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An Integrated Credit Based Framework for Fire Safety Assessment, Structural Verification and Retrofit Prioritization of Existing Buildings

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Abstract
Fire safety assessment of existing buildings is essential for improving occupant protection, structural reliability, and resilience, particularly in aging buildings with occupancy and safety conditions. This study develops an integrated credit-based framework for fire safety assessment, structural verification, and retrofit prioritization of existing buildings. The framework combines a review of fire safety codes and standards, visual inspection, targeted non-destructive and partial-destructive testing (NDT), structural verification, and retrofit recommendations. The assessment comprises 9 fire safety domains, with each domain assigned a four-level score from 0 to 3, producing a maximum score of 27. The framework was applied to 3 RCC buildings representing residential, institutional, and commercial occupancies. Building A obtained a score of 7/27 and was classified as Low performance; Building B scored 16/27 and achieved a Moderate rating, while Building C achieved the highest score of 22/27, corresponding to a high rating. Targeted NDT was conducted to verify structural conditions, and the findings were consistent with deficiencies identified through visual inspection and credit-based assessment. Based on the identified deficiencies, retrofit and maintenance measures were recommended. The results demonstrate that the proposed framework provides an approach for differentiating fire safety conditions, supporting structural verification, and prioritizing retrofit interventions in existing buildings.

Keywords - Fire Safety Assessment, Credit-Based Framework, Structural verification, Non-Destructive Test (NDT), Existing Building, Retrofit prioritization

1. Introduction

Fire safety and structural reliability are fundamental requirements for ensuring the safety, functionality, and resilience of existing buildings [1]. Urbanization, population growth, aging building stock and ongoing changes in uses have led to a significant number of existing buildings being vulnerable to fire hazards that may not have been taken into account in their design phase [2,3]. Fire damage may result in major damage to structural and non-structural elements, reduction in load bearing capacity, deterioration and a heightened hazard of progressive or partial collapse [4]. The effects are especially significant in older buildings when the construction, materials, fire protection systems, and structural drawings do not meet the current safety requirements [5]. Thus, to identify vulnerabilities and establish suitable intervention strategies, existing buildings must be systematically assessed [6].

Traditional fire safety assessment practices focus on a specific element, e.g., fire extinguishers, emergency exits, fire detection systems and/or evacuation provisions [7]. Although these measures are important, they do not provide a comprehensive understanding of the interaction between fire exposure and structural performance. When exposed to high temperatures, the strength, stiffness, deformability and material properties of structural components like reinforced concrete beams, columns, slabs and steel elements change significantly [8,9]. Fire exposure may cause loss of strength of the reinforcement, spalling of concrete, cracking, loss of structural integrity, and degradation due to thermal expansion. Therefore, evaluating fire safety should consider the fire protection features at the building level as well as verifying structural performance to create a more accurate picture of the overall fire vulnerability of the building [10].

Variations in construction age, structural systems, occupancy properties, maintenance condition, material quality and modification during a building's service life are additional factors that complicate the assessment of existing buildings [11]. A uniform retrofit strategy would then lead to inefficient distribution of resources as not all buildings and structural components may be at the same risk. A systematic prioritisation process that can distinguish between buildings that need urgent attention and those that can be monitored regularly or that can be relatively improved is needed [13]. This is especially relevant for inventories of existing large buildings with limited financial, technical, and operational resources available for rehabilitation [14].

With this in mind, a credit-based assessment framework can offer a hands-on approach that allows for combining multiple fire safety and structural performance indicators together into a single assessment system [15]. Parameters that can be assigned credit scores do include fire prevention, detection and suppression facilities, evacuation provisions, building characteristics, structural condition, fire resistance, maintenance and emergency preparedness [16]. These parameters can be weighted to produce an overall safety score, from which buildings may be classified in various categories of risk or intervention [17]. This kind of structure can enhance transparency during decision making and minimise reliance on individual qualitative decisions.

Structural verification is a key part of the proposed framework to ascertain the capacity of critical structural members under current conditions and under deterioration due to an actual fire. Results of structural assessment can be used in conjunction with the fire safety score to determine when a building has structural weaknesses and fire protection weaknesses. Then retrofit prioritization can be determined based on the severity of risk, structure significance, occupancy characteristics and potential consequences of failure, as per the integrated assessment [18].

An integrated credit-based method to fire safety assessment, structural verification, and retrofit prioritization can then help facilitate a more systematic and risk-informed method for managing existing buildings. It can help building owners, structural engineers, fire safety professionals and building officials determine where there are major problem areas, where rehabilitation funds should be spent, and what retrofit designs are needed. The final intention of the framework is to improve the ability of the existing building to resist fire threats and to facilitate the management of the building for safer, more sustainable and economically sound operating conditions.

Therefore, this study aims to develop an integrated credit-based framework for assessing fire safety performance, supporting structural verification through targeted investigation, and prioritizing retrofit interventions for existing buildings. The framework is evaluated using three existing RCC buildings representing residential, institutional, and commercial occupancies to examine its practical applicability and ability to identify domain-specific deficiencies. The objectives of the study are to develop a credit-based framework for assessing the fire safety performance of existing buildings, evaluate their structural safety and fire resistance, and prioritize buildings and identified safety deficiencies based on credit scores and associated risk levels. The study further aims to recommend suitable retrofit measures by considering the safety condition, level of risk, effectiveness of the proposed intervention, and priority of the identified deficiencies.

