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Heritage-Conscious Fire Protection of Urban Housing in Denpasar and Badung, Bali

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Abstract Denpasar and Badung in Bali possess a rich cultural legacy, exemplified by bamboo and thatch buildings situated at significant locations. Fire hazards are significant in these "embedded" urban settlements due to extremely flammable construction materials, igniting sources from ceremonies and daily activities, as well as evacuation and accessibility issues. Interventions that lack sustainable profitability, cultural relevance, and technical precision endanger the preservation of living heritage and human safety. There is an urgent need for a comprehensive, evidence-based framework that includes multi-tiered fire protection measures that are effective and preserve Bali's urban history and cultural identity. A combination of methodologies is employed to examine the design constraints, governance issues, and fire hazards associated with culturally significant Balinese urban residences in Badung and Denpasar, Bali, Indonesia. Field surveys, semi-structured interviews, historical disaster risk reduction principles, and cultural heritage concepts were employed to develop a Bali Fire Risk Index (FR). The index consists of material vulnerability (M), ignition sources (I), building density (D), evacuation/access (E), and defence capacity. A convergent technique examines 120 residences in Denpasar and Badung, Indonesia, to develop quantitative fire risk profiles. The profiles illustrate product classification and historical methodologies. It offers qualitative insights on retrofitting, community resilience, and governance. Fires can rapidly propagate in highly populated urban environments utilizing thatch and bamboo materials. Furthermore, ceremonial ignition areas are more prone to experiencing their inception. In densely populated areas adjacent to sacred sites, bamboo and thatch structures exhibit low fire resistance. Furthermore, composite evacuation materials often exhibit diminished fire resistance. The majority of individuals encounter difficulties in upgrading due to governmental and financial apprehensions. The study provides civil engineers and architects with pragmatic guidance on materials, design, evacuation procedures, and regulatory compliance. This research intends to develop a fire prevention strategy tailored for Bali. This framework must protect Bali's expanding urban region and its citizens to assist elected authorities, families, and communities.

Keywords Balinese Urban Housing, Cultural Heritage, Disaster Risk Reduction, Fire Risk

1. Introduction

Historic towns and urban villages offer many fire risk factors: combustible materials used for the construction of buildings, ceremonial objects, as well as everyday ignition sources, difficulties in evacuating mid-high-rise buildings, and accessing housing locations. Measures that are not technically sound, culturally meaningful, or sustainable in the long term, threaten both human safety and cultural heritage. There is a demand for an evidence-based multi-layered fire prevention initiative, which respects

Bali's urban heritage and culture.

Bali is a renowned destination for travelers due to its stunning landscapes and rich history. An increasing number of individuals are relocating to the southern region of the island, encompassing Denpasar and Badung. Urban areas pose navigational challenges due to their high population density, particularly when accessing cultural or religious sites. Traditional Balinese home compounds, communal shrines, and family temples (*sanggah/ merajan*) are not only aesthetically pleasing structures that have withstood the passage of time, but also residences for numerous generations, preserving social order, ritual practices, and cultural memory. It is asserted that the city's unique social, cultural, and architectural context significantly reduces its susceptibility to fire compared to other cities [1], [2], [3]. Numerous antiquated residences retain traditional roofs constructed from bamboo, timber, and thatch.

The likelihood of a fire originating from these items is extremely high. Because of their well-organized layout, these courtyards are susceptible to fire [4]. This condition can be attributed to factors such as the use of incense during ceremonies, outdated electrical appliances, and inadequate investment in the area's infrastructure. The location has been significantly damaged. Due to factors such as the area's history, increased ritualistic activities, the layout of the space, and the effectiveness of the regulations, the materials are more susceptible to fire under specific circumstances [5]. To endure this challenging period, this study must devise a plan to protect Bali's genuine cultural heritage from the engulfing flames. Despite Bali as a whole continuing to attract visitors from around the globe, Badung and Denpasar, two cities in southern Bali, have recently experienced a surge in tourism. When large crowds gather around major religious and cultural landmarks, streets can become congested and difficult to navigate.

The architectural miracles of traditional Balinese residential complexes, communal shrines, and family temples have historically accommodated Balinese families and their ritual practices, social structures, and cultural heritage. The fire danger in this city is substantially reduced as a result of its unique social, cultural, and architectural characteristics [6]. Bamboo or timber for structuring roofs is still prevalent on a significant number of traditional residences (Figure 1). Ignition can ignite these elements [7]. Navigation is complicated, and the courtyards' configuration facilitates the ignition and propagation of flames (Figure 2). This condition is precipitated by the lack of a strategy to improve the facilities, the aging of the electrical equipment, and the need for exposed flames for specific ceremonies. The situation is intolerable. In these environments, the risk of object ignition is exacerbated by factors including the effectiveness of the regulatory framework, the evolution of ritual practices, the geographical configuration, and the historical context [8]. To protect Bali's genuine cultural heritage and its inhabitants from fire hazards, a policy is needed.

Figure 1. Bamboo and Wood for the roof structure of the Balinese house

Figure 2. Offerings and ceremony activities in the courtyard of the Balinese house

The proliferation of policy initiatives that intersect in Bali further complicates this challenge. In collaboration with other organizations, the Disaster Management Agency called *Badan Penanggulangan Bencana Daerah* (BPBD) in Bali Province, is advocating for greater emphasis on preparedness and resilience in Disaster Risk Reduction (DRR) plans at the provincial and local levels. The cultural history of Bali, which combines physical and non-physical elements, is simultaneously protected by rigorous regulations. In 2012, UNESCO recognized this region as a cultural landscape [9], [10]. However, the implementation of fire prevention strategies in historical management and spatial planning remains inconsistent. The operational level of urban housing does not address issues such as fire safety, historical preservation, and problem resolution. It is not only desirable but also essential to develop a fire protection system that is in harmony with Bali's cultural heritage. This framework must be robust enough to mitigate fire risk, while also being adaptable and cognizant of Bali's unique cultural, architectural, and social characteristics. Denpasar and Badung are two districts that possess distinct yet comparable heritage dynamics, tourism demands, and disaster management systems. The objective of this initiative is to fill a significant gap in the field by combining expertise in urban planning, civil engineering, fire safety, and historical preservation into a practical, expandable framework.

This research outlines major contributions to urban planning, disaster risk reduction, and heritage conservation. Theoretically, this study builds upon the existing literature of risk reduction for conservation of heritage by developing a Fire Risk Index (FR) explicitly tailored to the intricacies of physical-bio-spatial-local governance interactions at a heritage district level in Bali, Indonesia.

