao and the openness and inclusiveness of government policies have provided a relaxed and free environment for the development of cultural diversity in Macao's urban public spaces (Zhang & Chan, 2022). This study found through a comprehensive survey of the entire urban area that graffiti activities in Macau encompass both government-led, professionally created art and graffiti painted by ordinary citizens and tourists. The environments in which graffiti is found cover a wide variety of public spaces, such as squares, streets, residential areas, commercial areas, waterfront spaces, parks, transportation hubs, tourist attractions, and schools. These factors highlight the strong diversity in the urban density, form, land use, and types of public spaces where graffiti is found, which is why this study selected Macau as its research area.

The research team identified a total of 160 graffiti sites in public open spaces within the urban area of Macau through observation. The location of each graffiti site was recorded using a single positioning device to collect latitude and longitude data, which were then marked on a map to create a map of graffiti sites within the study area (Fig. 2). This study categorizes graffiti into two main types: graffiti tags (Type A) and graffiti murals (Type B). Graffiti tags consist of simple graffiti and painted text (Fig. 3).

3.3. Data collection

This paper utilises three data sources: an on-site audit of visual elements and surrounding environmental elements related to graffiti, basic demographic information about participants, and participants' assessments of their perceived safety in relation to graffiti.

3.3.1. Decision attribute collection

This study was conducted from March 2023 to April 2024 in Macau, where data were collected through a questionnaire survey of pedestrians passing by graffiti sites. The aim was to explore participants' perceived safety regarding graffiti and its surrounding environment. The order of questionnaire distribution locations was randomly selected by researchers from 160 graffiti sites. Considering seasonal variations and the patterns of pedestrian activity observed at graffiti sites during initial observations, the questionnaire surveys were uniformly scheduled during the summer from 14:30 to 17:30 daily and during the winter from 13:30 to 16:30 daily to ensure coverage of the primary pedestrian activity periods. This study employed a continuous survey method, collecting data continuously at each graffiti site until 30 valid questionnaires were successfully obtained. If the target sample size was not achieved on a given day, the survey would continue at the same time the following day. If the environment of a graffiti site changed during the questionnaire distribution period, the questionnaire for that site would be redistributed.

Before completing the questionnaire, researchers explained the purpose of the questionnaire, the time required to complete it, and the confidentiality of participation to on-site participants, and obtained their informed consent. The questionnaire consists of two parts: basic demographic information and a perceived safety rating. The perceived level of safety was measured using a 7-point Likert scale ranging from 1 to 7 (1 = very unsafe; 7 = very safe), based on the range used by Ran-kavat and Tiwari (2016) to assess the relationship between pedestrians' sense of place safety and built environment factors. There was no time limit for completing the responses, and all participants were voluntary. As a token of appreciation for their participation, each pedestrian received a commemorative sticker featuring a Macau-themed design. Researchers distributed questionnaires to a total of 10,241 individuals, of whom 5772 refused to participate. After excluding 7 incomplete or missing responses, a total of 4462 questionnaires were ultimately collected.

The perceived safety score is converted into discrete values using the Natural Breaks (Jenks) method. When the perceived safety $D < 4.967$, it is represented by the number 1; when $5.833 > D \geq 4.967$, it is represented by the number 2; and when $D \geq 5.833$, it is represented by the number 3.

3.3.2. Conditional attribute audit

This study used on-site audits to collect graffiti visual elements and surrounding environmental elements at each location as conditional attributes for subsequent RST analysis. Compared to other types of data collection methods, on-site audits have the advantage of focusing on capturing environmental element information from an objective perspective and based on objective measurement standards, thereby effectively avoiding the omission of detailed environmental information (Gidlow et al., 2018). It should be emphasized that in the preceding analysis, we used the term 'elements' to refer to visual and environmental features, primarily emphasizing their fundamental constituent attributes in the study. However, in the RST analytical framework, these elements and their specific manifestations are used as signal units with explanatory functions. Therefore, this paper adopts the term 'cues' for these signal units. This study identified 20 cues (Appendix A) as a preliminary audit framework through literature review and expert experience. Prior to the formal audit, three trained researchers conducted a preliminary audit of 60 graffiti sites, negotiated ambiguous condition attributes, and ultimately reached a consensus on the audit standards shown in Fig. 4.

Subsequently, researchers conducted a formal audit of 160 graffiti sites in Macau. The formal audit was conducted concurrently with the distribution of the perceived safety questionnaire. Within the first fifteen minutes of distributing the first questionnaire at each location, three researchers conducted on-site audits of the visual cues and environmental cues of the 160 graffiti sites based on their attributes. If the