2. Literature Review

The research has focused on creating a systematic and quantitative method of assessing fire safety in buildings rather than just a compliance-based evaluation approach, more and more in recent years. Alfalah et al., (2023) [19] designed a Building Fire Safety Assessment (BFS) system using the Analytic Hierarchy Process (AHP) and applied it to two cases to generate meaningful and comparable hazard and safety ratings and to support decision-making for fire protection and fire prevention needs. Zhou et al., (2026) [20] further improved this approach by constructing a fire performance evaluation system for existing public buildings that includes building characteristics, fire protection and rescue, fire facilities and equipment, and HVAC and electrical systems. The critical remediation indicators were identified by applying the AHP-CRITIC weighting method and then used to build a Bayesian Network model to quantify the fire-risk and guide targeted renovation decisions. Similarly, Konopski et al., (2022) [21] developed an AHP-based fire safety assessment model using Fire Hazard and Fire Safety Indices, demonstrating that human factors and combustible materials substantially influence fire hazards, while intelligent AI/IoT systems and passive protection can provide significant safety benefits. Özşahin et al., (2026) [22] also proposed an IVIF-SWARA-based decision-making framework for prioritizing fire safety measures in mass timber buildings, identifying fire compartmentation, evacuation planning, load-bearing capacity, fire resistance of connections, and early detection systems as critical factors. Furthermore, Alrasheed et al., (2026) [23] showed that Building Information Modeling (BIM), advanced simulation, fire behaviour analysis, real-time monitoring, and compliance tools have the potential to enhance fire safety planning and risk management in high-rise buildings. All of these studies highlight the critical role of weighted indicators, expert decision making, quantitative risk analysis and digital technologies in arriving at a more holistic fire safety evaluation.

In recent years, a number of studies have centered on the development of systematic methods for the assessment of the existing building and the identification of retrofit interventions by applying a risk based and multi-criteria decision-making process. Liu et al., (2024) [24] presented an intelligent diagnostic assessment model of existing residential buildings based on the combination of machine learning techniques and indicators for building conditions, which could identify the condition and renovation requirements in existing residential buildings quickly and accurately. Maidi et al., (2024) [25] proposed a nonlinear pushover-based approach to assess the seismic resistance of existing structures and quantify the level of strengthening needed to meet target performance. Likewise, Ahmed et al., (2025) [26] created an overall evaluation system to visualize seismic retrofit alternatives with economic, social, environmental, vulnerability and resilience indicators to inform the selection of retrofit strategies. Lee et al., (2025) [27] additionally introduced risk assessment by combining seismic and postseismic fire scenarios in a Bayesian Network framework to aid in risk-informed repair and retrofit decisions. Regarding building retrofitting, Teng et al., (2026) [28] applied Fuzzy Delphi Method and Analytic Hierarchy Process (AHP) to prioritize building-envelope retrofit measures according to energy and carbon performance indicators, whereas Nwosu et al., (2026) [29] recommended Retrofit Feasibility and Economic Rehabilitation Indices to evaluate technical and economic feasibility of retrofitting ageing masonry buildings. Furthermore, Jin et al., (2026) [30] compared alternatives for strengthening by using nonlinear finite-elements analysis and application of AHP–entropy based multi-criteria evaluation accounting for structural performance, embodied carbon, cost and construction time. While these studies show the value of quantitative indicators, weighting schemes and decision-support tools for retrofit planning, most address particular hazards or performance criteria. Thus, there is a lack of comprehensive design that merges fire safety assessment, structure verification, and retrofit ranking on the structural level for existing buildings.

3. Methodology

The proposed fire safety assessment framework for existing buildings was developed and applied using a sequential and systematic approach. The methodology combines review of national and international fire safety codes and standards, development of performance-based assessment domains, credit allocation and fire safety classification, visual assessment of existing buildings, targeted Non-Destructive Testing (NDT), structural verification and retrofit prioritization. The proposed framework is intended to complement current regulations, to create a clear pathway to identify basic compliance and to create a clear pathway for enhanced fire safety and resilience. Figure 1 illustrates the overall methodological flow, and the following subsections provide details on the procedures.

3.1. Review of Existing Fire Safety Codes and Standards

The process for developing the proposed framework starts with a systematic review of the national and international fire safety codes and standards to determine the baseline level of regulation for the evaluation of existing buildings [31]. The National Building Code of India (NBC 2016) [32], Bureau of Indian Standards (BIS) [33], National Fire Protection Association (NFPA) [34], International Organization for Standardization (ISO) [35] are the primary concerns of the review while developing the initial framework [36].

The examined provisions address the key components of fire safety such as fire-resistant construction, compartmentation, fire detection and alerting, fire suppression, evacuation and egress, firefighter access, structural fire performance, occupant preparedness, and maintenance. Specific attention is paid to existing building requirements and to provisions related to retrofitting, evacuation, training, and new fire-safety technologies.

Conventional prescriptive methods are also explored as limitations in the review. There are codes in place which offer basic minimum safety standards; however, there is not much difference between basic compliance and enhanced fire safety performance in existing code compliance approaches. The review identifies inadequate consideration of maintenance, recovery planning, and incorporation of emerging technologies as important limitations.

The codes and standards identified and reviewed are considered the regulatory baseline for the proposed framework as identified by the identified requirements and limitations. Enhanced safety, technological integration and resilience-oriented practices are then included in the assessment system, based on credit, as additional performance-based criteria, to complement or supplement existing requirements for safety [35].

3.2. Framework Development

The proposed framework is developed by combining the fundamentals of existing fire safety standards and the principles of performance-based assessment. The domains of assessment selected include active, passive, structural, operational, and post-fire safety requirements, which are representative of a comprehensive assessment of the performance of building fire safety. Equal weighting was used for each domain to minimise the influence of any single domain and to simplify the comparative assessment of buildings of different building type and occupancy.