From a practical perspective, this study offers actionable, design-based recommendations for civil engineers and architects on incorporating safety improvements into heritage structures, balancing structural integrity, fire resistance, and traditional cultural components. It includes objective-oriented interventions from material treatment to non-invasive structural retrofitting and culturally appropriate spatial planning. In addition, this research suggests a multi-scalar framework connecting household-, neighborhood-, and policy-scale interventions, with specific consideration of local material culture and sacred space, as well as existing governance regimes in Bali. These findings are intended to directly guide policy-making by pinpointing key governance gaps and providing avenues for regulatory harmonization and capacity-building. In the long term, this research will contribute to more resilient and locally authentic urban settlements in Bali and could be a model for other rapidly urbanizing cities with strong heritage qualities [10], [11].

The paper begins with an exploration of the fire risk and cultural heritage as key information for the study. The research method used to investigate the fire protection in urban housing in Bali is then presented and explained. The fire safety conditions in Denpasar and Badung were used as the data for the assessment of Balinese urban housing. Finally, the safety and cultural heritage in the Balinese urban housing are presented along with conclusions.

2. Fire Risk and Cultural Heritage

2.1. Heritage Governance Interfaces and Policy Integration

The issues of national rules called *undang-undang* (*UU*), Regional regulations called *peraturan daerah* (*Perda*), and local wisdom regulations called *awig-awig* in managing cultural assets have complicated the organization and development of cultural heritage in Bali. Frameworks of governance for cultural heritage are often geared towards maintaining both living tangible and intangible values. When contoured, through zoning, protected area designation, and traditional architectural regulations [12], [13]. Applying these frameworks in a rapidly urbanizing context, particularly around everyday life and contemporary infrastructure needs, is exceptionally challenging. However, links between policies, such as heritage governance and disaster risk reduction (DRR), are either unclear or lack clear implementation plans for collaboration. Both want to protect human health and property, but their objectives in doing so may differ.

In contrast, aspects of heritage conservation value authenticity and non-interventionism, which may sometimes conflict with DRR, as building resilient structures and preparing for a prompt response, may involve significant, unsustainable modification [14], [15]. Dissecting the myriad ways that heritage governance has been studied regionally [16], [17], [18] and worldwide reveals a common challenge, especially for sustaining both cultural preservation and disaster resilience: achieving cross-sectoral policy integration. Integration requires collaboration, alignment of legal instruments, and clarity over the roles and responsibilities of those engaged in DRR (local government, heritage authorities, community leaders, and residents) [19]. In Bali, the governance context embodies customary village institutions (*desa adat*) and temple committees. Involving people and respecting the traditional decision-making process is critical.

2.2. Fire Risk and Safety in Heritage Buildings

Traditional Balinese architecture uses bamboo, various types of wood, palm fiber (*ijuk*), and thatch or reeds (*alang-alang* for roofs) (Figure 3). Such materials are culturally essential and eco-friendly, but they are also remarkably flammable, with flames spreading at very high speed, making them unfriendly from a fire protection perspective. Specifically, bamboo and thatch ignite easily and burn hot, producing substantial heat and smoke. Studies investigating the fire performance of natural materials indicate that avoidance of such hazards will require specific treatment and design approaches [20], [21]. The drier and more brittle the materials become, the more vulnerable they are, especially in heritage buildings. These materials become more susceptible, specifically due to the usual layout of Balinese house compounds [3]. These layouts, with many buildings clustered around a common courtyard, and often with shared walls or extremely close rooflines between buildings, can cause a fire to spread rapidly throughout an entire complex, or even to adjacent properties [22].

Figure 3. Reeds and palm fibre for the roof of Balinese buildings in Kuta

Figure 4. The rituals that always use fire or incense in the courtyard, called *natah*, in a Balinese housing

While central and open courtyards called *natah*s were important for rituals and social gatherings, they could potentially be hazardous if not managed, especially where ceremonial fires were involved (Figure 4). The following are major fire risk factors in these settings: (a) combustibility of domestically-used construction materials; (b) densely packed urban configurations with limited fire breaks and narrow access to emergency service; (c) existing widespread sources of ignition, including ceremonial open fires, incense offerings, cooking fires (semi-open kitchens with gas stoves and/or firewood), and old or informally-installed electrical systems; (d) lack of fire detection and extinguishment infrastructure within and around households in communities; and (e) a possible deficiency in systematic fire safety education and awareness specific to heritage-unique vulnerabilities. Understanding these interrelationships is crucial for developing appropriate fire protection plans that minimize the impact on the cultural significance of traditional architecture.

2.3. Practical Retrofit Design and Retrofitting Approaches in Heritage Districts

Retrofitting historic buildings to make them less susceptible to fire is extremely difficult, as it requires balancing cultural authenticity with compliance with contemporary building codes. The conventional retrofit approaches, typically designed for contemporary pathways, aggressively intervene on heritage buildings by altering their appearance, structural capacities, and/or ritualistic role [23], [24]. Practical retrofit design in heritage precincts, then, must be heritage considerate; that is, it should be based on approaches that are minimally invasive, reversible if required, and compatible with existing materials and construction systems.

So significant methods are: (a) Material therapies: Coatings or imbue coatings utilizing fire-retardants on flammable resources like bamboo and timber. Further testing is required to establish the efficiency and durability of these treatments on conventional styles. They meant that it should not alter the appearance of the original substances or hasten their degeneration. (b) Passive compartmentalization: Installing fire-rated barriers or partitions that prevent the spread of fire without altering the open-plan nature of spaces or obstructing sacred sightlines. This partition aims to provide lightweight, safe panels that can be easily installed or removed, and to serve as changeable obstacles built only during high-risk times. (c) Making existing load-bearing elements stronger so they do not need to fall over in a fire—structural reinforcement. On the other hand, this needs to be done without losing touch with traditional building forms and materials. d) Concealed detection and suppression-integrated fire detection (smoke and heat detectors, etc.) and active protection system (fire extinguishers, or sprinkler) located in architectural elements that entrench with the historical building context.

Safe electrical upgrades: retrofitting old electrical systems with proper conduits, circuit breakers, and grounding, ensuring new installations are concealed and do not pose a fire hazard or visual nuisance. Improved access and egress: the creation of defined, well-lit evacuation routes considering the city layout, and the establishment of gathering points.