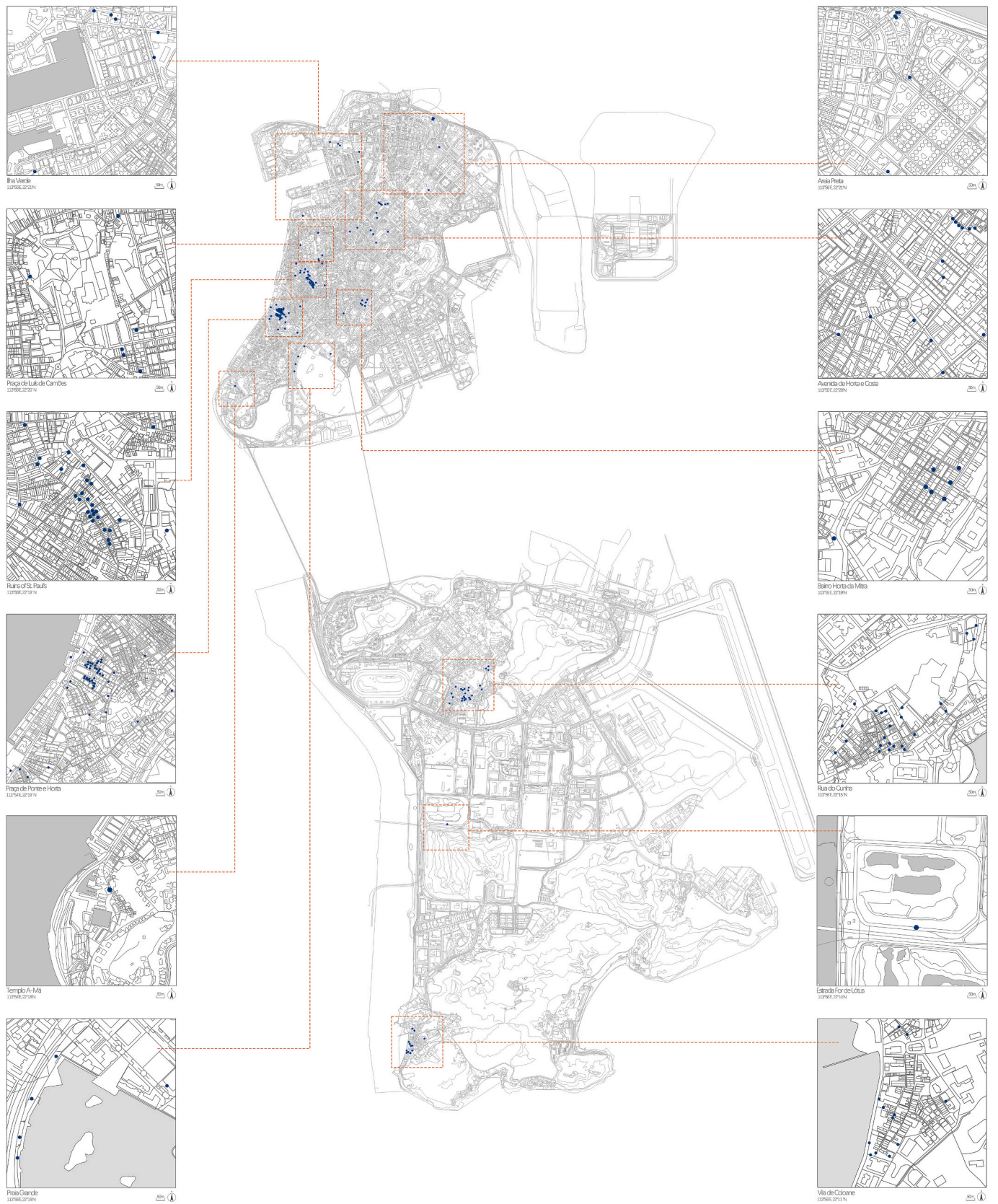


Fig. 2. Spatial distribution map of graffiti in Macau.



A (Graffiti Tags)

B (Graffiti Murals)

Fig. 3. Graffiti types.



Fig. 4. Audit standards for graffiti visual elements and environmental elements.

questionnaire distribution spanned multiple days, an environmental information audit and verification were conducted before the next day's distribution to prevent changes in the environment during the survey period. After the audit was completed, three researchers discussed the results and reached a consensus. Based on the post-audit data, the initial environmental cues were screened. It was ensured that the environmental cues ultimately included in the analysis appeared in the sample with a frequency meeting the minimum statistical threshold ($\geq 15\%$ of observation points had the cue). Therefore, the following environmental elements were excluded due to their lack of practical discriminative

value: (1) Windows, balconies: Due to the influence of Macau's typical high-density built environment, all sample points had natural surveillance within a 5-m radius ($SD = 0$); (2) Abandoned buildings: Only one sample point (0.6%) was located near an abandoned building, which was not statistically representative.

For another environmental cue, graffiti visibility audit, this study utilized the Isovist Analysis (ISA) feature in the UCL DepthmapX (version 0.8.0) software to create a visibility map of graffiti locations. The visual cohesion coefficient is used to measure the strength of spatial boundaries in visually defining an area. This study employed the value

of the Visual Clustering Coefficient (VCC) to assess the ease with which graffiti is observed. According to Formula (1), under fixed spatial conditions, the larger the visible field of view of an object, the weaker the limiting effect; conversely, the stronger the limiting effect, the harder it is for graffiti to be seen.

$$\text{Visual Clustering Coefficient}(g_1) = \frac{K}{k(k-1)} \tag{1}$$

After that, the Natural Breaks (Jenks) method was used to convert the complete data of the graffiti visibility into discrete values. Finally, graffiti visibility is classified based on the median visual aggregation coefficient (0.744): graffiti with lower visibility (visual aggregation coefficient ≤ 0.744) is represented by the number 1; graffiti with higher visibility (visual aggregation coefficient > 0.744) is represented by the number 2.

4. Results

4.1. Participant profile

According to the results of Table 1 for each variable, it can be seen that there are 4462 participants in the random sample. Among them, 2873 are females (about 64.4%) and 1589 are males (about 35.6%), with a much higher percentage of females than males. The age bias is towards young people between 20 and 30 years old (about 80.4%), and according to MGTO’s statistics on the state of tourism (2024), young people present potential advantages in tourism, indicating that Macau is a popular tourist destination for young people.

In addition, non-parametric tests were used to determine if there were differences in perceived safety when comparing different graffiti types, and viewer scale data and information on the types of graffiti audited were collected and statistically analyzed. Because the Kolmogorov-Smirnow test (KS test) and Shapiro–Wilk test (SW test) were performed on the data using IBM SPSS software, the tests do not meet the criteria for a normal distribution ($p < 0.05$). Therefore, a non-parametric test was required, especially since the variables were category-type variables (two groups: graffiti tags and graffiti murals). The Mann-Whitney U test was used, and the results show that the null hypothesis is rejected ($p < 0.05$), i.e., the distributions of perceived safety for graffiti tags and graffiti murals are not the same, meaning that different types of graffiti show significant differences in perceived safety. The median safety index of graffiti murals was 6.00 (interquartile range: 5.00–7.00), significantly higher than that of graffiti tags at 5.00 (interquartile range: 3.00–6.00). Thus, it can be concluded that graffiti murals are perceived as safer for people than graffiti tags, as shown in Table 2.

At the same time, the difference in perceived safety by gender was also tested, and the (KS and SW) tests for its normal distribution were carried out. The results do not conform to the normal distribution (both $p = 0.000 < 0.05$). Non-parametric tests were also needed. The Mann-Whitney U test was applied, and the results rejected the original

Table 1
Table on demographic variables.

Characteristics	Classifications	Frequency (n = 4462)	Percentage (%)
Genders	Male	1589	35.6
	Female	2873	64.4
Age	Under 20 years old	281	6.3
	20–30 years old	3587	80.4
	31–40 years old	358	8.0
	41–50 years old	151	3.4
	51–60 years old	61	1.4
	61 years and over	24	0.5
Identities	Tourist	3802	85.2
	Resident	660	14.8
Qualifications	University and above	3992	89.5
	Other	470	10.5

Table 2
Graffiti type-rank sum test.

