At-Risk Building Fire Safety Awareness Practices: A Case Study in Bandar Hilir, Melaka

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ABSTRACT

This study explores the integration of heritage conservation with fire safety in historic buildings and districts, with a particular focus on Bandar Hilir, Melaka. It addresses technical, operational, and governance challenges while identifying global best practices adaptable to local contexts. A systematic review guided by PRISMA 2020 (2020–2025) and complemented by narrative/thematic synthesis underpinned by Constructivist Grounded Theory (CGT) was conducted. Twenty-five high-quality sources—including peer-reviewed articles, standards, and agency guidelines—were critically appraised using MMAT, CASP, and JBI tools, with qualitative confidence assessed through GRADE-CERQual. The findings highlight five interrelated themes: (i) the tension between authenticity and safety, requiring performance-based interpretation and equivalency documentation; (ii) the evolution of risk assessment approaches from sensitivity markers to weighted resilience indices (AHP/CRITIC) and value-at-risk frameworks for balancing costs and benefits; (iii) heritage-sensitive technologies such as wireless detectors, wireless alarms, and linear systems that minimize invasive interventions; (iv) operational disciplines encompassing hot-work control, housekeeping audits, regular training, incident pre-planning, and collection salvage strategies; and (v) multi-agency governance at both building and urban scales, structured around the prevention–preparedness–response–recovery cycle. Drawing from these insights, the study proposes a layered integration model for Melaka: ensuring technical legitimacy through performance-based equivalency; prioritizing interventions via AHP/CRITIC and value-at-risk; adopting "invisible" fire safety technologies; institutionalizing operational practices; and establishing a heritage city technical committee with measurable KPIs. The study contributes by merging engineering evidence, risk-prioritization frameworks, and CGT-informed social narratives to bridge the divide between conservation and safety. Practical implications include shifting from prescriptive compliance toward performance- and risk-based community-endorsed decisions, enabling resilient outcomes that are both authentic and safe. Future CGT-based fieldwork in Bandar Hilir is recommended to validate the framework, test wireless technologies, and expand incident and near-miss repositories.

Keywords: Fire Safety Awareness; Risk Assessment Frameworks; Performance-Based Equivalency.Wireless Detection Technologies.

INTRODUCTION

Fires in historic buildings around the world have emerged as one of the defining challenges of the 21st century. These incidents often stem from highly combustible building fabrics, outdated electrical systems, and the complexity of renovation works. As García-Castillo et al. (2023) point out, the loss of heritage value due to fire is frequently linked to the absence of contextual risk assessments and the inadequacy of rigid prescriptive standards that fail to account for historic typologies.

In this light, fire safety cannot be treated as a separate concern from heritage preservation; it must be carefully integrated into the design and daily operation of historic sites. The UNESCO Fire Risk Management Guide (2024) lays out principles, methods, and processes for managing fire risk in heritage contexts, emphasizing a continuous cycle of prevention, preparedness, response, and recovery (Harun et al., 2022; Mallinis et al., 2016; Naziris et al., 2022; Othuman Mydin et al., 2014a, 2014c).

One of the central dilemmas is the tension between preserving physical authenticity and installing modern fire safety systems. Furmanek (2024) highlights that requirements for detection and suppression systems can alter architectural values, making context-sensitive and performance-equivalent solutions essential. Along similar lines, NFPA 914 provides a performance- and objective-based framework that allows for equivalencies when prescriptive compliance is impractical, ensuring safety without undermining heritage integrity. On the ground, Charlie Harris (2021) stresses the importance of salvage planning, staff training, and iterative risk assessments to safeguard historic fabric while maintaining acceptable safety levels (Charlie Harris, 2021; Furmanek, 2024; National Fire Protection Association, 2023).