Likely, this will entail improving existing pathways, providing limited access points for emergencies, or proactively managing crowds during ceremonial events. Local masons, traditional builders, and heritage experts should be employed to ensure that retrofits are both practical and appropriate to the culture and sustainable within the region [25], [26], [27].

3. Research Method

3.1. Investigating Fire Risk in Urban Housing

Through a convergent mixed-methods, multiple-case study design, this research interrogates the design of multi-level pathways to fire risk and protection in urban housing that embodies meaningful cultural heritage in Bali (Figure 5). The multiple-case study design concentrates on Denpasar and Badung as two unique yet comparable urban environments that can produce both general and specific insights [28]. Denpasar, as the provincial capital, is characterized by its high population density, intense urbanization, and the significant presence of a historical core within a rapidly modernizing urban fabric. Badung Regency, on the other hand, includes significant urbanized zones, particularly those adjacent to major tourism corridors.

A triangulation of data sources was utilized to ensure comprehensive coverage and enhance the validity of findings, including policy and archival documents, field data, stakeholder voices using semi-structured interviews, and spatial data.

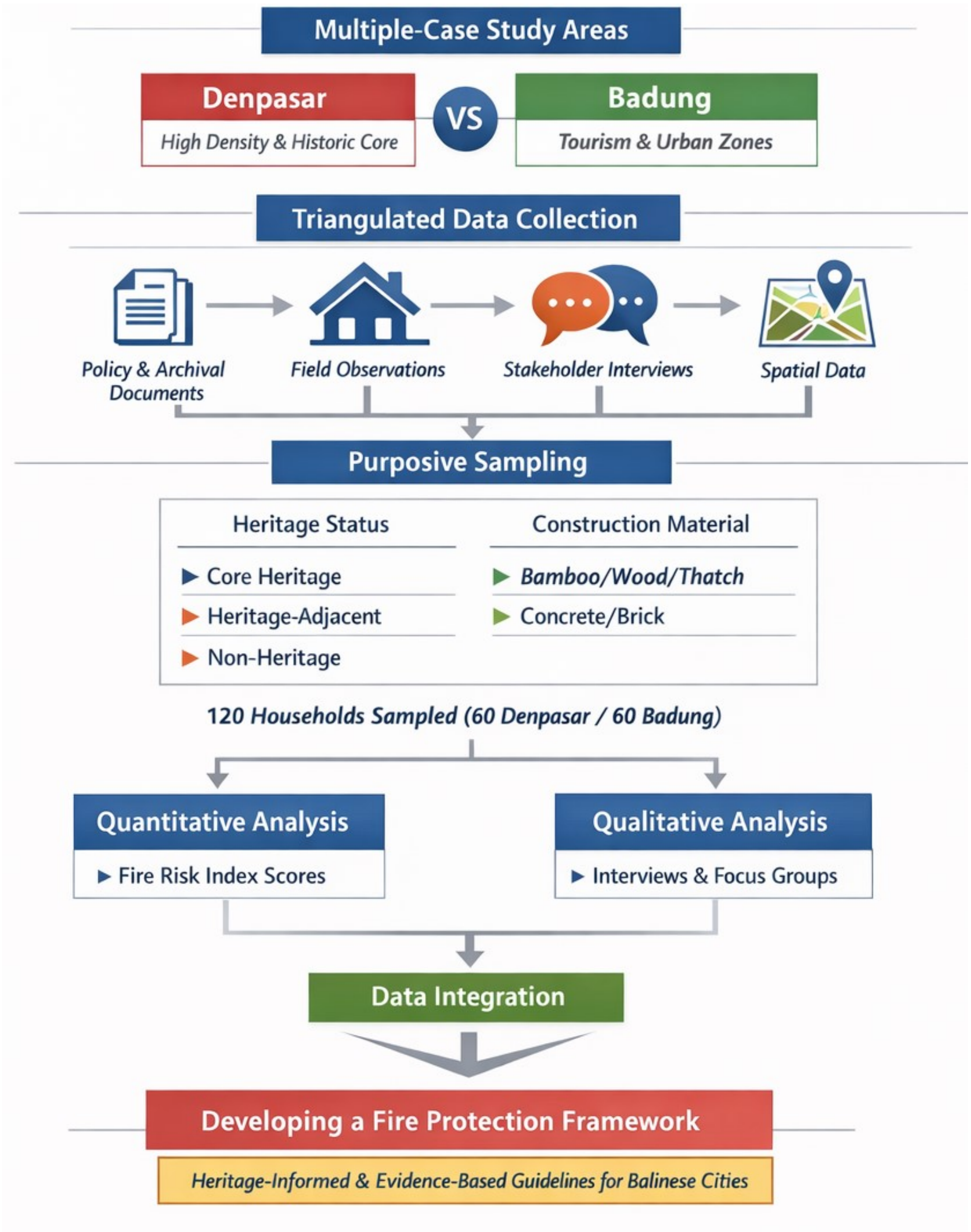

Figure 5. Diagram of research method

Details of the sampling for this study were purposive, representing urban housing units with a range of heritage contexts and risk profiles in Denpasar and Badung. In each study area, urban and rural districts were selected, and we purposively sampled (60 Denpasar and 60 Badung) households. Households were stratified according to two important criteria: (a) heritage status (core heritage compounds with active temples, peripheral heritage-adjacent compounds, and non-heritage but traditionally-influenced homes) and (b) primary construction material (mainly bamboo/wood/thatch compared with mixed materials including concrete/brick). This stratification ensured the sample included a variety of variations in material vulnerability and cultural importance central to the research questions. The estimated sample size was based on previous mixed-methods research, including populations at risk in urban areas, which sought to achieve adequate variation for quantitative calibration of the FR index as well as qualitative saturation through interviews.

In a convergent mixed-methods design, both quantitative and qualitative data are collected and analyzed simultaneously, then combined during interpretation. Such integration will allow for an in-depth understanding of the research problem, in which quantitative data (e.g., Fire Risk Index scores) provide objective risk assessments. On the other hand, qualitative data (e.g., interviews, focus groups) provide nuanced details about human perceptions, governance challenges, and cultural practices [29]. Develop a clear, heritage-informed, evidence-based fire protection framework for Balinese cities. This framework will provide civil engineers, architects, and policymakers with valuable guidelines.