Variate	Median (p25, p75)	Two-Sample Rank-sum Test	
		z	p
Graffiti tags	5.00(3.00,6.00)	-18.152	0.00***
Graffiti murals	6.00(5.00,7.00)		

*** $p < 0.001$.

hypothesis, implying that the distribution of perceived safety is not the same for different genders, which can be interpreted to mean that there is a significant difference between males and females when it comes to perceived safety from graffiti ($p = 0.000 < 0.05$) (Table 3).

4.2. Rough set analysis results

The RSA technique was used to process the decision table for all attributes of the graffiti and the environment (Table 4). The conditional attributes consist of 16 visual cues of the graffiti and 2 cues of the physical environment, taking the value of the Perceived Safety Scale of the participants as the decision attribute (D). Since the attributes must be discrete data, this study was conducted to discretize the continuous data on graffiti visibility as follows: if the visual aggregation coefficient is small ≤ 0.744 , it is represented by the number 1, and if the visual aggregation coefficient is > 0.744 , it is represented by the number 2. Secondly, the perceived safety ratings on a 7-point scale were also continuous data, requiring the aid of Excel to arrange the raw data from largest to smallest and present it in a line graph, dividing the data into three segments and referring to the values at the inflection points, which are represented by the number 1 when the perceived safety $D < 4.967$ (Unsafe), by the number 2 when $5.833 > D \geq 4.967$ (General), and by the number 3 when $D \geq 5.833$ (Safe). After that, the computation of the data was started and the overall quality of the decision class approximation boundaries was obtained as 0.9875 and the approximation accuracies of the three decision classes are 1.0000, 0.9608, and 0.9714 (Table 5), which resulted in an overall average accuracy of 56.88% (Table 6).

In order to improve the classification rate and obtain the minimum number of attributes, the core conditional attributes, as well as the degrees of importance, were calculated and filtered using the ROSE2 software (Table 7). From the table, it can be seen that 6 visual cues of graffiti and 2 environmental cues are the core factors affecting human perceived safety, i.e., Lightness (X_2), Hue (X_3), Composition (X_5), Style (X_7), Material (X_{10}), Shape (X_{14}), Street Cleanliness (X_{17}), and Graffiti Visibility (X_{18}). Of these, (X_2) Lightness has the highest level of importance (0.337), followed by (X_3) Hue (0.3) and finally (X_{17}) Street Cleanliness (0.073).

To generate minimum coverage rules, the decision table after attribute approximations was approximated and processed using ROSE2 software (Table 8). A total of 52 rules were generated from the dataset. Among them, 17 rules are suitable for ‘Unsafe ($D = 1$)’, 18 rules are suitable for ‘General ($D = 2$)’, and 17 rules are suitable for ‘Safe ($D = 3$)’. Moreover, the data percentage threshold was set to 10%, and a total of 7 rules meet the grade (as shown in Table 9), of which, 2 rules are suitable for ‘Unsafe ($D = 1$)’, 2 rules are suitable for ‘General ($D = 2$)’, and 3 rules are suitable for ‘Safe ($D = 3$)’. We only considered rules that satisfy the condition that the graffiti and the combined environmental cues meet $D = 1$ and $D = 3$, and if they do, then there is a certain probability that

Table 3
Gender-rank sum test.

Variate	Median (p25, p75)	Two-Sample Rank-sum Test	
		z	p
Male	6.00(5.00,7.00)	-3.872	0.00***
Female	6.00(4.00,7.00)		

*** $p < 0.001$.

Table 4
Decision table for graffiti and the physical environment.

	Variable	Elements	Cues	Cases									
				1	2	3	4	5	6	...	160		
Conditional attributes	X_1	Saturation	1 = Low 2 = High	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	X_2	Lightness	1 = High contrast & low lightness 2 = High contrast & high lightness 3 = Low contrast & low lightness 4 = Low contrast & high lightness	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	X_3	Hue	1 = Cold 2 = Warm	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	X_4	Lack of color	1 = Yes 2 = No	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	X_{17}	Streets cleanliness	1 = Clean 2 = Unclean	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	X_{18}	Graffiti visibility	1 = High 2 = Low	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Decision attributes	D	Perceived safety	1 = Unsafe 2 = General 3 = Safe	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 5
Accuracy of perceived safe classification.

Quality of classification:0.9875				
Variate	Number of objects	Lower approximation	Upper approximation	Precision
1	41	41	41	1.0000
2	50	49	51	0.9608
3	69	68	70	0.9714

Table 6
The average accuracy and approximate accuracy for each category.

Average accuracy (%)	Correct	Incorrect	None
Total	56.88 ± 16.41	43.13 ± 16.41	0.00 ± 0.00
1	57.00 ± 29.09	43.00 ± 29.09	0.00 ± 0.00
2	46.79 ± 18.68	53.21 ± 18.68	0.00 ± 0.00
3	59.85 ± 19.78	40.15 ± 19.78	0.00 ± 0.00

Table 7
Core attributes and importance.

	X_2	X_3	X_5	X_7	X_{10}	X_{14}	X_{17}	X_{18}
Importance	0.337	0.225	0.144	0.181	0.125	0.162	0.073	0.125

Table 8
Core attributes decision table.

	Cues	Cases									
		1	2	3	4	5	6	7	8	...	160
Core attributes	X_2 Lightness	2	1	3	2	2	1	2	1	2	2
	X_3 Hue	2	1	3	2	2	1	2	1	2	2
	X_5 Composition	2	1	3	2	2	1	2	1	2	2
	X_7 Style	2	1	3	2	2	1	2	1	2	2
	X_{10} Material	2	1	3	2	2	1	2	1	2	2
	X_{14} Shape	2	1	3	2	2	1	2	1	2	2
	X_{17} Street cleanliness	2	1	3	2	2	1	2	1	2	2
	X_{18} Graffiti visibility	2	2	1	2	1	1	2	2	1	2
Decision attributes	D Perceived safety ratings	1	2	3	3	3	3	3	1	2	2

people will show unsafe/safety with respect to perceived safety. In order to justify these rules, it was necessary to rely on the knowledge and experience of domain experts to review and interpret these rules. This study used a form of logical language to express these decision rules (Table 10).

According to the rules shown in Table 9, a visual decision rule flow

Table 9
Coverage exceeding 10% rule table.

