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Sustainable Fire Safety Assessment and Rapid Visual Screening Framework for Existing Buildings

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Abstract

This study investigates fire safety compliance in existing buildings using a dual-method approach: a stakeholder survey and a Rapid Visual Screening (RVS)-based Fire Safety Rating System. A survey of 50 professionals—including architects, engineers, fire officers, and occupants—identified key barriers such as inadequate safety measures (40%) and poor retrofitting practices (30%). Statistical analysis using SPSS revealed a significant negative correlation between fire safety compliance and building age. Chi-square tests confirmed that older buildings are notably more non-compliant ($\chi^2 = 50.000$, $p < 0.001$). Based on these insights, a comprehensive RVS framework was developed to evaluate six critical domains: fire prevention, detection systems, suppression systems, emergency escape, structural protection, and preparedness. Field application in 10 residential, commercial, and educational buildings exposed major deficiencies—particularly in escape routes and suppression systems in commercial buildings. Reliability testing validated the framework's effectiveness as a practical assessment tool. The study also integrates sustainability elements, such as solar-powered alarms and eco-friendly extinguishers, to promote resilient, future-ready fire safety strategies. This research offers a scalable model for assessing and improving fire safety in aging urban infrastructure, with implications for policy, regulatory reform, and urban resilience planning.

Keywords: Fire Safety Compliance, Fire Safety Rating, Infrastructure Safety, Rapid Visual Screening (RVS), IBM SPSS

1. Introduction

Metropolitan development in cities like New Delhi has escalated the risks linked to non-compliance with fire safety regulations. As population growth outpaces infrastructure development, municipalities become increasingly vulnerable. The World Health Organization (WHO) reports that over 180,000 casualties result from fire incidents globally each year, many of which occur in urban areas. In India alone, the National Crime Records Bureau (NCRB) documents 12,000 fire-related deaths annually, primarily in urban cities. Such statistics underscore significant vulnerabilities in city infrastructure, a trend mirrored across Africa and Southeast Asia. Outdated regulations and informal settlements compound fire safety challenges in these regions. The global patterns highlighted here necessitate the implementation of more innovative fire safety strategies in urban environments.

Existing fire safety standards, such as the National Building Code (NBC) 2016, issued by Bureau of Indian Standards, (2016), provide a comprehensive framework for ensuring safety during fire emergencies. These guidelines cover fire-resistant construction materials, detection and suppression systems, and evacuation planning. However, implementation remains inconsistent nationwide, with over 40% of buildings in Indian metropolitan areas failing to meet basic standards. Key challenges contributing to this issue include high implementation costs, limited stakeholder awareness, and inadequate enforcement mechanisms. Similar issues persist across many developing countries, where outdated infrastructure and informal settlements exacerbate risks. Older buildings, in particular, often suffer from outdated systems and a lack of regular safety audits, leaving occupants vulnerable in the event of a fire.

Law and Spinardi (2021) explored how the specialized language and practices of regulatory professionals influenced fire safety outcomes. They argued that the complex interplay between technical codes and expert judgment often impacted the effectiveness of safety measures. Benson and Elsmore (2022) emphasized the importance of integrating fire safety expertise during building design and planning processes. They highlighted how early involvement of fire safety professionals and strong governance frameworks helped identify and mitigate fire hazards, while weak enforcement mechanisms often compromised fire safety standards.

Building on these perspectives, studies have explored quantitative and systematic approaches to assessing fire risks more comprehensively. For instance, Alfalah *et al.* (2023) employed the Analytic Hierarchy Process (AHP) to evaluate building fire safety. The method systematically assigned hazard and safety ratings to buildings, demonstrating its effectiveness through case studies. Similarly, Ketsakorn and Phangchandha (2023) applied AHP within educational institutions, facilitating the structured evaluation and prioritization of fire risks for targeted mitigation strategies. These advancements underscore the importance of structured frameworks for assessing fire safety in complex environments.

Further advancements are evident in large-scale assessments. Wang *et al.* (2021) integrated the Fuzzy Analytic Hierarchy Process (FAHP) to account for intricate interdependencies between fire risk factors. This nuanced approach highlighted the utility of advanced evaluation techniques for complex building structures. Another innovative study, Y. Zhang *et al.* (2024) combined the spatial Markov chain model with an indicator system to provide a more objective analysis of fire occurrence probabilities and potential consequences.

Li *et al.* (2020) introduced an evaluation index system tailored to fire hazards specific to high-rise construction phases. The model's feasibility was validated through case studies, offering valuable insights into objective fire risk assessment during construction. Kumar *et al.* (2023) emphasized the necessity of enhancing egress systems for the elderly. They employed methods such as the Delphi technique, AHP, and fuzzy comprehensive risk evaluation to identify gaps in current systems.

On a broader scale, Xin and Huang, (2013) presented a scenario-based methodology for analyzing residential fire risks, providing structured strategies for mitigation. Similarly, L. N. Zhang *et al.* (2024) offered a scientific approach for early fire risk detection using an indicator system. These contributions further solidify the need for proactive, structured risk assessment frameworks.