3.2. Multi-Criteria Risk Assessment and FR Index Theory; Strengths/Limitations

Multi-criteria risk assessment (MCRA) is a systematic approach that combines diverse quantifiable and non-quantifiable aspects of risk, often in a hierarchical structure, with weights assigned to their importance [30], [31], [32]. For heritage fire risk, one of the most effective MCRA tools is the Fire Risk (FR) Index, which combines multiple variables into a single score for comparisons and action prioritization [33]. A FR index will have a theoretical basis, recognizing that fire risk is not a single entity but a combination of factors, each determined by distinct vulnerabilities and impacts [32].

Standard components include: material flammability, ignition potential, use and occupancy characteristics, structural integrity, and availability of early detection and extinguishment [34]. So the good things about the FR index approach such a measure can: (1) illustrate a comprehensive risk profile by analyzing various domains; (2) organize and clarify the assessment process, especially when the associated weights are provided via expert elicitation methods (e.g., analytical hierarchy process [AHP]; (3) highlight relative riskiness, thereby enabling focused interventions and (4) facilitate communication across stakeholder communities by translating complex risk information into a unit/lifeline score [32], [33], [35].

However, this approach has some limitations: (a) subjectivity in the weights assigned to different criteria may impact on final risk score; (b) data quality of each component is difficult or not possible to find especially in informal or heritage-rich urban areas; (c) the accuracy of the model depends on the exhaustiveness of the chosen criteria and validity of their measurement; and (d) the index may not reflect the dynamic characteristics of risk, primarily behavioral or that related to unexpected changes in urban settings. Despite these disadvantages, an overall FR index that is well-calibrated to the setting conditions is an essential instrument for understanding, measuring, and managing fire risk [30], [31], [32], [33] in heritage settings where a single-factor approach is unsuitable.

The quantitative analysis in this paper is based on the Fire Risk Index (FR). It is compound and reflects a structured method for the systematic assessment and comparison of fire risk to different types of urban residential housing units in Bali. The FR is a linear combination of 5 significant components, with each reflecting a diverse threat component to fire risk in these historical areas. The Fire hazard index is given by the relation:

$$FR = w\_1 M + w\_2 I + w\_3 D + w\_4 E + w\_5 P$$

M represents Material Vulnerability, I denotes Ignition Sources, D signifies Building Density and Proximity, E corresponds to Evacuation and Access Factors, and P indicates Protection Capacity. The weights w_1, w_2, w_3, w_4, and w_5 indicate the relative significance of each component concerning the overall fire risk. For this preliminary draft, the weights are assigned as follows: w_1 = 0.28, w_2 = 0.26, w_3 = 0.18, w_4 = 0.14, and w_5 = 0.14. These example weights illustrate a scenario in which the primary factors influencing fire risk in Balinese heritage housing are the flammability of materials and the existence of ignition sources. The subsequent most significant factor is spatial density, succeeded by evacuation and protective capabilities. These weights would be derived from empirical data and validated by experts, such as fire safety specialists, heritage conservationists, and local authorities, using methodologies like the Analytical Hierarchy Process (AHP), and corroborated through field observations and historical incident records during the implementation phase.

There are five sections to the FR index, and they are ranked from 0 to 1, with 1 being the highest risk or lowest capacity and 0 being the lowest risk or highest capacity:

- **M (Material** Vulnerability**):** The fire resistance and flammability of key construction materials are evaluated. A higher numerical value indicates a greater sensitivity to materials mostly made of thatch (*alang-alang*), bamboo, or unprotected wood (for example, roofs and walls). Fire-treated materials, such as concrete, brick, or masonry, have decreased characteristics.

- **I (Ignition Sources):** Determine the prevalence and severity of probable fire sources in the facility. Indicators include the frequency of ceremonial open flames (such as incense burning or ritual fires), the type and condition of cooking appliances (including open flame cooking or gas stoves near combustible materials), and the age and condition of electrical installations (particularly informal wiring or visible deterioration).
- **D (Building Density and Proximity):** Evaluates the proximity of structures and the interstitial distance, both of which influence fire spread. Properties in busy urban districts with small internal courtyards are often more valuable than those with large floor plans, shared walls, or restricted buffer zones between buildings.
- **E (Evacuation and Access Factors):** The accessibility of the site is assessed, taking into account both the ability of individuals to evacuate and the timely arrival of emergency services. Fire trucks and other emergency vehicles are less useful if they can't reach evacuation routes. For instance, obstacles such as narrow lanes with a single exit, intricate floor plans, and blocked gates can hinder the effectiveness of evacuation routes.
- **P (Protection Capacity):** Evaluates the current fire safety processes and response tactics to determine their effectiveness. This checklist covers the presence of water sources (hydrants, community wells), smoke and heat detectors, fire extinguishers, community-based fire response organizations, and frequent safety exercises. Decreased figures imply insufficient protective capacity.

The FR index based on MCRA (Figure 6), thus calculated, provides a quantifiable snapshot of fire risk, allowing for the identification of high-risk areas and the prioritization of targeted interventions. This quantitative backbone is then enriched and validated by qualitative findings.