NO	Rule	Decision attributes	Number of compliancerules
1	$(X_2 = 3) \& (X_5 = 1) \& (X_{14} = 1) \& (X_{17} = 2)$	$(D = 1)$	5 (12.20%)
15	$(X_2 = 3) \& (X_3 = 1) \& (X_7 = 1) \& (X_{14} = 1) \& (X_{18} = 1)$	$(D = 1)$	5 (12.20%)
18	$(X_2 = 2) \& (X_3 = 1) \& (X_7 = 1) \& (X_{10} = 2) \& (X_{18} = 1)$	$(D = 2)$	6 (12.00%)
23	$(X_3 = 1) \& (X_7 = 1) \& (X_{10} = 2) \& (X_{14} = 2) \& (X_{18} = 1)$	$(D = 2)$	6 (12.00%)
37	$(X_3 = 1) \& (X_{10} = 1) \& (X_{17} = 1) \& (X_{18} = 2)$	$(D = 3)$	8 (11.59%)
38	$(X_2 = 3) \& (X_3 = 1) \& (X_5 = 2) \& (X_7 = 2) \& (X_{17} = 1)$	$(D = 3)$	7 (10.14%)
39	$(X_7 = 2) \& (X_{17} = 2) \& (X_{18} = 1)$	$(D = 3)$	7 (10.14%)

Table 10
Linguistic forms of decision rules.

NO	Rule	Decision attributes
1	If the graffiti colors are low contrast and low lightness, and the color composition is contrasting, and the shape of the structure is curved, and the street is unclean, then perceptually people will feel unsafe	(D = 1)
15	If the color of the graffiti is low in contrast and lightness, and the hue is cool, the style of the content is abstract, and the shape of the structure is curved, and the visibility of the graffiti is weak, then people will feel unsafe in terms of perception.	(D = 1)
37	If the color palette of graffiti colors is overall cooler, and the materials used to make it are hand-painted, and if the street is clean, then people will feel perceived to be safe.	(D = 3)
38	If the brightness of the graffiti colors is low contrast and low lightness, and the hue is cool, and the composition of the colors is harmonious, and the style of the content of the image is figurative, and the street is clean, then people will feel safe.	(D = 3)
39	If the style of the graffiti image content is figurative and the street is unclean and the graffiti is less visible then perceptually people will feel safe	(D = 3)

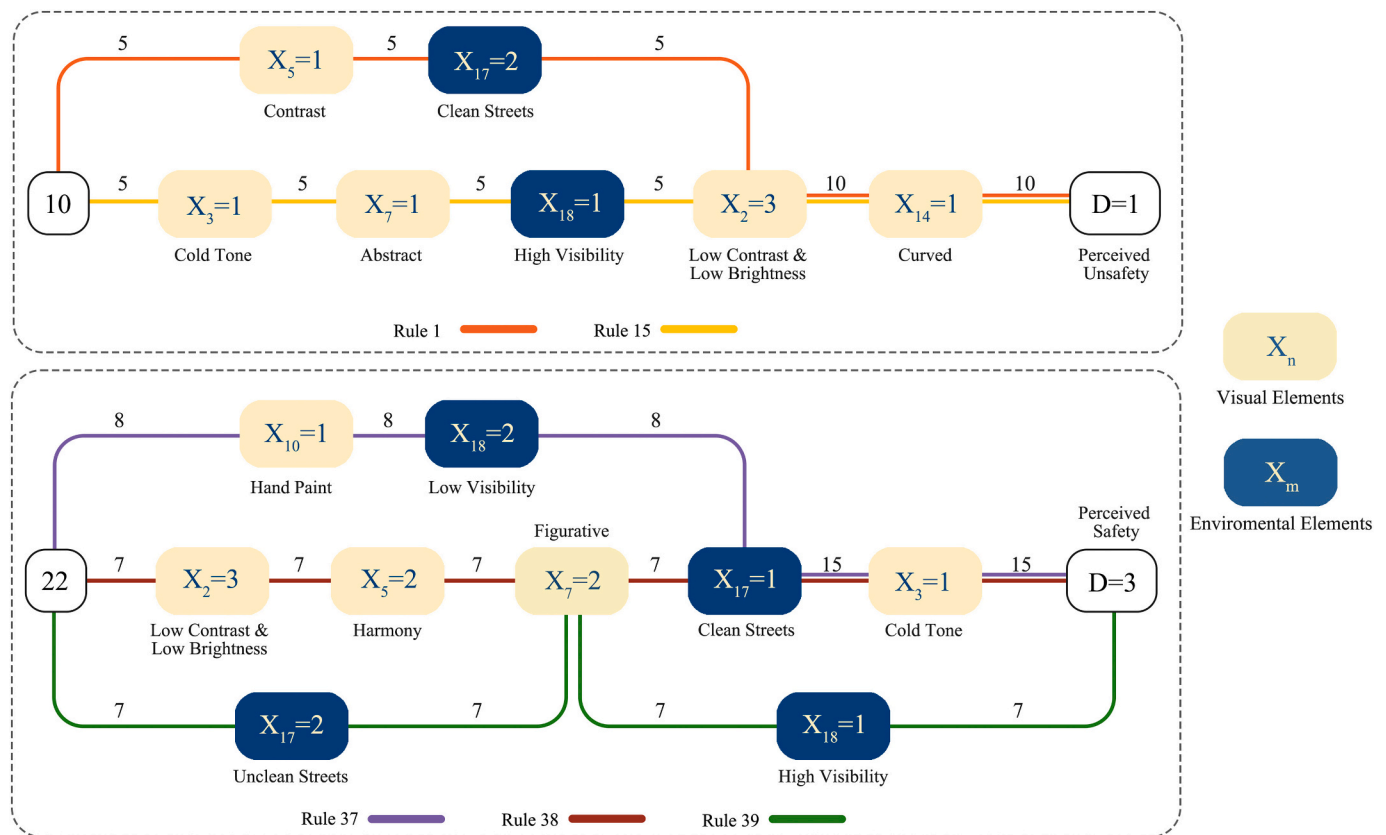
network diagram can be obtained (Fig. 5). The flow diagram shows the distribution of samples supporting specific decision attributes on different rule paths from left to right. Each path in the figure represents a decision rule. Each decision rule is composed of multiple conditional attribute nodes. The numbers between the nodes represent the number of samples covered by the rule (i.e., branch flow). The flowchart generation steps are shown in Appendix B. By connecting different conditional attributes to the common decision results, a visual rule network

diagram is constructed to reveal the causal path relationship between graffiti characteristics and their matching environment and perceived safety. It can provide a predictive reference for perceived safety for urban managers in the process of graffiti creation. According to the network diagram, a total of 3 decision rules supporting ‘safety perception’ were identified, indicating that environmental characteristics that meet these rules are helpful to improve people’s safety perception. At the same time, a total of 2 decision rules supporting ‘perceived unsafe’ were generated, suggesting that if the graffiti cues and environmental cues corresponding to these rules are presented during the graffiti creation process, people may perceive the environment as unsafe.