3.3. Credit-Based Fire Safety Assessment Framework

Prescriptive fire safety codes give the basic level of code compliance that is required for buildings, but may not sufficiently distinguish between basic compliance and higher levels of fire safety. To overcome this drawback, the suggested credit system provides a framework of structured assessment system based on performance in addition to the current code requirements. The framework allows buildings to earn credits based on their level of compliance, improvements, technology integration and resilience-oriented practices. This method offers a progressive evaluation process which can help identify deficiencies in a systematic manner and make the necessary decisions for fire improvement and retrofit.

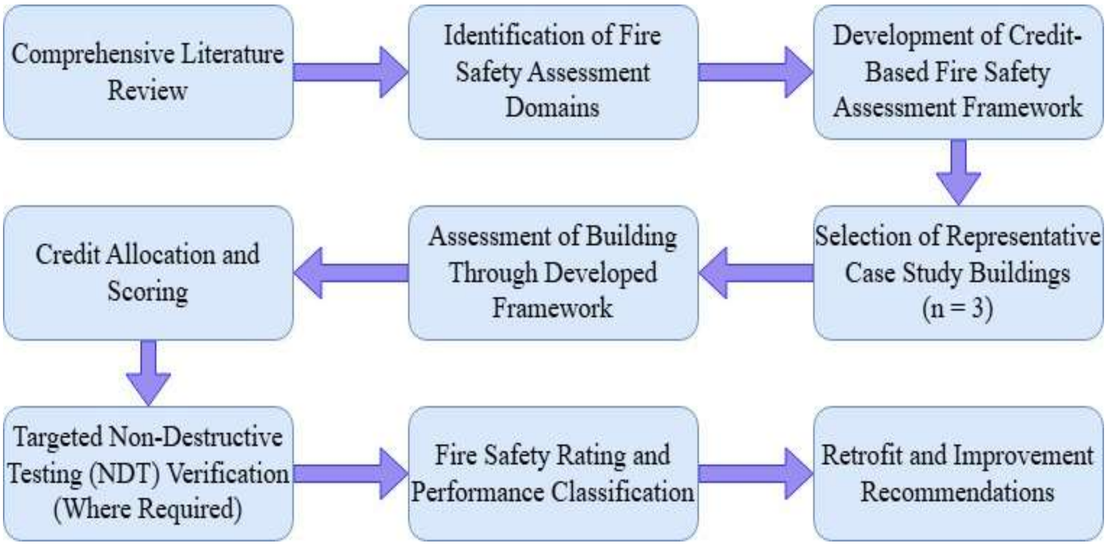

Fig. 1 Methodological Framework for Developing a Performance-Based Fire Safety Credit System

Table 1. Overview of Proposed Fire Safety Assessment Framework

Framework Component	Description
Assessment Domains (9)	Fire-Resistant Construction, Compartmentation and Barriers, Suppression Systems, Detection and Alerting, Evacuation and Egress, Firefighter Access, Structural Fire Performance, Post-Fire Recovery and Resilience, Occupant Education and Maintenance
Scoring System	Each domain is assessed on a scale of 0 to 3, with increasing scores representing improved fire safety performance and resilience.
Scoring Definition (0–3)	0 = non-compliance 1 = Basic code compliance 2 = Enhanced performance 3 = Innovative and resilience-aligned practices
Assessment output	Fire safety performance score ranging from 0 to 27, obtained by summing the scores of all nine domains.
Performance Classification	Low = 0 to 9 Moderate = 10 to 18 High = 19 to 24 Exceptional = 25 to 27
Secondary Verification	Buildings classified as Low or Moderate, or showing significant structural distress, may undergo targeted NDT at selected locations.
Structural Verification	NDT findings, visual observations, and available structural information are used to evaluate the condition and adequacy of critical structural components.
Decision Support	The final assessment supports retrofit prioritization and recommendations for maintenance, rehabilitation, or strengthening, where required.

The proposed framework is organized around nine areas of critical fire safety, each of which was chosen to represent a required compliance element that offers guidance on both improved and resilience-focused performance. The framework is shown in Figure 1 and key elements, the scoring system and performance classification are summarized in Table 1. The following subsections provide a description of the assessment domains, credit allocation methodology, fire safety performance classification, and targeted NDT integration, as well as a proposed retrofit decision process.

3.4. Assessment Domains

The proposed credit-based framework evaluates the fire The proposed credit-based framework includes nine critical assessment domains: active protection, passive protection, evacuation, structural performance, emergency response, post-fire resilience, occupant preparedness and emergency response. The domains were chosen to cover a wide range of both basic coding standards and targeted performance indicators. Each domain is the primary topic of the fire safety construction and is further assessed by the use of the relevant sub-indicators. The assessment takes into account the extent and quality of safety measures in place as well as how they are working, how well they are integrated, maintained and developed, and how they could support building resilience. This domain-based approach allows the proposed framework to highlight specific gaps and to differentiate between minimum compliance, enhanced performance and resilience-oriented practices.

3.4.1. Passive Fire Protection and Structural Safety

Passive fire protection is an essential part of a building's fire safety system methodology, as it not only helps to limit the spread of fire and smoke but also helps keep the building stable during a fire. The fire-resistant construction and compartmentation and barriers are included in this domain. Fire-resistant construction deals with the fire resistance of structural and non-structural elements, fire-retardant materials, protective coatings, and actions that help to ensure the structural integrity during extended fire exposure. Compartmentation and barriers are about fire-rated walls, doors, glazing, smoke barriers, protected service shafts and other features that limit the spread of fire and smoke between spaces. The framework also incorporates Structural Fire Performance, which looks at how well key structural elements can perform in fire environments. The combination of these provisions help to restrict fire spread, protect life and minimize the risk of structural collapse.