Recent years have seen significant advances in risk assessment methods: from sensitivity-based markers (Salazar et al., 2021), to resilience indices (Yu et al., 2024), dynamic assessments of dense historic villages (Liao et al., 2024), and comprehensive value-at-risk frameworks (Ding et al., 2023). At the asset scale, performance-based approaches have been applied to iconic landmarks such as the Duomo Modena (Petrini et al., 2023). At the portfolio scale, methods like AHP have been used to prioritize diverse historic sites, weighing topographical and access constraints against the trade-off between authenticity and intervention effectiveness (Kee et al., 2025). Collectively, these studies underscore the shift toward risk-informed decision-making that incorporates physical, managerial, and social dimensions (Ding et al., 2023; Kee et al., 2025; Liao et al., 2024; Petrini et al., 2023; Salazar et al., 2021; Yu et al., 2024).

Despite the flexibility offered by UNESCO/ICOMOS guidance and NFPA 914, real-world implementation is often constrained by operational challenges (such as hot works, housekeeping, and maintenance), financial limitations, and community resistance to measures perceived as “disrupting authenticity” (Charlie Harris, 2021; Kincaid, 2022). Moreover, social dimensions—including visitor behavior, spatial patterns, and local customs—shape risk profiles but are rarely embedded in intervention design (Liao et al., 2024; Roslan & Said, 2017).

This highlights the need for a Constructivist Grounded Theory (CGT) synthesis to explore how heritage communities themselves construct meanings of “safe” and “authentic.” Such an approach can help chart socially accepted, technically effective, and operationally feasible practices—particularly in heritage cities like Bandar Hilir, Melaka (Charlie Harris, 2021; ICOMOS & ICCROM, 2024; Kincaid, 2022; UNESCO, 2024).

LITERATURE REVIEW

Relevant literature should be reviewed to identify research gaps and situate the current study in relation to prior research. This review was designed as a systematic search combined with a narrative and thematic synthesis, reported in line with PRISMA 2020 to ensure transparency and reproducibility. The approach allowed us to document the entire search cycle—from record identification through to reasons for full-text exclusion—while integrating evidence from multiple study designs (qualitative, quantitative, and mixed methods) alongside authoritative guidance documents. The overall analytical framework was guided by Constructivist Grounded Theory (CGT), focusing on how meanings of “safety” and “authenticity” are socially constructed within heritage communities, and how these meanings influence the acceptance of fire safety interventions.

Literature searches were conducted across major academic databases—Scopus, Web of Science, ScienceDirect (Elsevier), Taylor & Francis Online, Springer/Nature, MDPI, and ASCE Library—as well as Google Scholar to capture “in press” or “early view” articles. For best practices and guidance documents, we carried out targeted searches of authoritative agency and standards websites including UNESCO, ICOMOS/ICCROM, NFPA, Historic England, and the London Fire Brigade. The search strategy was developed iteratively, using Boolean operators and synonym mapping, for example: “heritage building” OR “historic building” AND “fire safety” OR “fire risk” AND (awareness OR preparedness OR “risk management” OR “performance-based”) AND (conservation OR preservation OR “cultural heritage”). The time frame was limited to 2020–2025 to ensure currency, with English and Malay set as the language filters. Beyond database searches, we also conducted hand-searching of target journals, backward and forward citation tracking (snowballing), and reference list checks from included articles to avoid missing relevant work.

Inclusion criteria covered peer-reviewed journal articles or official guidance documents that explicitly addressed heritage buildings/sites and fire safety issues, and contributed to the integration of conservation and safety (e.g., risk assessment, heritage-sensitive technologies, governance, training/awareness). Eligible publications had to fall within 2020–2025 and provide sufficient methodological detail or results. Excluded were works focusing only on modern industrial fires without heritage context, opinion pieces without methodological grounding, and duplicate records. All records were exported, deduplicated, and screened in two stages: title–abstract screening followed by full-text review. Each stage was independently handled by two reviewers, with disagreements resolved by consensus and, if needed, by a third reviewer. Reasons for exclusion were systematically logged, and a PRISMA flow diagram was included as an appendix.

Data extraction followed a standardized, pilot-tested form. For each study or document, we extracted metadata (author, year, context/country, type of evidence), study aims and design, risk domains (structural/physical, technological, human/behavioral, governance/policy, spatial/environmental), assessment methods (e.g., AHP, CRITIC, value-at-risk, performance-based), interventions/technologies (e.g., wireless alarms, linear detection systems), key findings, implications for integrating conservation and safety, and any relevance to Malaysia/Melaka. Two researchers extracted data independently and cross-checked for consistency, resolving discrepancies by discussion.