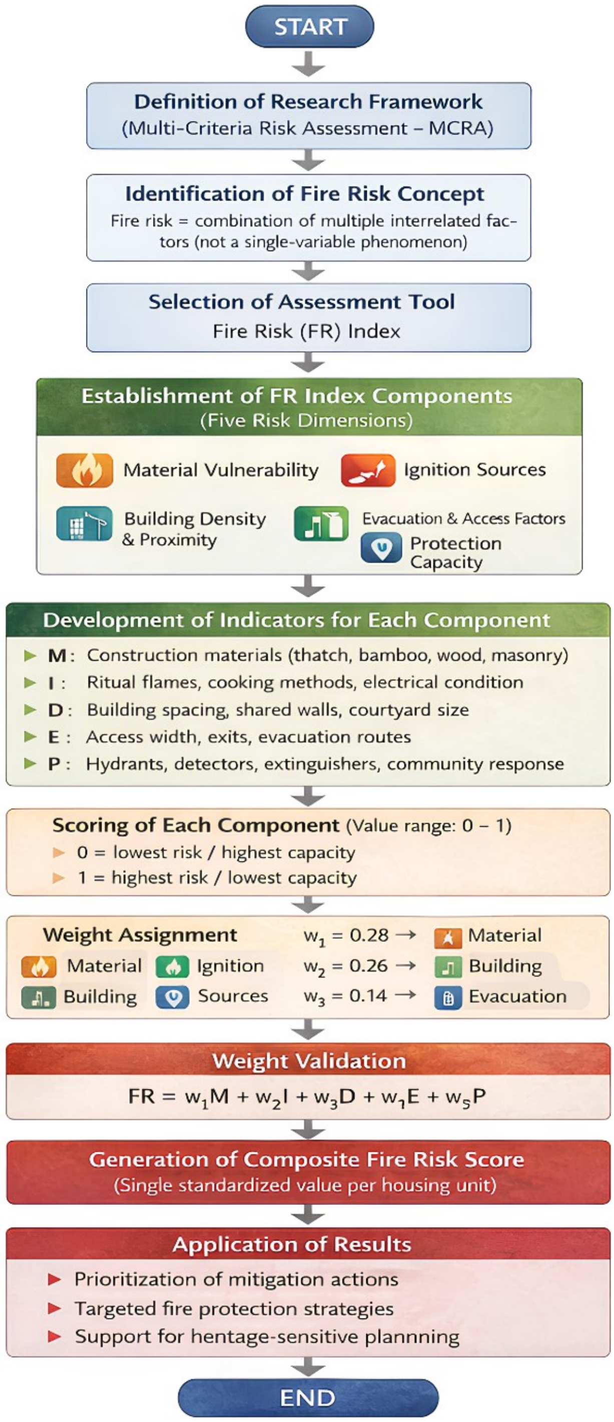

Figure 6. Fire Risk Index (FR) assessment process based on Multi-Criteria Risk Assessment (MCRA)

4. The Results: Fire Safety Condition in Denpasar and Badung

The following results were derived from the methodological framework applied to a sample data set outlined in the next section, comprising 120 houses in Denpasar and Badung, classified by heritage status and primary construction materials. These are the expected patterns and insights from a well-executed study and actually tell the whole story based on suggested methods.

4.1. Descriptive Sample Characteristics

Table 1 presents a representative sample of the 120 households surveyed: 60 households from Denpasar and another 60 from Badung. The classification of heritage status reveals specific characteristics: core heritage, peripheral heritage, and non-heritage. In Denpasar, the core heritage compounds (n=20) tended to have a median of building age of 42 years and a higher percentage of traditional bamboo/thatched roofing (60%). Eighty-five per cent of these houses had cooking activities occurring in or near internal courtyards. In Denpasar, by contrast, all non-heritage homes (n=15) were mixed, were of a younger median of building age (26 years), and had a substantially lower courtyard cooking prevalence (40%). The same patterns appeared in Badung, although the homes were slightly younger across all categories. That might be because the area has been developed more recently. Similarly, core heritage compounds in Badung (n=18) were still heavily dependent on bamboo-thatched materials (61%) and courtyard cooking (78%). The descriptive statistics reveal that the two regions feature diverse housing styles, each with varying levels of exposure and protection.

4.2. FR Index Results

The Fire Risk Index (FR) calculations indicate that fire risk varies significantly across housing types. Overall, bamboo compounds/thatched compounds were found to have greater mean FR values than mixed-material compounds. With this hypothetical weighting (w_1=0.28, w_2=0.26, w_3=0.18, w_4=0.14, w_5=0.14), the FR of bamboo/thatched compounds was represented as a mean FR of approx. 0.615 (on a scale of 0-1). Such conditions were primarily due to high material vulnerability (M=0.85) and also considerable ignition sources (I=0.55). In contrast, mixed-material compounds exhibited a lower average FR of ~0.497, which was driven by lower material vulnerability (M=0.45) and higher protection capacity (P=0.60).

Table 2 provides detailed means of FR by heritage status and material type. The highest FR (mean FR = 0.62 for bamboo/thatched core heritage) was always observed in the case of core heritage compounds (especially those built up with bamboo or thatched materials). This result suggests that the use of traditional materials and cultural connections inevitably increases the fire risk. In addition, within core heritage zones, mixed-material compounds had a marginally higher FR (mean FR ≈ 0.49) than mixed-material homes that were not heritage (mean FR = 0.52). Heritage areas show increased risk regardless of material due to spatial density and access concerns.

Table 1. The Condition of housing in Denpasar and Badung

Site	Heritage Status	n	Material Type (approx.)	Median Age of Dwelling (years)	Households with Cooking around Courtyard (%)
Denpasar	Core heritage	20	Bamboo/ thatched 60%; mixed 40%	42	85
Denpasar	Peripheral heritage	25	Bamboo/ thatched 48%; mixed 52%	38	68
Denpasar	Non-heritage	15	Mixed 100%	26	40
Badung	Core heritage	18	Bamboo/ thatched 61%; mixed 39%	35	78
Badung	Peripheral heritage	22	Bamboo/ thatched 41%; mixed 59%	32	63
Badung	Non-heritage	20	Mixed 100%	24	36

Table 2. Fire Risk (FR) of urban housing in Denpasar and Badung

Heritage Status	Material Type	Mean FR
Core heritage	Bamboo/thatched	0.62
Core heritage	Mixed-material	0.49
Peripheral heritage	Bamboo/thatched	0.61
Peripheral heritage	Mixed-material	0.50
Non-heritage	Bamboo/thatched (illustrative)	0.58
Non-heritage	Mixed-material	0.52

Figure 7. Narrow access of the house in Kuta

4.3. Spatial Distribution

Spatial Distribution of FR Hotspots Denpasar and Badung (Figure 1). The largest concentrations of FRs (dark red) reside in the dense urban core of Denpasar, particularly through older traditional neighborhoods and larger temple clusters. It is characterized by many buildings in proximity to one another, narrow, often twisting lanes and many conventional building materials (Figure 7). If the blocks are tightly packed with adjacent walls and a constant eaves height, a small fire can quickly propagate into a large one. Specific high-risk locations in proximity to the Denpasar city and other areas of tightly packed *banjar* are shown in Figure 8. These are also the regions that had large values of M and D in the FR index. The overall FR in Badung was generally lower. However, risk areas (orange-red) were still found in corridors along more widely open, older tourist accesses, as well as in areas with spatial changes. Older traditional structures, untidy settlements, and enterprises characterize these areas. High I (ignition sources) from commercial kitchens and antiquated electrical systems, along with moderate D values, contribute to this. It is important to stress, at the same time, that risk is not equally distributed. It is shaped by urban form and how heritage features compound contemporary urban challenges.