3.4.2. Active Protection, Evacuation and Resilience

Early detection, suppression, safe evacuation and effective firefighting operations depend on active fire protection and emergency-response measures. These are Suppression Systems, Detection and Alerting, Evacuation and Egress and Firefighter Access. Suppression systems include sprinkler systems, water-mist systems and enhanced or intelligent suppression systems. Detection and alerting include smoke and heat detection and manual alarms, networked detection and real-time monitoring. Evacuation and egress relate to exits, escape routes, emergency signage, protected stairways and things that make it easier to move about safely. Fire access includes fire appliance access, fire lifts, refuge areas and provisions to support emergency operations. Post-Fire Recovery and Resilience also takes into account measures that promote rapid recovery and minimise downtime while enhancing the building's capacity to continue to operate or be restored after a fire. Occupant Education and Maintenance covers training, periodic inspections, fire-safety maintenance practices, and occupant readiness, which contribute to long-term fire-safety performance. Table 2 provides a summary of the nine domains and the associated assessment criteria.

3.5. Credit Allocation Methodology

The proposed framework comprised each assessment domain and sub-elements of these domains to be evaluated on a four-level scoring system. The score ranges are 0 (non-compliant or not providing the required provision), 1 (baseline compliance with the minimum regulatory requirement), 2 (improved performance, design or system integration) and 3 (innovative, resilience-oriented practice aligned with risk-informed fire safety objectives). This progressive scoring approach allows the framework to recognise the distinction between meeting the minimum code, and achieving higher levels of fire safety performance, which was not possible with traditional binary compliance assessment. Table 3 provides a summary of the points assigned to each possible performance level and the criteria used to determine them. There are 9 assessment domains with a maximum of 3 credits per domain, so the maximum fire safety credit score is 27. The overall credit score is obtained by summing the scores assigned to the nine domains:

$$\mathrm{C_{FS}} = \sum_{\mathrm{i}=1}^{9} \mathrm{C_i}$$

where $\mathrm{C_{FS}}$ represents the overall fire safety credit score and $\mathrm{C_i}$ represents the score obtained for the $\mathrm{i^{th}}$ assessment domain. The resulting score is subsequently used for fire safety performance classification, as described in Section 3.6.

3.6. Fire Safety Performance Classification

The total marks achieved based on the scheme of assessment proposed are the overall rating of the building's fire safety performance. The total score determines which of the four performance levels (Low, Moderate, High and Exceptional) the assessed buildings fall into. This classification clearly shows the level of fire safety performance and offers guidance on the amount of attention and intervention required. Buildings can have various scores, with lower scores indicating that more detailed investigation or immediate or targeted corrective actions may be needed, while higher scores may indicate that preventive maintenance and periodic monitoring may be sufficient. The classification also serves as a standard for the need for additional structural investigation or retrofit intervention. Table 1 summarizes the corresponding performance categories and ranges of scores.

3.7. Existing Building Assessment and Visual Inspection

A fire safety assessment framework was developed based on the credits, and applied to three existing buildings with various building types, structural features, and occupancy conditions. The building configuration, the level of occupancy, the current fire safety measures, structural characteristics, the condition of maintenance and other relevant safety features were all assessed. The nine assessment domains were used for systematic visual inspection to determine the status of fire-resistant construction, compartmentation, suppression, detection and alerting, evacuation and egress, fire fighter access, structural fire performance, post-fire recovery and resilience, and occupant education and maintenance.

The findings from the inspection were checked against the set criteria and given a score (0 – 3) for each domain. The scores were computed building-wise in each domain to get the preliminary fire safety performance score and classification of buildings. Targeted NDT and structural verification were considered for buildings that exhibited low or moderate performance, significant deterioration, or potential structural deficiencies. The results from the two analyses are used for integrated fire safety–structural assessment and retrofit prioritization.

3.8. Targeted Non-Destructive and Partial-Destructive Testing

The visual assessment is a preliminary evaluation of building fire safety performance, but a visual inspection alone may not be sufficient to detect concealed deterioration or deficiencies in important structural elements. Thus, Non-Destructive Testing (NDT) is added as a secondary verification step to be targeted. Further, buildings in the Low (0–9) classification should be investigated by a comprehensive NDT survey, while buildings in the Moderate (10–18) classification should be investigated by selective NDT at critical locations and structural members. Buildings rated as High (19-24) and Exceptional (25-27) are typically acceptable for periodic monitoring and routine inspection, except for any buildings that show significant structural distress or deterioration during the visual assessment. The findings of NDT are then applied alongside the findings of visual inspection to help verify the structure and to be integrated into the overall building assessment. The associated NDT requirements and suggested actions are provided in Table 4.

3.9. Integrated Fire Safety–Structural Assessment

The integrated assessment is the combination of the credit-based fire safety score, visual inspection findings, targeted NDT results, and structural verification to provide an overall picture of the safety condition of the existing buildings. If structural capacity and demand data are available, the structural adequacy ratio can be used to express the adequacy of critical structural members.

$$\mathrm{R_{SA}} = \frac{\mathrm{C}}{\mathrm{D}}$$

where C represents the assessed structural capacity and D represents the corresponding structural demand. A value of $\mathrm{R_{SA}} \geq 1.0$ indicates adequate structural capacity, whereas $\mathrm{R_{SA}} < 1.0$ indicates inadequate capacity requiring further investigation or intervention. The combined fire safety and structural assessment results are subsequently used to identify critical deficiencies and establish retrofit priorities.

3.10. Retrofit Decision Framework

The final phase of the proposed system provides retrofit recommendations based on the integrated fire safety and structural assessment results. Retrofit priorities are determined based on the overall fire safety performance, structural condition, NDT findings, and severity of identified deficiencies. Buildings that need to be acted on immediately are prioritized for major retrofit or major rehabilitation, buildings with moderate deficiencies are prioritized for targeted improvements, and buildings with satisfactory performance are prioritized for preventive maintenance and periodic monitoring. The corresponding retrofit decision matrix is presented in Table 5.