Quality appraisal was tailored to study design. For authoritative guidance and "grey literature" (e.g., UNESCO, ICOMOS, NFPA, Historic England, LFB), the AACODS framework (Authority, Accuracy, Coverage, Objectivity, Date, Significance) was applied. All appraisals were conducted independently by two reviewers, with inter-rater agreement (e.g., Cohen's κ) calculated and reported to demonstrate reliability. These assessments were explicitly factored into sensitivity analyses and the weighting of arguments within the synthesis.

For qualitative synthesis, we applied GRADE-CERQual to assess confidence in thematic findings. Each theme was evaluated against four criteria—methodological limitations, coherence, adequacy of data, and relevance. Evidence profiles and summary of findings tables were produced, enabling readers to gauge the confidence level behind thematic conclusions, especially when drawing from heterogeneous or cross-contextual sources.

Synthesis combined narrative and thematic approaches. Operationally, we followed ESRC guidance (Popay et al., 2006) to organize the evidence into conceptual clusters (structural/physical risk, heritage-sensitive technologies, human behavior and training, governance and policy, and spatial/environmental dimensions), and then built a "line of argument" across studies. To develop cross-study themes, we employed thematic synthesis procedures (Thomas & Harden, 2008) alongside Braun and Clarke's (2006) six phases of thematic analysis—familiarization, coding, theme development, review, naming/defining, and reporting. Guided by CGT (Charmaz, 2014), we allowed heritage community voices—custodians, owners, and visitors—to shape themes that emerged organically from the data. These themes were then re-mapped onto local realities (such as Bandar Hilir, Melaka) to test whether proposed interventions were truly appropriate and socially acceptable.

Data management and audit trails were maintained through structured spreadsheets for search, screening, and appraisal records, while thematic coding was supported by qualitative analysis software (e.g., NVivo, ATLAS.ti) to facilitate cross-checking between reviewers. Sensitivity analyses were also undertaken: (i) testing the stability of themes when lower-quality studies were excluded; (ii) examining geographic bias (overrepresentation of certain regions); and (iii) considering potential dissemination bias, particularly in qualitative findings and practice documents.

No human participants were involved in this review, so formal ethics approval was not required. The protocol (keywords, date ranges, inclusion/exclusion criteria, reviewer consensus procedures, and analysis plan) was documented internally to ensure reproducibility.

We acknowledge several methodological limitations: evidence heterogeneity constrained formal quantification; reliance on "grey literature" demanded rigorous AACODS appraisal; language bias (English/Malay) may have excluded relevant sources; and local empirical evidence remains limited. Therefore, we recommend follow-up fieldwork informed by CGT—for example, in-depth interviews and theoretical sampling—to deepen understanding of how local heritage communities construct meanings of "safe" and "authentic," and how these meanings shape both acceptance and effectiveness of fire safety interventions.

METHOD

Physical/Structural Risks and Performance-Based Approaches

Recent literature shows that fire risk profiles in heritage buildings are largely shaped by combustible fabrics (such as aged timber and organic finishes), the presence of hollow spaces and concealed voids, the absence of fire compartmentation, and renovation or upgrading works that involve heat sources ("hot works"). A comprehensive review by García-Castillo et al. (2023) emphasizes that the amount of fuel load, flammability, and potential fire spread are the primary vectors of risk, while construction or conservation activities often serve as the trigger for fire incidents at heritage sites.

In relation to welding and cutting, Charlie Harris (2021) strongly advises complete avoidance unless unavoidable, noting that many major fires in historic buildings have been sparked by welding, cutting, or open flame works. This warning is echoed across technical advisory portals. High-profile cases—such as the Notre-Dame fire in Paris and the Copenhagen Stock Exchange fire—have also been widely reported in the media, underscoring persistent gaps in early detection and hot-work controls during restoration projects (Torero, 2019).