4.4. Material Vulnerability and Spatial Configurations

The correlation analyses revealed a significant positive association between Material Vulnerability (M) and the total FR index ($r = 0.68$, $p < 0.01$). This result indicates that the selection of building materials is the key factor in exposure to fire risks. FR scores were consistently higher for structures that predominantly used bamboo, thatch, and/or untreated wood. But thatch is particularly vulnerable, especially the kind made of reeds called *alang-alang* or palm fiber called *duk*, because it ignites easily and burns very hot (See Figure 1). Finally, both the number of internal courtyards and the proximity of buildings (D) had a strong positive association with FR ($r = 0.45$, $p < 0.01$). Core heritage compounds, which are typically designed with multiple family dwellings tightly constructed around a central courtyard, provide rapid fire spread from one building to the next (Figure 9). Laid bare were the gaps in protective barriers — often the simple concrete walls, or sometimes fire-resistant partitions between one section of a compound or another — that in existing, un-retrofitted homes were often missing entirely or were insufficient. Even where such barriers existed, their efficacy was most often undermined by utility access holes or makeshift extensions. A multivariate regression model ($R^2 = 0.54$, $p < 0.001$) confirmed that M and E (Evacuation and Access Factors) were the most important predictors of FR, followed by P (Protection Capacity). At the same time, I (Ignition Sources) and D (Density) also significantly, but moderately, improved the model's explanatory power. In other words, while the materials certainly matter, so do spatial planning and emergency access, as they are key components in overall risk reduction.

Source: Google Earth image, retrieved on 1 November 2025

Figure 8. The density of housing in Denpasar

Figure 9. Pavilions constructed close to each other are located around the courtyard in Sanur, Denpasar

4.5. Ignition Sources and Behavior

However, the togetherness (or rather, the complex interaction) of traditional ways of doing things and modern conveniences was revealed during the analysis of ignition sources (I). For instance, in 46% of core heritage compounds, ceremonial ignition sources included open flames for offerings (e.g., incense and oil lamps) and ritual fires (e.g., during cremations or large temple festivals). While they are typically handled with cultural awareness, their proximity to highly combustible items or large crowds at ceremonial events makes them inherently hazardous. Fires often started in cooking areas, ranging from 62% of core heritage compounds to 36–40% of other compounds. Common hazards included gas stoves, which were often placed against wooden surfaces or close to thatched walls, and firewood burning in semi-open courtyards. Problems arising from electrical faults in ageing installations were identified as high risk and high prevalence across core heritage (18%) and up to 22% in mixed-material compounds. Combine that with poor wiring, overloaded circuits, and simply not maintaining the system, and getting a professional upgrade made matters worse. The risk of ignition was also influenced by seasonal or ritual-related factors, peaking during major festival seasons, when many more ceremonial activities occur. Fire detectors (P) were negatively correlated with FR ($r = -0.35$, $p < 0.05$), although small in magnitude ($p = 0.037$), indicating that the presence of FR had a positive effect. Nevertheless, the general absence of detectors in heritage zones (25–35%) indicates a significant shortfall in basic preventive measures. This condition demonstrates the need for culturally appropriate fire safety programming that engages with both social practices and the continuity of culture within the context of fire safety, for everyday behaviors and ceremonial practices.

4.6. Evacuation Access and Firefighting Readiness

Evaluation of the first factors of the evacuation and access (E) stage was also found problematic, especially in the core heritage areas. The average alley width in these areas was 2.2 meters, which is generally not suitable for modern firefighting vehicles (Figure 10). For instance, larger fire trucks typically require a minimum clearance of 3–4 m. Median alley widths in peripheral areas improved to 2 8 m, whereas access was wider in non-heritage zones (median 3 5m). The median distance from core heritage compounds to the nearest main road accessible by emergency vehicles was 75-90 m. This accessibility made response times worse. This condition is likely due to more dispersed areas under development. The presence of a fire hydrant or readily available water source (P) was highly variable. This condition indicates that the infrastructure is unequal. According to emergency responders, it took an average of 15 minutes or less to reach a water point (Figure 11). When fires ignite fast, this is a huge difference. Other barriers to rapid evacuation included narrow internal paths in compounds, multiple-storey structures, and locked gates or walls, which enhanced security but could hamper rapid exit during emergencies.

Figure 10. Small passages in Denpasar

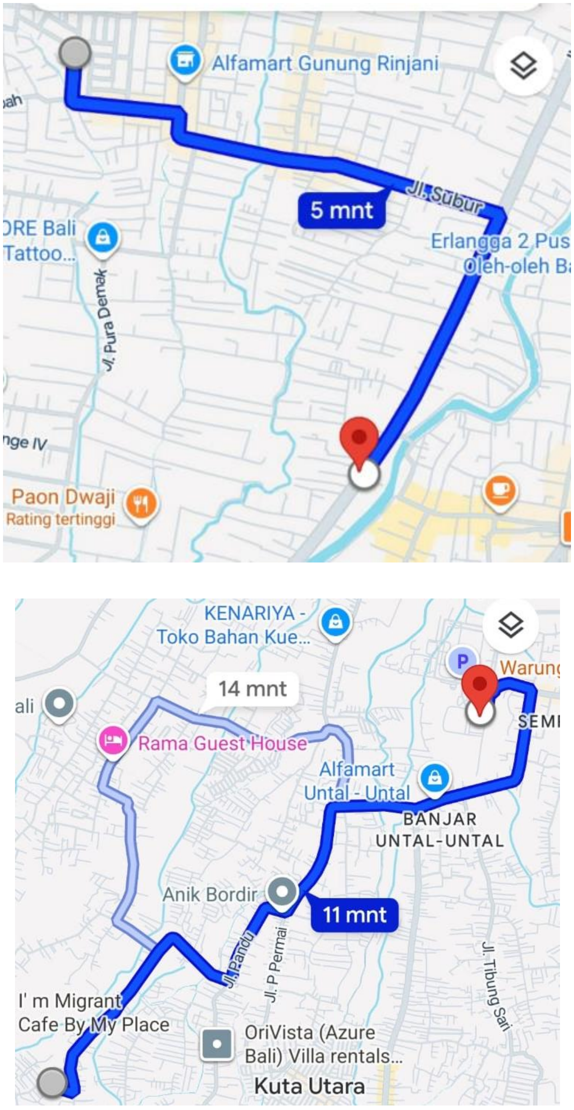

Figure 11. The route of fire fighter that has a response time of less than 15 minutes for settlements in Denpasar (upper) and Badung (below), retrieved from Google Maps 2 November 2025

4.7. Governance and Institutional Context

Qualitative findings from interviews and focus groups were freely accessible and revealed significant governance shortcomings, despite the existence of disaster risk reduction policies at both provincial and municipal levels, as well as heritage conservation policies. Stakeholders likewise see a gap between high-level policy intentions and their on-the-ground implementation at heritage compounds and informal settlements.