3.11. Post-Retrofit Reassessment and Validation Framework

When retrofit measures are undertaken, a re-assessment may be carried out after retrofit to assess improvements in fire safety and structural performance. This reassessment includes reviewing the changes to the fire safety provisions, a visual inspection of the retrofitted components, and additional NDT or structural verification as needed. The post retrofit assessment results are compared with the initial assessment to see if the building has improved the performance category and if the deficiencies identified by the initial assessment have been resolved.

The improvement in fire safety performance can be quantified by comparing the pre- and post-retrofit credit scores as:

$$\Delta \mathrm{C_{FS}} = \mathrm{C_{FS,post}} - \mathrm{C_{FS,pre}}$$

Where $C_{FS,post}$ and $C_{FS,pre}$ represent the fire safety credit scores after and before retrofit, respectively. The percentage improvement can further be expressed as:

$$I_{FS} = \frac{C_{FS,post} - C_{FS,pre}}{C_{FS,pre}} \times 100$$

The reassessment therefore provides a basis for validating the effectiveness of the recommended interventions and confirming whether further improvement or monitoring is required.

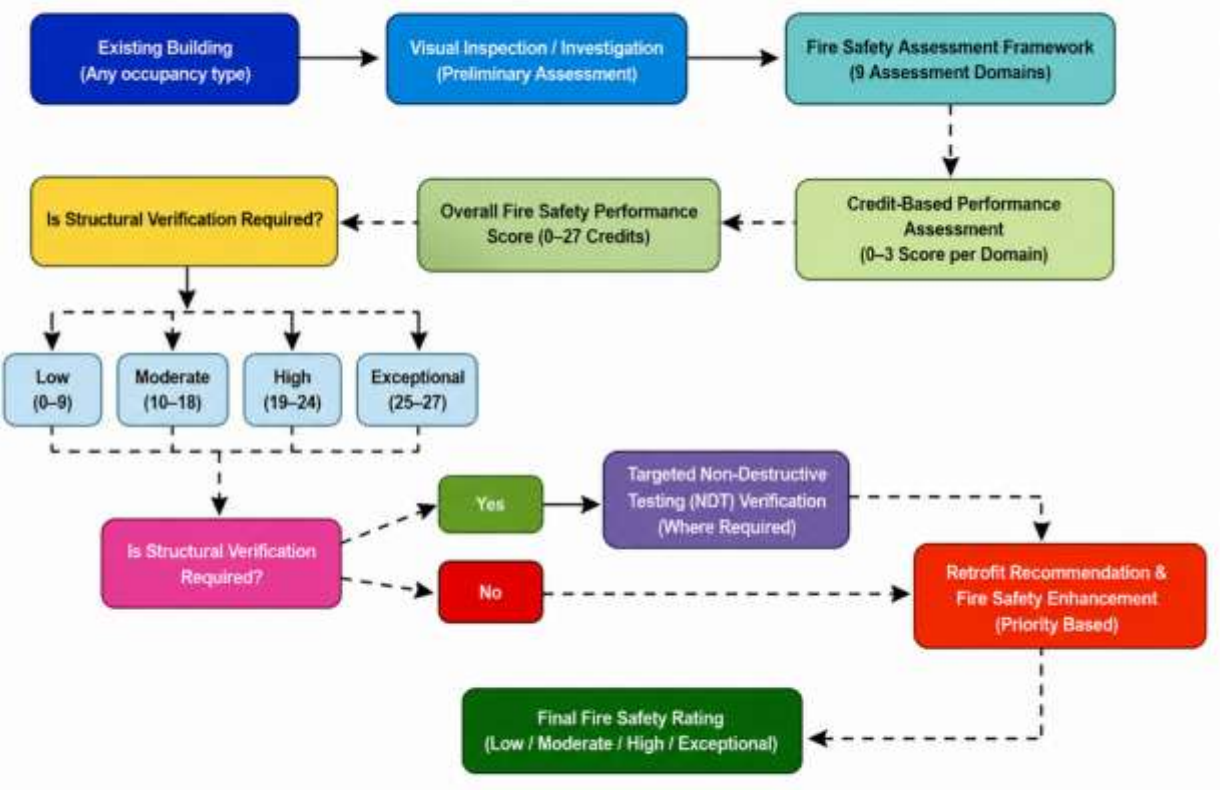

Fig. 2 Conceptual Framework of the Proposed Integrated Fire Safety Assessment Model

Table 2. Proposed Criteria for Enhanced Fire Safety in Buildings.

Domain	Basic Code Requirement	Credit-Based Enhancement	Expected Performance Benefit
Fire-Resistant Construction	Minimum fire resistance rating for structural elements.	Fire-retardant construction, intumescent coatings and advanced fireproofing materials.	Improve structural integrity and stability under prolonged fire exposure.
Compartmentation and Barriers	Fire Compartments and fire related partition	Fire-resistant glazing, smoke barriers, and protected service shafts.	Restricts fire and smoke spread to improve occupants' safety
Suppression Systems	Basic sprinklers protection	Water mist-system, zoned suppression, intelligent suppression control.	Enhances fire suppression to reduce property damage.
Detection and Alerting	Smoke detection and manual alarms.	Networked multi sensor detection with monitoring in real time	Improve early fire detection and emergency response
Evacuation and Egress	Code-compliant exits and signage	Dynamic signage, wide stairwells, automated doors.	Improve evacuation under emergency condition
Firefighter Access	Basic fire appliance access.	Fire lifts, refuge zones, and vertical staging	Improve emergency access and operational

		corridors.	efficiency
Structural Fire Performance	Prescriptive fire resistance rating	Performance-based structural fire designing	Enhances resilience of structure under fire incident
Post-Fire Resilience	Limited guidance in existing codes.	Modular replacement system, resilient insulation redundant load paths	Accelerates recovery, and minimizes downtime.
Occupant Education & Maintenance	Periodic inspection and fire plans	Digital training, regular drills, and maintenance system audits.	Improve Preparedness and long term fire safety