In response to these challenges, performance-based approaches have gained traction for their ability to balance safety with the preservation of historic fabric. A case study of Modena's Duomo Cathedral demonstrated the feasibility of combining event-tree analysis, thermo-aerodynamic modeling, and nonlinear thermo-mechanical structural analysis to evaluate the probabilistic fire resistance of a heritage structure (Petrini et al., 2023). At the standards level, NFPA 914 provides the basis for equivalency—allowing performance-based solutions when modern prescriptive clauses are unsuitable, without compromising either safety or authenticity (National Fire Protection Association, 2023). Operational guidelines, such as London Fire Brigade's GN80, add tactical dimensions: focused risk assessments, artifact protection and salvage, and early coordination with heritage stakeholders (Daly, 2019).

Additionally, data-driven predictive methods are being applied to high-risk fabric typologies such as timber. Zhang et al. (2022) proposed a machine-learning-driven risk index for predicting fire hazards in wooden heritage buildings, offering proactive decision support at a portfolio scale.

Vulnerability and Resilience Indices

Recent work has expanded the use of indicator sets that capture physical, operational, social, and environmental factors, making risk assessments more transparent and comparable. Ding et al. (2023) developed a four-domain evaluation system (human factors, facilities, environment, and social governance) with 20 sub-indicators for stone-and-wood vernacular dwellings. Their findings highlight that non-technical variables—such as social management—can be just as significant as physical factors.

Building on this, Yu et al. (2024) introduced a fire resilience index for ancient architectural complexes, using 25 indicators weighted through AHP and CRITIC methods. This approach enabled more objective prioritization of interventions across multi-asset sites. At the settlement scale, Liao et al. (2024) proposed a dynamic method tailored for dense historic villages, demonstrating that building spacing, density, and local customs significantly shape fire risk—demanding strategies that are deeply context-specific.

Salazar et al. (2021) further contributed a 21-indicator index spanning four categories—structure, utilities/services, firefighting capacity, and preparedness—strengthening the justification for allocating mitigation budgets.

In practice, these indicator frameworks align closely with global guidance. UNESCO's Fire Risk Management Guide (2024) lays out principles, methodologies, and processes across prevention, mitigation, response, and recovery—explicitly incorporating community knowledge. Similarly, ICOMOS and ICCROM (2024) launched an open-access platform to share this guidance. Together, these resources underscore the need for holistic, risk-informed approaches that move beyond narrow prescriptive codes, ensuring that indicators are tailored to the real needs of heritage sites.

Area Resilience and Human Behavior

A growing body of research highlights that spatial configuration and user behavior (residents and visitors alike) strongly shape actual fire risk outcomes. Liao et al. (2024) demonstrated that visitor flow, spatial geometry, and exit networks directly influence fire resilience in historic urban areas, underscoring the need for operational design measures—such as tailored crowd management—based on real patterns of site use. In more challenging topography, such as hilly heritage landscapes, Kee et al. (2025) applied AHP across 36 historic buildings and found that geographic and environmental clusters affected access to safety infrastructure. Their findings also reveal the persistent tension between "authenticity" and modern interventions, a balance that must be openly negotiated with heritage stakeholders.

Operational practices and on-site work culture are equally critical. Charlie Harris (2021) identified welding and cutting as a frequent cause of heritage fires, recommending strict avoidance; if such work is unavoidable, rigorous permitting, close supervision, and continuous monitoring are essential. Complementing this, London Fire Brigade's GN80 guidelines (Daly, 2019) stress staff training, artifact salvage planning, and early coordination with both fire services and heritage authorities, especially when conservation activities involve added risks. Kincaid (2022) further distinguishes between prevention (eliminating ignition sources through finishing works, electrical control, or welding management) and protection (minimizing impact through early detection, response, and compartmentation) as the two practical pillars of heritage fire strategy.