Additionally, to further explore how different types of graffiti and scene cues affect men’s and women’s perceived safety differently, this study set the difference between men’s and women’s safety perception scores as the decision attribute S, through attribute reduction and rule extraction. A total of 20 rules were generated. With the data percentage threshold set at 10%, four rules met the criteria (Table 11). Among these, 1 rule met $S = 1$ (Females reported significantly higher perceived safety than males), 2 rules met $S = 2$ (Perceived safety did not differ significantly between genders), and 1 rule met $S = 3$ (Males reported significantly higher perceived safety than females). Similarly, these decision rules were expressed using logical language (Table 12), and a visualised decision rule flow network diagram was obtained (Fig. 6).

5. Discussion

Previous studies on urban environments and perceived safety have provided valuable insights for this research. Perceived safety is influenced by both external environments and personal characteristics (Zou, 2023). Regarding graffiti, the effects of graffiti on public perceived safety are mostly either positive or negative. Further studies have



*Rules with coverage greater than 10%

Fig. 5. Decision rule flowchart.

Table 11
Genders perceived safety coverage exceeding 10% rule table.

NO	Rule	Decision attributes	Number of compliance rules
1	$(X_2 = 2) \& (X_{15} = 1) \& (X_{17} = 2) \& (X_{18} = 1)$	$(S = 1)$	2 (11.76%)
4	$(X_5 = 1) \& (X_{10} = 1) \& (X_{15} = 2) \& (X_{18} = 1)$	$(S = 2)$	13 (11.40%)
16	$(X_2 = 4) \& (X_{10} = 1)$	$(S = 2)$	14 (23.28%)
18	$(X_2 = 3) \& (X_5 = 1) \& (X_{15} = 1)$	$(S = 3)$	3 (10.71%)

Table 12
Genders perceived safety linguistic forms of decision rules.

NO	Rule	Decision attributes
1	If the graffiti is on unclear street and has high visibility, high contrast, high brightness and symmetrical structure, then women perceive it safer than men	$(S = 1)$
4	If the graffiti is hand-drawn, has asymmetrical design elements and is located in a highly visible environment, then the difference in perceived safety between men and women is relatively low	$(S = 2)$
6	If the graffiti is hand-drawn, has low contact and high lightness, then the difference in perceived safety between men and women is relatively low	$(S = 2)$
18	If the graffiti has the factors of low contrast, low brightness, contrast and Symmetrical, then men feel more safer than women	$(S = 3)$

explored the influence of graffiti types and personal characteristics on people’s perceptions. This study focuses on the multiple conjunctural causations of graffiti visual cues and surrounding environmental cues, aiming to identify which combinations of environmental elements influence public safety perceptions.

5.1. The impact of graffiti with different types

Previous studies conducted from the perspective of the Broken Windows Theory (BWT) have consistently shown that graffiti and other uncivil behaviors are negatively correlated with perceived safety (Austin & Sanders, 2007; Velasquez et al., 2022). Multiple studies have also provided causal evidence of the relationship between the presence of graffiti and perceived safety through randomized controlled experiments under controlled conditions (James & O’Boyle, 2019; Navarrete-Hernandez et al., 2021). Although some studies have used tag-style graffiti to represent all graffiti and explored gender differences in the impact of graffiti on perceived safety, they found that women perceive unwanted graffiti tags as unsafe (Navarrete-Hernandez et al., 2021). However, there remains a lack of empirical research based on perceived safety, and there is insufficient consideration of the perceived differences caused by graffiti diversity. This study explores the most effective measures for conveying positive or safe messages to different audiences.

Unlike the findings of previous studies, the results of this study indicate that not all graffiti has a negative impact on human perception. This study not only confirms significant gender differences in perceived safety but also finds that respondents perceive different types of graffiti (graffiti tags and graffiti murals) as having varying levels of perceived safety, with graffiti murals being perceived as safer. This finding supports the hypothesis proposed by Navarrete-Hernandez et al. (2021) that mural-type graffiti may not be perceived as a negative factor. The findings are also consistent with other studies, which have shown that the lowest levels of perceived safety are associated with gang graffiti, while mural graffiti is associated with the highest levels of perceived safety (Austin & Sanders, 2007).

5.2. Synergistic effects

Existing research on graffiti in urban environments has been controversial. Previous studies exploring the relationship between graffiti and perceived safety have primarily focused on evaluating safety based on graffiti itself. However, in other studies examining subjective perception, researchers have recognized the limitations of independent effects and emphasized the synergistic effect of various environmental factors on subjective experiences and emotional responses (Velasquez et al., 2021; Wang, Li, et al., 2025). Therefore, this study adopts a Signalling theory perspective to systematically and comprehensively explore how graffiti visual cues interact with other environmental cues in the surrounding area to influence the public’s overall perceived safety in their environment. This study used the Rough Set Approach (RSA) analysis method to identify seven decision rules, i.e., if-then rules. Through these rules, This research found that each rule was not the result of a single cue, but rather the result of the synergistic effects of multiple cues. As Ko and McKelvie (2018) emphasized, when multiple signals coexist, they produce interactive effects.