Table 3. Credit Allocation Criteria

Score	Assessment Level	General Interpretation	Example
0	Non-compliance	Required provision absent or non-functional	No smoke detector installed
1	Code Compliance	Meets minimum regulatory	Stand-alone smoke detector
2	Enhanced performance	Exceeds minimum code through system integration	Networked smoke and heat detection system
3	Resilience-Oriented Practice	Advanced technologies exceeding current code provisions.	AI-enabled multi-sensor detection integrated with the building management system

Table 4. Integration of Framework with Targeted NDT

Fire Safety Rating	Structural Condition	Recommended NDT	Suggested Action
Low (0-9)	Deficiencies -very high	Comprehensive NDT	Detailed structural assessment and immediate retrofitting.
Moderate (10-18)	Possible hidden deterioration	Selective NDT	Targeted/Selective retrofitting
High (19-24)	Deficiencies –minor visual	NDT only if distress is seen	Maintenance - Preventive
Exceptional (25-27)	No significant concern	Periodic Monitoring	Routine inspection

Table 5. Fire Safety Decision Matrix

Final Rating	Assessment Level	Structural Investigation	Retrofit Strategy	Reassessment
Low	Critical	Immediate	Retrofit - Major	Only after completion
Moderate	High	Targeted NDT	Retrofit - Selective	Within 12 months
High	Medium	If required	Minor improvement	Periodic review
Exceptional	Low	Not required	Routine maintenance	Scheduled inspection

4. Result and Discussion

4.1. Overview of the Case Study Buildings

As a proof of the versatility of the proposed credit-based framework, three existing buildings were chosen as case studies to illustrate its application on diverse building types and occupancy conditions. The chosen buildings are residential, institutional and commercial, and vary in building height, age, building structure and in-situ fire safety measures. This diversity allows proposed framework to be tested in a wider spectrum of practical building scenarios. Photographs of the selected case-study buildings are presented in Figure 3, while their general characteristics are summarized in Table 6.

The selected buildings include a four-storey existing residential building constructed approximately 20 years ago, a six-storey school building comprising two basements, a ground floor, and three upper floors, constructed approximately 15 years ago, and a relatively new commercial building comprising a stilt level and 12 floors, constructed within the last 10 years. The differences in the age of buildings, levels of occupancy, building heights, and building configurations provide a valuable opportunity to explore the consistency and applicability of the suggested credit-based fire safety assessment framework.

4.2. Credit-Based Framework Application

This credit-based framework was implemented on an individual basis with each of the three buildings being selected as case studies. The four-level scoring system were used to assess each of the assessment domains, and the Fire Safety Performance Score was calculated by adding up the individual domain scores. Active and passive fire protection measures, preparedness of occupants, structural fire performance, and post-fire recovery and resilience were all part of the assessment.

The assessment results for all three buildings are shown in Table 7 and the fire safety scoring distribution across the domains is shown in Figure 4. The findings show that the older residential building performed poorly in structural fire performance, detection and alerting and in post-fire recovery and resilience, while the comparatively newer buildings showed comparatively good performance across some fire safety areas. One of the major benefits of the proposed framework is that it enables domain-wise assessment. In addition to the overall score, the framework highlights specific areas of weakness that need to be addressed. Therefore the assessment not only gives a rating for the overall fire safety performance but also assists with identifying areas of non-conformance within a domain and for guiding targeted corrective and retrofit actions.

4.3. Structural Verification Using Targeted Non-Destructive and Partial-Destructive Testing

The developed credit-based framework is a basic evaluation of a building's fire safety; however, a visual inspection is not always sufficient to detect concealed deterioration or deficiencies in critical structural components. Hence, selective non-destructive and partial-destructive testing was carried out at certain locations and structural members to further investigate their condition. Figure 5 shows representative photographs and Table 8 is a summary of the recorded observations.

The NDT test was performed with the following parameters: surface hardness, concrete quality, condition of the reinforcement, and possible internal defects. Initial visual assessment and credit-based evaluation were compared to the test findings to look for consistency of the detected structural deficiencies. The NDT results were used to provide additional evidence of the structural condition of the buildings assessed, thereby building upon the basis for further structural rehabilitation and retrofit recommendations.

4.4. Comparative Assessment of Case Study Buildings

The developed credit-based framework was tested to determine its applicability on buildings of various ages, occupancy types and configuration. The summary of the result from the fire safety assessment is given in Table 7 and the domain-wise comparison is shown in Figure 4. The proposed framework identified differences in the buildings' fire safety performance by considering variations in active and passive fire protection, occupant protection, structural fire performance and post-fire recovery and resilience. Building A (Residential) had the lowest score, 7 of 27, which is a Low-performance rating. Building B (Institutional) scored 16/27 (Moderate) while Building C (Commercial) had the highest score of 22/27 (High).

The comparison suggests that the older residential building had more deficiencies in the following areas: Compartmentation, Suppression systems, Detection and alerting, Structural fire performance, and post-fire resilience, while the newer buildings had comparatively better performance in several areas. The targeted NDT findings were used to provide additional evidence of the structural condition found in the initial assessment. The comparative results show that the proposed framework is capable of distinguishing the fire safety performance of buildings and the domain-specific deficiencies that need to be addressed and improved.