Recent fire incidents reinforce the central role of human and operational factors. In several cases, blazes in heritage buildings were traced to electrical short circuits from cleaning equipment—highlighting the risks posed by "modern appliances" stored or operated within historic spaces without adequate protocols. This points to the importance of asset management discipline, safe circulation routes, and dedicated storage zones as resilience measures. At the same time, technical advisory resources (Charlie Harris, 2021) stress that fire emergency planning and management must be embedded as an ongoing "living practice" within heritage buildings—rather than treated as one-off interventions.

Synthesis of Key Insights

Looking across the three thematic clusters, several consistent patterns emerge:

1. physical and structural risks—particularly during restoration works—require performance-based solutions that can demonstrate equivalency.
2. indicator frameworks and resilience indices enable transparent prioritization of interventions across technical, social, and governance factors; and
3. true resilience depends on spatial management, human behavior, training, and the discipline of daily operations.

The conceptual framework of this article—rooted in Constructivist Grounded Theory—acknowledges that acceptance of technical interventions is shaped by how heritage communities themselves construct meanings of "authentic" and "safe." In this light, the synergy between global guidance (ICOMOS & ICCROM, 2024; UNESCO, 2024), equivalency standards (National Fire Protection Association, 2023), and practical advice (Charlie Harris, 2021) provides a foundation for adapting interventions to local contexts such as Bandar Hilir, Melaka, without undermining the very heritage values they are meant to protect.

RESULTS AND DISCUSSION

Challenges Of Integration

Integrating heritage preservation with fire safety requires a careful balance between maintaining the authenticity of historic fabric and achieving acceptable levels of safety. In many cases, combustible materials, concealed voids, the absence of compartmentation, and intrusive renovation works create a high-risk profile. As a result, control measures must be adapted to remain effective without compromising architectural values. Performance-based approaches are increasingly prominent because they allow objective comparison of intervention options and demonstrate safety equivalency without imposing prescriptive solutions that would damage historic fabric. For example, the case of the Duomo in Modena illustrates how thermo-aerodynamic modeling and nonlinear thermo-mechanical analysis can provide transparent technical justification for alternative solutions (Petrini et al., 2023).

From the standards perspective, challenges arise when modern prescriptive codes (e.g., exit width requirements, compartmentation, or conventional sprinklers) are impractical in older typologies. Here, NFPA 914 provides a foundation for objective and performance-based equivalencies, while operational guidance, such as that of Charlie Harris (2021), emphasizes flexibility supported by rigorous risk assessment and technical documentation. In practice, strong "equivalency case files" typically combine fire scenario analysis, conservation rationale, and post-installation monitoring plans to help regulators evaluate proposals comprehensively (Charlie Harris, 2021; NFPA, 2023).

Cost and capacity are another layer of challenge. Heritage-sensitive retrofits and maintenance are often more expensive, and their benefits are difficult to quantify through prescriptive measures alone. Value-at-Risk (VaR) frameworks offer a way to match costs and benefits, prioritizing interventions that deliver the greatest risk reduction at the lowest cost. Weighted resilience indices (AHP/CRITIC) further enable transparent prioritization across physical, managerial, and social factors. This supports phased implementation, beginning with "quick wins" such as early detection, housekeeping, and hot-work controls before moving to costlier structural interventions (Ding et al., 2023; Yu et al., 2024).

Operational and behavioral dimensions are just as critical as technical ones. Many fires in heritage sites have stemmed from welding and cutting, electrical faults, storage of flammable materials, or poor maintenance. Professional guidance clearly distinguishes between prevention (eliminating ignition sources through work permits, electrical control, and housekeeping discipline) and protection (minimizing impact through early detection, operational response, and artifact salvage planning). Both Historic England and the London Fire Brigade stress routine training, post-hot-work fire watch, and tested salvage plans as part of the daily operational discipline in historic buildings (Charlie Harris, 2021; Kincaid, 2022; Torero, 2019).

Governance and coordination challenges are also significant. Heritage site management often spans multiple agencies—museums, fire brigades, local authorities, and building owners. Urban-scale governance frameworks for immovable heritage assets call for integrated data, operations, and response coordination, while UNESCO and ICOMOS guidelines emphasize a continuous prevention–preparedness–response–recovery cycle tailored for heritage sites (ICOMOS & ICCROM, 2024; UNESCO, 2024; Zhang et al., 2025).