Specifically, according to the rule flowchart (Fig. 5), when perceiving unsafe ($D = 1$), there are two sets of deterministic rules, in which the structure is curved shape ($X_{14} = 1$) and the color lightness is low contrast and low lightness ($X_2 = 3$). These two visual cue factors are common to both sets of rules and can be interpreted as important factors in perceiving unsafe ($D = 1$). When graffiti is perceived as safe ($D = 3$), there are three sets of deterministic rules. Both cues indicating a clean street ($X_{17} = 1$) and an unclear street ($X_{17} = 2$) appear in these three sets of rules, indicating that the cleanliness of the street can lead to perceived safety under different conditions. This finding is inconsistent with previous research, which isolated the relationship between street cleanliness and perceived safety, concluding that clean sidewalks are conducive to perceived safety (Bivina & Parida, 2019; Ferrer et al., 2015). Additionally, this study found that when the same cues interact with other cues, they can lead to different outcomes. For example, when graffiti visibility is low ($X_{18} = 2$) and combined with different visual cues of graffiti, it can result in a dual outcome of perceived safety. Previous

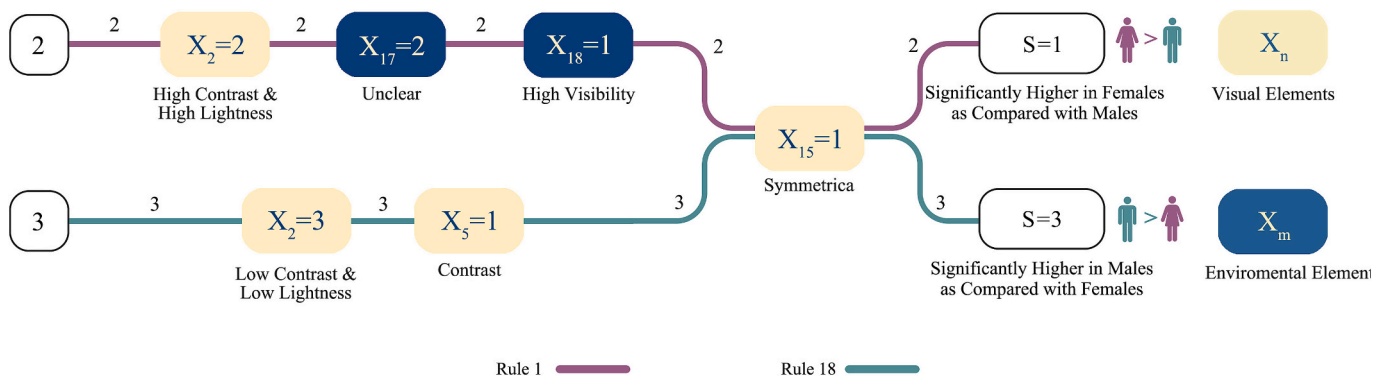


Fig. 6. Gender perceived safety decision rule flowchart.

research has emphasized that the likelihood of being seen is positively correlated with a perceived safety (Mahrous et al., 2018). In fact, correlation alone is insufficient to demonstrate the independent contribution of visibility or to represent the overall perceived safety in complex environments where visual cues are combined. This study found an interesting result: high graffiti visibility ($X_{18} = 1$) combined with certain specific visual cues of graffiti can also lead to feelings of unsafe.

This result is not surprising, as previous studies have largely examined street cleanliness and object visibility as independent cues, drawing established conclusions about their impact on perceived safety while ignoring their overall relationship with other cues in the environment. Signalling theory advocates exploring the synergistic effects of multiple signals in the environment. Therefore, when studying human perceived experiences, one should not isolate a single environmental cue but instead investigate its interactions with other environmental cues in the surrounding environment. The results of this study validate the idea of multiple signal effects, namely that when multiple signals coexist, the effect of a signal may differ depending on the influence of other coexisting signals (Ko & McKelvie, 2018).

This idea is also confirmed in other rules. The results of the study indicate that the same element (such as X_7 , Realism) combined with different cues in different ways (such as $X_7 = 1$ or 2) will cause consumers to receive different signals, thereby producing different perceived safety orientation. Such as when graffiti has low contrast and low lightness ($X_2 = 3$), a cool color tone ($X_3 = 1$), a figurative style ($X_7 = 2$), and a harmonious color composition, and is located on a clean street, it is perceived as safe ($D = 3$). On the contrary, graffiti with unchanged color brightness and tone, if abstract in style ($X_7 = 1$), with a curved shaped composition ($X_{14} = 1$), and high visibility ($X_{18} = 1$), will increase perceived unsafe. This indicates that although graffiti has a cool tone ($X_3 = 1$), low contrast, and low lightness ($X_2 = 3$), when combined with other cues, it will affect people's perceived safety to varying degrees. This result echoes the findings of Naletelich et al. (2023), namely that concrete images are less risky and safer than abstract images. In addition to the abstractness and concreteness of visual imagery, consumers' perceptions may also be influenced by other cues within the environment. Building on this, this study further examines the synergistic effects of abstract and concrete visual cues, graffiti's other visual cues, and different environmental cues on perceived safety. These results reflect the interaction between visual cues and their surrounding environmental cues and validate the multi-signal effect perspective.

5.3. Genders differences

In further analysis, this study also conducted an initial exploration of how different types of graffiti and environmental cues exert differing influences on safety perceptions across genders. Previous research has highlighted that environmental visibility is a critical design factor in addressing perceived safety issues (Gharaveis et al., 2018). The results of this study indicate that the impact of visibility on perceived safety for different genders is the result of synergistic interactions with other cues, rather than independent effects. For example, in Fig. 6, Rule 1: When graffiti is in a high visibility setting ($X_{18} = 1$) and on an unclean street ($X_{17} = 2$), graffiti itself has high contrast and high lightness ($X_2 = 2$), and a symmetrical structure ($X_{15} = 1$), females reported significantly higher perceived safety than males ($S = 1$). Previous studies have shown that women generally feel more concerned about their safety than men (McLean & Anderson, 2009; Te Braak & van Tienoven, 2025), but in the context of Rule 1, women exhibited significantly higher levels of perceived safety than men. This study also found that even when graffiti was present on an unclean street ($X_{17} = 2$), the multiple conjunctural causations of various cues resulted in women still perceiving higher levels of safety than men. This suggests that in the context of graffiti, the impact of untidy streets on women's perceived safety may be mitigated by visual cues. The influence on women's perceived safety levels is the result of the synergistic effects of cues such as Lightness (X_2), Streets

Cleanliness (X_{17}), and Graffiti Visibility (X_{18}), rather than being determined by a single cue. The impact of environmental disorder on women's perceived safety is weakened by visual cues, which supports the findings of James and O'Boyle (2019) that the presence of graffiti can weaken perceptions of other factors in a scene.

It is worth noting that all three cases in Rule 18 involve graffiti labels, which may indicate that women perceive lower safety levels than men when it comes to graffiti of this type. Additionally, both Rule 1 and Rule 18 include the cue of symmetrical ($X_{15} = 1$), but when this cue is combined with different cues, it leads to two completely different results: 'Females reported significantly higher perceived safety than males' ($S = 1$) and 'Males reported significantly higher perceived safety than females' ($S = 3$). This further validates the notion that the same cues can produce different effects on perceived safety when combined in different scenarios.