4.5. Retrofitting Prioritization and Recommendations

The findings from the credit-based assessment and targeted NDT were used to determine the appropriate retrofit measures and their prioritisation for the selected buildings. The overall fire safety performance, domain specific deficiencies and the condition of the structure were used to recommend interventions. The retrofit priorities and the measures for each are summarized in Table 9.

Building A earned the Low fire safety rating in the score of 7/27, which means there is a need for high priority intervention. The suggested solutions are: Replacement of fire detection and suppression systems, rehabilitation of fire rated compartmentation and evacuation provisions, and rehabilitation of deteriorated structural members. Overall, Building B has been rated Moderate (16/27) and needs to make targeted improvements, especially in the areas of compartmentation and structural fire protection, as well as preparedness and maintenance for fire safety. Building C scored 22/27 and is rated high, and will require mostly routine maintenance and periodic fire-safety audits as well as selected improvements where deficiencies are identified.

The results indicate that the proposed framework is able to convert the assessment results obtained from each domain into tangible retrofit action and prioritize retrofit actions based on the level of risk and deficiency in each domain. This provides a structured basis for allocating retrofit efforts and resources among existing buildings.

4.6. Framework Validation and Discussion

The implementation of the proposed credit-based framework on three buildings with different ages, occupancy types, and configurations demonstrated its ability to provide a systematic assessment of fire safety performance. The framework organized buildings based on the overall fire safety rating, and identified deficiencies for each fire safety domain. The domain-based scoring system offers more information on the specific areas that require fire safety improvements, in comparison to a pass/fail compliance-based system. The targeted NDT assessment was used to provide additional information on the structural conditions identified during the initial assessment. The NDT results followed a similar pattern to the deficiencies found in the visual inspection and the credit-based assessment, thus adding support for the applicability of the proposed framework. Furthermore, retrofit recommendations were incorporated in the framework which allows the framework to convert the outcomes of the assessments into actionable recommendations for the fire safety performance of existing buildings. The proposed framework showed that it can be applied to the selected case-study buildings, but it has only been empirically validated in three RCC buildings. The findings should, therefore, be viewed as preliminary validation of the framework and not as a full validation of the framework over all building types. Further studies involving a larger number of buildings, different occupancy types, structural systems, construction materials, and geographical conditions are required to establish its broader robustness and applicability.

The proposed framework was validated using three existing RCC buildings representing residential, institutional, and commercial occupancies, with differences in building age, height, occupancy density, configuration, and existing fire-safety provisions. The three buildings were purposefully selected to provide contrasting practical assessment scenarios and to examine whether the framework could distinguish different levels of fire-safety performance and identify domain-specific deficiencies. The objective of this validation was to demonstrate the practical applicability, operational feasibility, and assessment capability of the proposed framework rather than to establish statistical generalization across the entire population of existing buildings. The three case studies produced clearly differentiated fire-safety scores of 7/27, 16/27, and 22/27, corresponding to Low, Moderate, and High performance, respectively, while the targeted NDT findings provided additional support for the observed structural conditions. Therefore, the present results should be considered as preliminary or pilot validation of the framework, and broader validation involving a larger number of buildings with different structural systems, construction materials, occupancy types, and geographical conditions is recommended in future research.

Fig. 3 Photographs of Three Case Study Buildings

Table 6. General Characteristics of the Selected Case Study Buildings

Parameters	**Building A**	**Building B**	**Building C**
Occupancy Type	Residential	Institutional	Commercial

		(School)	
Building Age	>20 years	15 years	<10 years
Structural System	RCC Frame	RCC Frame	RCC Frame
Number of Floors	G + 3	2 Basements + G + 3	Stilt + 12
Building Category	Low-rise	Mid-rise	High-rise
Occupancy Density	Moderate	High	High
Year of Assessment	2026	2026	2026

Table 7. Fire Safety Assessment Results of the Case Study Buildings

Assessment Domain	**Maximum Score**	**Building A**	**Building B**	**Building C**
Fire-Resistant Construction	3	2	2	2
Compartmentation and Barriers	3	0	1	3
Suppression Systems	3	0	2	3
Detection and Alerting	3	1	2	3
Evacuation and Egress	3	1	2	2
Fire-fighter Access	3	1	2	3
Structural Fire Performance	3	1	1	2
Post-Fire Resilience	3	0	1	1
Occupant Education & Maintenance	3	1	3	3
Total	**27**	**7**	**16**	**22**
Performance Rating		**Low**	**Moderate**	**High**