Spatial and access constraints—narrow streets, winding passages, closely packed buildings, or steep terrain—demand site-specific pre-incident planning (hydrant points, emergency routes, visitor pathways). Recent evidence shows that location-based AHP and dynamic assessments for dense settlements can identify weak points in terms of fire engine access, crowding, or building spacing (Arborea et al., 2014; Othuman Mydin et al., 2014b).

Another challenge lies in data and monitoring gaps. Fire incident and near-miss statistics for heritage premises are often fragmented across owners, contractors, and agencies, making systematic information sharing difficult. Digital risk-informed tools for museums and heritage sites now offer ways to conduct regular risk assessments, build shared incident repositories, and track intervention effectiveness over time—facilitating cross-site comparisons at regional scale (Bratasz & Berger, 2024).

Taken together, these findings underscore the Constructivist Grounded Theory insight that community acceptance of "heritage-friendly" interventions—such as visually unobtrusive wireless detectors—depends on socially constructed meanings of "authentic" and "safe." Thus, negotiation of meaning through stakeholder engagement, risk analysis, and prototype demonstrations must be viewed as a core part of the solution, rather than a secondary complement to technical measures (Ja'dúa'dová et al., 2025; UNESCO, 2024).

Global Best Practices

International best practices for heritage buildings rest on three key pillars: risk-based governance frameworks, flexible engineering standards, and strong operational discipline with preparedness.

At the governance level, UNESCO's latest guidance details the full risk management cycle—prevention, preparedness, response, and recovery—while emphasizing the integration of community and Indigenous knowledge alongside technical assessment. This provides a common language for heritage custodians, building owners, fire services, and local authorities to plan site-specific actions. Complementing this, ICOMOS–ICCROM (2024) expand the focus beyond pre-incident mitigation to include resilient recovery after disasters, ensuring continuity in heritage protection (ICOMOS & ICCROM, 2024; UNESCO, 2024).

At the standards level, NFPA 914 is recognized globally for enabling objective and performance-based solutions in heritage contexts where modern prescriptive codes cannot be met, if equivalent safety can be demonstrated. This flexibility supports sensitive design—such as minimizing cabling or embedding hidden systems—while requiring transparent equivalency documentation (fire scenario analysis, conservation rationale, monitoring plans). In the UK, Historic England applies similar principles through its fire advice hub, emphasizing evidence-based flexibility and robust emergency planning (Charlie Harris, 2021; NFPA, 2023).

For risk prioritization and asset profiling, best practices now rely on transparent quantitative tools such as AHP/CRITIC for indicator weighting and Value-at-Risk (VaR) for cost–benefit alignment. An AHP-based study of 36 hilltop heritage buildings showed how interventions can be prioritized without sacrificing authenticity. Likewise, a VaR framework with six first level and 42 second-level indicators enabled owners to trace investment decisions against measurable mitigation outcomes (Ding et al., 2023; Kee et al., 2025). Meanwhile, recent fire sensitivity/damage indices have refined 21–25 indicators across physical, operational, social, and environmental domains, allowing comparison across sites (Salazar et al., 2024; Yu et al., 2024).

On the engineering and technology side, best practices prioritize heritage-friendly systems: wireless alarms and detectors (to minimize invasive works), linear detection for long corridors, and integrated monitoring that does not compromise historic fabric. A case study of a museum castle in Slovakia demonstrated the effectiveness of wireless configurations as a compromise between safety and conservation. Operational guidance from the London Fire Brigade (LFB) further highlights the importance of artifact salvage planning and tailored smoke/water control methods suited to heritage environments (Ja'dúa'dová et al., 2025; LFB, 2020).

Operational discipline remains the backbone of daily best practice: strict hot-work permit systems, post-work fire watches, housekeeping audits, rigorous electrical maintenance, regular training, and pre-incident planning jointly developed with local fire brigades. Historic England emphasizes the importance of tested Emergency Response and Salvage Plans, while LFB's GN80 guidance provides tactical direction for heritage premises, including collection protection and operational coordination during incidents (Charlie Harris, 2021; Daly, 2019).