6. Conclusion

6.1. 6.1 Theoretical implications

This study examines the causal relationship between multiple conjunctural causations of graffiti visual cues and environmental cues with perceived safety, making valuable contributions to understanding graffiti's impact on safety perception. The theoretical contributions are primarily manifested in two aspects.

First, this study empirically demonstrates that the multiple conjunctural causation of visual cues and environmental cues from graffiti on perceived safety is a comprehensive effect rather than an independent one. This provides theoretical support for using Signalling theory to explain the interactive influence of multiple environmental signals on perceived safety, clarifies the basis of multi-source signals in the formation of perceived safety, and offers a new theoretical perspective for research related to urban public art.

Secondly, this study employed the Rough Set Approach (RSA) technique to identify the core features influencing perceived safety, as well as the causal decision rules for graffiti and environmental cues that respectively lead to perceived unsafe ($D = 1$) and perceived safety ($D = 3$) conditions. Unlike most previous studies that focused on the negative impacts of graffiti on cities, this research further specifies which visual cues of graffiti, when combined with other environmental cues, amplify or weaken the public's perceived safety. Additionally, it explores gender differences in how graffiti visual cues and their surrounding environmental cues influence perceived safety. These findings provide more specific and detailed evidence for studies on the relationship between graffiti and perceived safety in public spaces. This helps us to comprehensively and systematically understand the impact of graffiti on perceived safety in different urban public space environments.

6.2. Practical implications

This study contributes knowledge about the causal effects of graffiti visual cues and their surrounding environmental cues on public perception, providing valuable decision-making references for policymakers, especially managers of urban public spaces. According to Bove and Benoit (2020), signals represent a cost. As signal senders, public spaces face the practical problem of how to convey safety signals more effectively and at lower cost when faced with diverse public space planning and numerous element choices. Causal rules generated using RSA technology provide quantitative evidence for urban managers to accurately identify which visual cues and environmental cues, when combined, can influence public perceived safety. Based on this evidence, urban managers can effectively enhance the perceived safety of urban public spaces by reasonably planning graffiti and configuring related environmental facilities, thereby more effectively conveying appropriate safety signals. This enables urban managers to make scientific decisions under resource-constrained conditions, optimize investment

and cost allocation, and avoid misallocation and waste of graffiti management resources.

6.3. Limitations and future research

This study also has some limitations. Firstly, with explored graffiti within Macau, and the vast majority of participants were concentrated in the 20–30 age group, so the conclusion may not be extrapolated to other cities and other age groups. In the future, when examining the issue of graffiti perceptions in other cities, evidence of perceptions of people of different age groups can be provided as a way of enhancing the broad applicability of the results.

Secondly, this study also suggests that curved shapes are more likely to be visually insecure. However, [Hübner and Fillinger \(2016\)](#) confirmed the hypothesis that curved images are more popular than images of angular factors. Their study did not show a relationship between popularity and perceived safety. Therefore, future research could further explore these visual attribute features comprehensively across the two dimensions to address the problem of performance differences.

Thirdly, there are many other environmental factors surrounding graffiti, not all of which are covered in this study. For example, the environmental factor of ‘windows’, which act as surveillance, is not included as an environmental cues because it is not differentiated in the city of Macau, and may be found differently in other cities studied in the future.

Finally, the results of this study are based on exploratory findings that reveal associative patterns in the context of graffiti, rather than causality inferred through statistical analysis. Future research plans to use a control group design (including sections of road without graffiti) to further validate the marginal effects of graffiti on perceived safety.

CRedit authorship contribution statement

Yue Mao: Writing – original draft, Visualization, Validation,

Appendix A

Appendix A

Graffiti visual characteristics guidelines framework.

Themes	Elements	Cues	Descriptions	Source
Color	X ₁ : Saturation	1 = Low/ 2 = High Saturation	Saturation refers to the degree of vividness of a color and is often studied in relation to people or products using the categories of low and high saturation.	Kunz et al., 2020 ; Chamberlain et al., 2022 ; Pichierri & Pino, 2023 ; Expert experience
	X ₂ : Lightness	1 = High contrast & low lightness/ 2 = High contrast & high lightness/ 3 = Low contrast & low lightness/ 4 = Low contrast & high lightness	Luminance is the perceived intensity of light. Darkness refers to darkness in terms of lightness, and high contrast refers to a large change in the lightness of different colors in the picture.	Wilms & Oberfeld, 2018 ; Chamberlain et al., 2022 ; Expert experience
	X ₃ : Hue	1 = Cold tone/ 2 = Warm tone	(Purple, green) and other colors close to blue are cool tones, and (yellow, orange) and other colors close to red are warm tones.	Porter & Mikellides, 1976 ; Llinares et al., 2021
	X ₄ : Lack of color	1 = Yes/ 2 = No	Is the overall color of the picture monotonous. Monochrome, black and white are referred to as monotonous and not rich in color.	Chamberlain et al., 2022 ; Expert experience
	X ₅ : Constituent	1 = Contrast/ 2 = Harmony	Color contrast refers to: relative colors on the color ring, sharp color differences create a strong visual impact. Harmony of colors refers to similar or adjacent colors on the color ring.	Chamberlain et al., 2022 ; Expert experience
Content	X ₆ : Familiarity	1 = Familiar/ 2 = Unfamiliar	Is the content of the picture common or familiar to life.	Chamberlain et al., 2022 ; Expert experience
	X ₇ : Realism	1 = Abstract/ 2 = Figurative	Figurative and imagery refer to the depiction of objects that are clear representations of what they look like in real life, i.e. what they were originally intended to be, while abstract imagery refers to the use of imaginative or fantastical factors to distort the appearance of an object in reality for artistic or symbolic purposes.	Chamberlain et al., 2022 ; Naletelich et al., 2023

(continued on next page)

Investigation, Formal analysis, Data curation, Conceptualization. **Xu Zhang:** Writing – review & editing, Visualization, Software, Resources, Investigation, Data curation. **Lei Xiong:** Methodology, Conceptualization. **Bo-Wei Zhu:** Writing – review & editing, Conceptualization. **Guan-Qiang Wang:** Writing – review & editing, Resources, Conceptualization. **Zi-Jie Zou:** Software, Resources, Data curation. **Gwo-Hshiong Tzeng:** Supervision.

Ethics statement

This study does not involve “human subject research”. Research does not require ethical review.