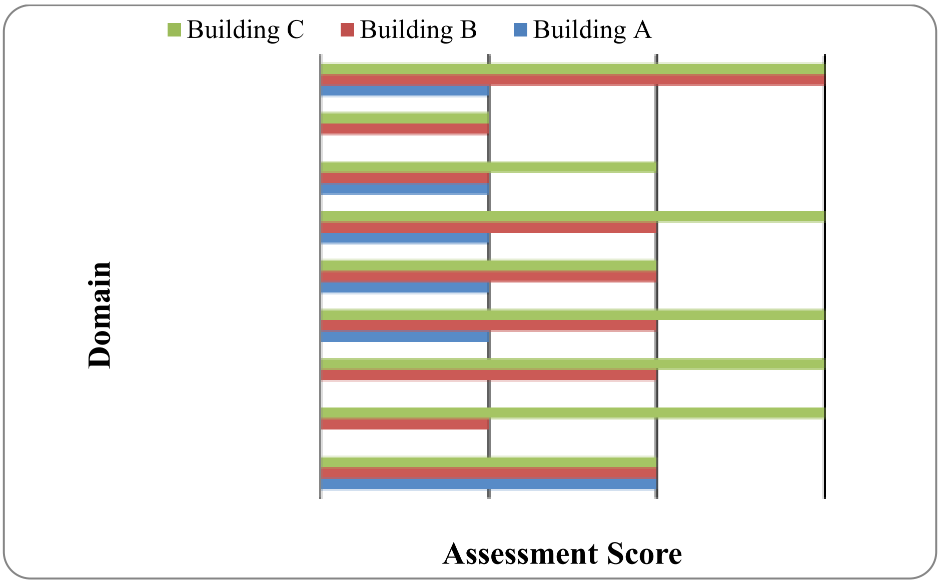

Fig. 4 Domain-wise Comparison of Assessment Scores

Fig. 5 Representative NDT Test Photographs

Table 8. Summary of Targeted NDT

Parameter	**NDT Technique**	**Structural Element Tested**	**Key Observations**	**Overall Interpretation**
Building A (Residential)	Rebound Hammer	Column and Beam	Low to moderate rebound values, less surface hardness in few members.	Due to age and localized deterioration, detailed rehabilitation is recommended.
	Ultrasonic Pulse Velocity (UPV)	Columns and Beams	Varied from fair to good, some sections showed reduced wave transmission.	Minor concrete degradation or localized discontinuities require further investigation.
	Half Cell Potential	Columns	Potential of Moderate corrosion observed.	Observed at localized areas, corrosion mitigation and maintenance recommended.
	Core Cutter	Column	Concrete strength is sufficient, but lower than expected	Confirms structural integrity with aging deterioration observed.
Building B (Institutional)	Rebound Hammer	Columns and Beams	Uniform rebound values	Quality of concrete is satisfactory.
	Ultrasonic Pulse Velocity (UPV)	Columns and Beams	No significant discontinuities observed and good UPV results.	Members are in good condition, consistent with the visual inspection findings.
Building C (Commercial)	Not Required	-	Based on the High fire safety rating and absence of significant visual deficiencies, NDT verification was not considered necessary.	Periodic Monitoring and Routine inspection are considered sufficient.

Table 9. Proposed Retrofit Recommendations for the Case Study Buildings

Parameters	**Identified Deficiencies**	**Recommended Retrofit Measures**	**Priority**

Building A (Residential)	Absence of suppression system, inadequate compartmentation, deteriorated members and limited post-fire resilience	Repair deteriorated structural members, Upgrade fire detection & suppression system, install fire-rated partitions, improve emergency signage & evacuation routes	High
Building B (Institutional)	Limited structural performance, Moderate compartmentation, and post-fire resilience is not sufficient	Improve Compartmentation, strengthen structural fire protection, conduct fire drills and periodic inspections	Mediu m
Building C (Commercial)	Minor deficiencies in post-fire resilience and structural performance	Periodic audits for fire safety, continue maintenance and selective upgrades to improve resilience	Low

5. Conclusion and Future Scope

5.1. Conclusion

An integrated credit-based framework was developed to assess the fire safety performance of existing buildings by combining visual inspection, targeted non-destructive and partial-destructive testing (NDT), structural verification, and retrofit prioritization. This study developed and demonstrated an integrated credit-based framework for fire safety assessment, structural verification, and retrofit prioritization of existing buildings. The framework combines nine fire safety assessment domains with a four-level scoring system ranging from 0 to 3, resulting in a maximum score of 27.

Its application to three RCC buildings representing residential, institutional, and commercial occupancies demonstrated that the framework can effectively differentiate overall fire safety performance and identify domain-specific deficiencies. Building A obtained 7/27 and was classified as Low performance, Building B obtained 16/27 and was classified as Moderate, while Building C obtained 22/27 and achieved a high rating. Targeted NDT investigations provided additional evidence regarding structural conditions and were generally consistent with deficiencies identified through visual and credit-based assessments.

The integrated assessment enabled retrofit priorities to be linked with the severity of fire safety and structural deficiencies. Accordingly, Building A required high-priority intervention, Building B required targeted improvements, and Building C primarily required routine maintenance and periodic monitoring. Overall, the proposed framework provides a structured, transparent, and practical approach for combining fire safety evaluation, structural verification, and retrofit decision-making. However, its validation is limited to three RCC buildings; therefore, broader application across different building types, structural systems, materials, and geographical conditions are required to establish its robustness and general applicability.

5.2. Future Scope

Future research can further enhance the robustness, applicability, and practical implementation of the proposed credit-based fire safety assessment framework. The following directions are recommended:

- Application to diverse building typologies: The framework can be evaluated across healthcare facilities, industrial buildings, mixed-use buildings, high-rise structures, and other critical occupancies to assess its broader applicability.
- Advanced structural monitoring and NDT: Integration of additional structural health monitoring systems and advanced NDT techniques can improve the accuracy and reliability of structural condition assessment.
- Digital implementation: A dedicated digital platform or mobile application can be developed to support rapid field-based assessment, automated credit calculation, performance classification, and generation of retrofit recommendations.
- GIS and BIM integration: Geographic Information System (GIS) and Building Information Modelling (BIM) can be incorporated to enable spatial visualization, building-level data management, risk mapping, and improved fire safety assessment and decision-making.
- Expanded validation: Future studies should involve a larger number of buildings with different structural systems, construction materials, ages, and geographical conditions to establish the robustness and generalizability of the framework.
- More research is required on long term effectiveness of framework and also on sustainability of the retrofit strategies.

Conflicts of Interest
There is no personal interest or financial pressure that could have influenced this study.

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Author 1 conceived the idea, developed methodology, prepared credit-based framework, executed testing on buildings and wrote draft manuscript.
Author 2 supervised the research work, improved the framework helped in results interpretation and revision of manuscript.
Both the authors have reviewed and approved the final manuscript.

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