Protection of heritage buildings from fire is a complex and holistic responsibility for the government. It encompasses the important subjects of policy development, financial distribution, rigorous implementation, and collaborative initiatives. It is governments that are the best protectors of our shared cultural inheritance. They do so by adopting strong legislation that sets out a comprehensive framework, providing sufficient funding, robust oversight and promoting close alliances at all levels. The above proactive fire prevention and full emergency response assuredly is more than just a legal obligation, but we are bound to protect this rich cultural heritage, so it can be preserved for generations. In order to preserve the history of our world from an ongoing threat of fire, we must continue to be vigilant, flexible, and completely committed to these principles.

Some key gaps were: (a) **Funding for retrofitting**: There are no specific funding pots available that respect heritage, making it difficult for homeowners to upgrade old stock without washing their character. (b) **Policy alignment**: There are no explicit harmonized rules that connect the motives of heritage agencies (preservation of sites) with those of DRR authorities (protection at scale). And this often leads residents to struggle to obtain the permits they need or to receive contradictory directions when they wish to make modifications. (c) **Enforcement:** Inconsistent enforcement of fire codes. Fire codes are not always enforced in heritage districts, as traditional building methods become less well understood (which is essential to deliver on). Still, nobody wants to incur civil disobedience equities against local cultural practice. (d) **Capacity building**: There are a few local masons, builders, or even local government officials who have learned how to use fire-retardant techniques that work and are also pleasing to look at and relate to when it comes to heritage materials. Various studies acknowledged the impact of community-level protection practices (e.g., neighborhoods watch groups, informal temple guardians, traditional mutual aid networks), but these practices were seldom systematically considered in either formal disaster risk reduction (DRR) strategies or formal building retrofitting programs.

The respondents emphasized the urgency of planning tools that integrate conservation and safety objectives. They demanded that clear pathways for retrofitting be defined; that material specifications include cultural heritage-friendly criteria; and that practitioners and inspectors receive rigorous training.

5. The Findings: Safety and Cultural Heritage

5.1. Integrated Technical in Fire Safety of Urban Housing

The juxtaposition of quantitative FR index outcomes and qualitative-rich data unequivocally indicates that Bali's urban heritage housing requires a fire protection framework that is inherently heritage-aware. It needs to fully integrate technical fire safety features with genuine cultural sensitivity and culturally informed living practices within Balinese compounds. The increasing Material Vulnerability (M) of bamboo and thatched structures, particularly in heritage areas with high population density, underscores the need for context-specific material interventions. Qualitative research indicates that you can't simply swap out traditional materials for contemporary non-combustibles without significant cultural pushback. However, that retrofitting must consider materiality, be carried out in a minimally invasive manner, be reversible, if need be, and respect the visual and ritual integrity of these sacred spaces. In many cases, such as applying certified fire-retardant treatments to *alang-alang* thatch that do not alter appearance, or using non-combustible partitions that maintain line of sight to temple shrines, significant improvements in compartmentalization can be achieved without compromising ceremonies. Such actions resonate with broader heritage conservation ideas emphasizing compatibility and reversibility [3], [22], [33], [36] in interventions that maintain cultural integrity.

The strong influence of Evacuation and Access (E) on the FR index demonstrates the spatial nature of urban design. Although the traditional Balinese compound form is highly prominent in the culture, tiny alleys, circuitous passages, and unconnected buildings make egress difficult for occupants and ingress difficult for emergency personnel. This difficulty means that fire protection planning must include protecting sacred sites and ritual areas, while ensuring exits for the population and access for emergency services. This creates a need for new spatial design tools that can track ceremonial timelines and ritual circulation passages, for instance, establishing short-term safety zones rather than permanent exclusion zones during major processions, as well as adaptable egress channels that retain ritual flow. The qualitative data similarly demonstrated the critical role that community networks played in promptly extinguishing the fire and rapidly evacuating individuals from the area. This is evidence of the importance of local knowledge and social capital for resilience. Any practical framework will have to be community-focused and built on existing social fabric, particularly temple committees and *banjar* associations, to disseminate risk information, collaborate, and access local fire safety resources.

Finally, the governance shortcomings we highlighted—the absence of integrated policy, funding, and technical expertise—constitute a significant barrier to achieving effective and comprehensive fire safety. So, governance integration is essential. It means that fire protection objectives should be formally embedded in heritage management plans and in systems of approval for retrofits. The fire protection measures include the presence of fire detection devices (smoke and heat alarms), fire extinguishers, water sources (such as hydrants and community wells), and the existence of organized community fire response teams or regularly scheduled safety exercises. These objectives require an overarching regulatory regime, an earmarked retrofitting fund that considers heritage, and robust capacity-building programs for local masons, conservators, and DRR personnel. This condition, in turn, will provide a basis for collaborative approaches to fire safety that also consider heritage.

5.2. The Framework of the Protection of Fire Safety and Cultural Heritage

By providing a Bali-specific framework that uniquely integrates civil engineering design principles with legacy conservation constraints, this study makes significant contributions to disaster risk reduction and heritage governance, two interdisciplinary fields. It employs a Fire Risk Index (FR) tailored to the specific features of material culture, spatial morphology, and socio-religious practices surrounding urban housing in Bali, thereby going beyond generic risk assessment models. Thus, this deepens the understanding of how local contexts influence vulnerability and resilience [33], [36]. It also emphasizes that heritage is not only a commodity but also a living system sensitive to context, and therefore, methods of protection must be adaptive and culturally appropriate [1], [2]. The findings corroborate the theoretical view that risk reduction in heritage is a fundamentally wicked problem that requires multi-scalar, integrated solutions that transcend disciplinary silos [32], [35], [36].

The study provides practical, actionable benefits to individuals at any level involved. The tool enhances knowledge of local-specific risk factors, empowering homeowners and communities to make informed decisions about straightforward, culturally accepted actions. For city planners/local governments, it provides a data-driven tool (the FR index and its spatial representation) to identify the most critical areas to focus on, optimize resource allocation, and develop more efficient policies [19]. For civil engineers, mechanical and electrical engineers and architects who must balance technical safety standards with heritage preservation mandates, the study is essential. It provides them with a framework for practical, aesthetic, and culturally appropriate retrofitting. These include suggestions for selecting materials, fortifying structures, and changing forms whilst honoring traditional forms. The FR index and the iterative qualitative validation process ensure the proposed framework is rigorous, both technically and socially/economically sound, in the Balinese context. This framework is a pragmatic guideline for rapid, urbanization-driven change processes in heritage districts to halt mass human and cultural losses [33], [36].