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Declaration of competing interest

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

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Appendix A (continued)

Themes	Elements	Cues	Descriptions	Source
Production	X ₈ : Text	1 = Yes/ 2 = No	The presence or absence of text can refer to the presence or absence of letters, words, graffiti fonts, and numbers in the picture.	Chamberlain et al., 2022; Expert experience
	X ₉ : Relationship with the environment	1 = Yes/ 2 = No	Whether the content of the graffiti image is clearly linked to the background environment or whether it is independent of each other.	Expert observation and experience
	X ₁₀ : Materials	1 = Hand-paint/ 2 = Spray-paint	The technical expression of using spray paint or pigment in the painting process.	Chamberlain et al., 2022; Expert experience
	X ₁₁ : Mark	1 = Brushstrokes/ 2 = Drops	The as traces left by the materials selected during the painting process. Hand-painting has traces of brush strokes and spray-painting is characterised by drips.	Chamberlain et al., 2022; Expert experience
Structure	X ₁₂ : Texture	1 = Rough/ 2 = Smooth	Rough textures refer to gradations of color and are layered, high relief and dense, while smooth textures are the opposite.	Chamberlain et al., 2022; Zhang & Chan, 2022)
	X ₁₃ : Complexity	1 = Simple/ 2 = Complex	Complexity is based on the number of factors and the overall simplicity of the visual. Generalise minimalist, simple, complex and dense as simple and complex.	Chamberlain et al., 2022; Expert experience
	X ₁₄ : Shape	1 = Curved/ 2 = Angled	The shapes of the edges of the shape surfaces of the picture factors change shape.	Silvia & Barona, 2009; Hübner & Fillinger, 2016; Chamberlain et al., 2022)
Environment	X ₁₅ : Balance	1 = Symmetrical/ 2 = Asymmetrical	An objective measure of picture balance based on symmetry. This is because symmetry and balance were shown to be highly correlated in the rating of aesthetic preference questions.	Wilson & Chatterjee, 2005; Hübner & Fillinger, 2016; Chamberlain et al., 2022
	X ₁₆ : Rhythm	1 = Yes/ 2 = No	In the context of painting, rhythm can be perceived as a structural factor. Whether the arrangement or repetition of picture factors forms a sense of regular visual rhythm. This sense of rhythm can be reflected through the repetition and variation of factors such as lines, shapes and colors, thus affecting the viewer's visual experience.	Tosaki & Tosaki, 2017; Expert experience
	X ₁₇ : Streets cleanliness	1 = Clean streets/ 2 = Unclean streets	Tidiness pertains to the degree to which the footpath is satisfactory, signifying the degree to which the footpath is clean and orderly.	Ferrer et al., 2015; Bivina & Parida, 2019
	X ₁₈ : Graffiti visibility	1 = High/ 2 = Low	The visibility of graffiti refers to the degree of visual access, i.e. the likelihood of being seen, and the qualifying effect of the visual aspect is generally measured using the visual aggregation factor.	Mahrous et al., 2018
	X ₁₉ : Window	1 = Yes/ 2 = No	There are windows, balconies, and other natural surveillance points around the graffiti.	Glasson & Cozens, 2011; Ceccato, 2019
	X ₂₀ : Derelict building	1 = Yes/ 2 = No	There are vacant and abandoned buildings around the graffiti.	Kondo et al., 2015; Deng et al., 2022

Appendix B. Decision rules based on flow network graphs

The flow graph developed by Ford and Fulkerson in 1962 is an effective tool for explaining path-dependent relationships based on a set of rough decision rules (Wang et al., 2010; Wang, Li, et al., 2025), providing detailed observable information. Each branch in the flow network graph is regarded as a specific decision rule, and the entire flow graph is used to depict the logical structure of the decision algorithm (Wang et al., 2010). Based on the flow graph structure and the Bayesian theorem, this model focuses on the extraction of decision-path characteristics as opposed to process optimisation (Cheng et al., 2013; Pawlak, 2002). The relationship between flow graphs and decision algorithms can be expressed as follows (Cheng et al., 2013; Pawlak, 2004; Wang et al., 2010).

A flow graph is a directed acyclic finite graph $G = (N, B, t)$, where N is a set of nodes, $t : B \rightarrow R^+$ is a flow function and R^+ is the set of non-negative real numbers. A branch $(x, y) \in B$, then x is the input of the branch (x, y) , and y is the output. The thought flow of a branch $(x, y) \in B$ is denoted by $t(x, y)$. For $(x, y) \in B$, $t(x, y)$ represents the amount of flow from x to y . The input of a node $x \in N$ is defined as $I(x) = \{y \in N : (y, x) \in B\}$, and the output set of a node $x \in N$ is defined as $O(x) = \{y \in N : (x, y) \in B\}$. Based on these concepts, the input and output of a graph G are defined as $I(G) = \{x \in N : I(x) \neq \emptyset\}$ and $O(G) = \{x \in N : O(x) \neq \emptyset\}$. For each node x in the flow graph, the inflow is defined as $t_+(y) = \sum_{x \in I(y)} t(x, y)$, and the outflow is defined as $t_-(y) = \sum_{y \in O(x)} t(x, y)$. This research assume that for any node x in the flow graph G , $t_+(x) = t_-(x) = t(x)$, and in this way, the total flow of the entire flow graph is represented as $t_+(G) = t_-(G) = t(G)$.

To measure the strength of each branch (x, y) in the flow graph $G = (N, B, t)$, the strength in this study is defined as $\rho(x, y) = t(x, y)/t(G)$. Obviously, $0 \leq \rho(x, y) \leq 1$. The strength of a branch indicates the percentage of the total flow passing through that branch. Each branch (x, y) in the flow graph G is associated with a certainty coefficient and a coverage coefficient. The certainty and coverage coefficients are respectively defined as $cer(x, y) = \rho(x, y)/\rho(x)$, and the $cov(x, y) = \rho(x, y)/\rho(y)$, where $\rho(x, y) = t(x, y)/t(G)$, $\rho(x) = t(x)/t(G)$ and $\rho(y) = t(y)/t(G)$ and they are all normalized flows. Furthermore, $\rho(x) \neq 0$, $\rho(y) \neq 0$, and $\rho(y) = t(y)/t(G)$ must hold. The certainty coefficient reflects the distribution of outflows from a node, whereas the coverage coefficient reveals the distribution of inflows to a node from different inputs. Together, these coefficients provide a straightforward interpretation of certain properties of flow distributions between branches in the entire flow network.

Data availability

Data will be made available on request.

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