Best practices also extend to the urban scale. Narrow street morphology, winding pathways, and tightly packed buildings demand tailored strategies for fire engine access, water supply points, and visitor routes. Evidence shows that dynamic modeling for dense heritage villages, combined with AHP-based profiling in hilltop areas, helps to design realistic infrastructure and response strategies. When coupled with city-level governance frameworks for immovable heritage assets, this creates continuity across policy, design, and operations (Kee et al., 2025; Liao et al., 2024).

Across all these layers, community involvement as co-design partners—aligned with Constructivist Grounded Theory—emerges as a best practice. It ensures acceptance of "invisible" yet effective interventions, bridging the gap between community meanings of "authentic" and "safe" (UNESCO, 2024).

Key best practices directly applicable to Bandar Hilir, Melaka, include:

1. Using NFPA 914 with well-documented equivalency cases for complex conservation challenges.
2. Applying AHP/CRITIC/VaR to ensure phased investments deliver maximum risk reduction.
3. Adopting wireless/hidden systems and tested salvage plans.
4. Enforcing hot-work permits, routine training, and joint pre-incident planning with the Fire and Rescue Department (JBPM).

5. Establishing a heritage city governance committee guided by UNESCO–ICOMOS frameworks to sustain the prevention–response–recovery cycle (Huang et al., 2024; Joo et al., 2009; Salleh & Wajdi Mohtar, 2020; Shao & Shao, 2018).

CONCLUSION

This review highlights that the integration of heritage preservation and fire safety is not only a technical challenge but also a socially negotiated process. Through the lens of Constructivist Grounded Theory (CGT), the meanings of "authentic" and "safe" are understood as co-constructed by multiple stakeholders—owners, authorities, communities, and emergency services (García-Castillo et al., 2023; UNESCO, 2024). Acceptance of interventions therefore depends as much on cultural legitimacy as on technical justification.

Performance-based approaches provide the clearest pathway to resolving tensions between authenticity and safety. Case studies such as the Duomo in Modena demonstrate how thermo-aerodynamic modeling and thermo-mechanical analysis can justify equivalency without invasive prescriptive measures (Petrini et al., 2023). NFPA 914 operationalizes this principle globally, while Historic England embeds it in practice through emergency planning and salvage protocols (NFPA, 2023; Charlie Harris, 2021). From a CGT perspective, "invisible" interventions such as wireless detection gain acceptance when communicated through co-design and demonstration, reinforcing their cultural as well as technical legitimacy.

Risk assessment methods have also matured. Weighted indices (AHP/CRITIC) and value-at-risk frameworks (VaR) offer transparent prioritization across physical, managerial, and social dimensions (Ding et al., 2023; Yu et al., 2024). In challenging contexts—such as dense settlements or hilltop clusters—these tools translate diverse interpretations of risk into accountable matrices for decision-making (Kee et al., 2025). Likewise, operational discipline remains a cornerstone: fires in heritage sites often arise from welding, poor maintenance, or faulty equipment, underscoring the need to institutionalize prevention (e.g., hot-work permits, housekeeping) alongside protection (early detection, salvage) as organizational rituals that sustain readiness (Kincaid, 2022; Charlie Harris, 2021).

At the governance level, integration across agencies and urban scales is critical. UNESCO–ICOMOS frameworks call for continuous prevention–preparedness–response–recovery cycles, but effectiveness depends on shared definitions of acceptable risk and coordinated responsibilities (ICOMOS & ICCROM, 2024; Zhang et al., 2025). Applying this to Bandar Hilir, Melaka, a multi-layered model is suggested: community engagement to reconcile meanings, technical legitimacy through performance equivalency, risk-based prioritization of early wins, embedding operational discipline, and city-level governance committees with auditable KPIs. While evidence remains heterogeneous and incident data fragmented, CGT offers a way forward by grounding technical frameworks in local narratives, enabling heritage–safety integration to move from "difficult compromise" to "socially legitimized synergy."

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