Historical buildings are very difficult (though incredibly important) to safeguard from fire. It requires a careful balance of preserving world heritage and utilizing contemporary safety systems. "By turning to fire risk assessments and innovative suppression technologies such as water mist or aspirating smoke detection—which do not detract from the building's historic fabric—prevention, protection, and partnership should be embraced by all professions." Heritage buildings require ambitious solutions to preserve their identity and enhance the safety of these structural systems and their users. AFP systems that are professionally installed and maintained are more than just sound financial investments—they're investments in our common cultural destiny.

This study's findings are important from the perspective of design and will compel civil engineers and architects working in heritage districts in Bali to adopt a truly heritage-sensitive approach to designing fire protection strategies. Such design implications demand an iterative process of working with a team comprising civil engineers, mechanical and electrical engineers, invited architects, heritage conservationists, masons from the local community, and local community leaders to ensure that engineering solutions can be reasonably implemented within local socio-cultural contexts.

These results provide a strong basis for major policy and programmatic reforms in Bali's disaster risk reduction and heritage conservation sectors. Such policy changes would not only reduce the risk of fires but also empower local communities and professionals to safeguard Bali's living heritage better, more sustainably.

There is a practical need for an affordable toolkit for engineers and architects working in Bali's heritage districts that helps them translate policy and design ideas into concrete, implementable action. It could be a rapid reference guide—or something like community-of-practice-based solutions—to ensure that the solutions discussed are culturally relevant and adhere to technological best-practice flows [6], [33], [37].

Such a comprehensive suite would equip civil engineers and architects to design fire-resistant solutions that are technically sound and have a low impact on Bali's invaluable cultural heritage. The solutions would enable its urban housing to be more resilient in the long term.

6. Conclusions

Denpasar and Badung are two cities on the island of Bali with a rich and distinguished cultural heritage. Evidence of this legacy is evident in the form of thatched and bamboo edifices situated near prominent landmarks. The use of combustible construction materials, both ceremonial and routine igniting sources, together with the challenges of accessing and evacuating these historically significant urban areas, collectively heightens the fire risks faced by these populations. The lack of technical rigor, cultural relevance, and long-term viability endangers human safety and the conservation of living heritage. To protect Bali's cultural legacy and urban history, it is imperative that the island swiftly implement a comprehensive, evidence-based strategy for establishing multi-tiered fire protection measures. In this context, it is crucial to safeguard Bali's cultural identity and legacy.

In this context, this study has proposed a comprehensive fire protection framework that integrates disaster risk reduction into civil engineering. mechanical and electrical engineers, and architectural design to preserve cultural heritage in urban housing areas in Denpasar and Badung, Bali. The most significant contribution of this research is a quantitative risk assessment tool, constructed from a Bali-specific Fire Risk Index (FR), comprising components of material vulnerability, ignition sources, building density, evacuation/access, and protection capacity. This quantitative evaluation, coupled with in-depth qualitative perspectives from key stakeholder groups, demonstrates that traditional bamboo/thatched structures based in proximity to densely populated urban settings, particularly along sacred sites, face significantly higher risks of fire due to the combination of flammable construction materials, high ignition sources (ceremonial and ordinary), and significant evacuation/access challenges.

Preserving historic edifices from the devastating effects of fire is paramount; however, this task is fraught with many formidable challenges. It requires a very delicate balance between heritage principles and state-of-the-art fire protection. Active fire protection systems are a beneficial method for the early detection and extinguishing of flames and preserving precious cultural heritage. We meticulously design and execute these routines. The aim of the program is to create a holistic, risk-based approach that promotes cooperation between heritage practitioners, fire engineers, and building managers. To preserve these valuable artifacts for the next generation, unique techniques and advanced devices such as water mist systems and aspirating smoke detectors should also be employed in conjunction with training and maintenance. People can freely express their emotions without fear of retaliation.

They identified chronic governance weaknesses above all, the absence of comprehensive policies, budget allocations, and technical capacity to implement heritage-appropriate retrofits as a primary impediment to adequate fire protection.

This research contributes by advancing a multi-scalar framework that provides actionable recommendations for households, neighborhoods, and policy. It offers civil engineers and architects practical design guidance for addressing materials, retrofitting buildings, and designing spaces that meet life-safety performance targets while retaining cultural identity and significance. Importantly, it provides policymakers with a mechanism to incorporate fire safety into heritage management plans, develop heritage-sensitive fire codes, and establish heritage-specific funding mechanisms. It emphasizes leveraging existing resilience networks and communicating risks in culturally appropriate ways. Such a holistic approach ensures that the interventions are technically sound, acceptable, and sustainable from a cultural perspective. It results in a higher usage rate among the community and, therefore, better sustainability.

While the study's findings provide a reasonable basis, there are still limitations in generalizing beyond Denpasar and Badung, and other FR indices need to be calibrated with real fire event data to move forward with future research.

This framework could benefit from comparative analyses with other Indonesian or Southeast Asian heritage cities and from evaluations of how it can be applied. Despite these issues, this research offers a contemporary, evidence-based framework for safeguarding human lives and living heritage alike. The quarrel framework encourages resilient, authentic and urban-based habitation that retains Balinese cultural identity whilst adhering to current civil engineering and architectural safety standards. This framework is achieved by harmonizing material suitability and safety enhancement, protecting sacred areas while enabling safe evacuation, and integrating DRR with heritage governance. It aims to ensure that Bali's urban heritage continues to be a living source of cultural identity and vitality amid the forces of rapid change operating at multiple levels.

Disaster measures can be taken with priority in heritage-rich urban residential areas at the planning, design, and management stages with mutual reinforcement among local authorities, heritage conservators and designers. This is to ensure that the intended fire protection design is realised. Lawmakers need to pass fire safety laws that take into account the needs and challenges faced by historic buildings, increase funding, and better train staff when it comes to basic maintenance and response during emergencies. Engagement with the community and presenting risks in culturally relevant terms might be important for generating the support or consent of a community. An important next step in this research would be to compare the Fire Risk Index of Bali with other urban historical sites in Indonesia and Southeast Asia. Comparative analysis and empirical calibration can further improve the framework. Continuing to urbanize and changing the built environments of Bali puts human lives and cultural heritage at stake. It is within the power of stakeholders to do so with these recommendations.

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