To address emergency response dynamics in complex settings, Nafiseh Lotfi, Behrouz and Behnam (2021) introduced a BIM-based framework for evaluating evacuation safety in high-rise buildings after post-earthquake fires. Their work highlights the importance of data-driven simulations and spatial planning for effective occupant evacuation during compounded hazards. Similarly, Meng *et al.*, (2024) proposed a theoretical framework integrating management models with smart early fire detection and suppression technologies, emphasizing automation and system integration for timely fire suppression. Complementing these innovations, Vincent *et al.*, (2024) explored rapid fire detection and early exiting techniques using AI-based sensing tools, which offer considerable potential for reducing evacuation time and improving survivability in urban buildings.

Recent research highlights the significant role of fire load density in increasing fire risks in office buildings, particularly in urban environments. A study done by Noman *et al.*, (2023) on fire load and temperature distribution in office buildings emphasizes the need for effective fire safety measures due to high fire load densities, which directly impact fire safety compliance. This study used regression analysis to get the results. Additionally, Kumar *et al.*, (2024) research on alkali-activated concrete demonstrates superior thermal performance compared to traditional concrete, offering an alternative material for improving building fire resilience (Thermal Performance Prediction for Alkali-Activated Concrete Using GGBFS, NaOH, and Sodium Silicate). These advancements align with the goals of this study, which aims to evaluate fire safety compliance and explore retrofitting strategies for enhancing fire resilience in urban buildings.

Lastly, comprehensive models have emerged to manage fire risks more flexibly and effectively. Mi *et al.* (2020) combined fuzzy theory and evidence reasoning for a robust evaluation framework, while Zou, Zou and Xiong (2023) proposed risk assessment techniques to address the complex factors contributing to fire incidents. These studies collectively emphasized the need for proactive assessment frameworks that balanced technical rigor and practicality.

Building on these advancements, this research aims to bridge the existing gaps by pursuing two primary objectives. The first objective is to assess the adequacy of current fire safety norms by conducting a structured survey targeting local stakeholders and professionals (Engineers and Architects) in the field. The survey data will be analyzed to evaluate the effectiveness of existing standards, drawing correlations between the survey results to identify areas for improvement. The second objective is to develop a criteria framework for Fire Safety Ratings using Rapid Visual Screening (RVS). While RVS has proven effective in assessing seismic vulnerability in the past, its application in evaluating fire safety remains largely unexplored. This gap presents an opportunity for further investigation and development of the framework.

Fire safety in existing buildings, especially those constructed several decades ago, has been a growing concern due to inadequate maintenance, outdated systems, and infrequent audits. These deficiencies pose serious occupants safety risks. This research introduces a structured Rapid Visual Screening (RVS) framework aimed at addressing these gaps. The framework not only assesses the physical and technical aspects of fire safety but also integrates sustainability features such as eco-friendly extinguishers and solar-powered alarms, which have been shown to improve overall fire safety compliance.

This tool offers stakeholders—such as building owners, regulators, and policymakers—a practical means of identifying high-risk areas and prioritizing corrective measures to improve fire safety outcomes in existing buildings. By addressing these gaps, this study aspires to contribute to the creation of safer, more resilient, and sustainable urban environments.

2. Materials and Methods

This research employs a mixed-methods approach to assess fire safety compliance and the integration of sustainability features in existing buildings. The mixed-methods approach combines both qualitative and quantitative techniques to offer a comprehensive understanding of the research problem, allowing for a more nuanced analysis. Specifically, the study combines survey-based data collection and the Rapid Visual Screening (RVS) method to gather both quantitative and qualitative insights. This framework ensures a thorough evaluation of fire safety measures, their effectiveness, and the integration of sustainability practices.

A structured questionnaire consisting of 50 questions was administered to building owners, facility managers, occupants, and professionals (Engineers and Architects) across New Delhi, India. The topics covered in the survey included fire safety systems, emergency preparedness, sustainability features, and maintenance practices. Additional questions were included to evaluate emergency signage, backup power systems, compliance with modern fire safety standards, and occupant training programs. The survey was conducted with 50 respondents from diverse building types, including residential complexes, commercial buildings, and educational institutions.

The questionnaire was carefully designed to capture both perceptual and factual data about fire safety measures. Respondents provided insights into the frequency of maintenance activities, the existence of evacuation plans, and their awareness of safety protocols. The collected data were analyzed using statistical tools, particularly SPSS, to identify patterns, correlations, and areas that require improvement. Visual aids, such as charts and graphs, were generated using Microsoft Excel, and AutoCAD to effectively present the findings.

2.1 Sample Characteristics

To ensure the sample accurately reflects the urban diversity of New Delhi, the study utilized a stratified sampling approach that captured variations across building types, construction ages, and geographical zones. While the selection was not fully randomized, this strategy was designed to reflect the practical variations in fire safety conditions across the city's diverse built environment.

The selected samples were distributed evenly across the five major zones of Delhi—Central, North, South, East, and West—with 10 buildings from each zone. Within this zonal framework, buildings were further classified by usage: the sample included: Residential buildings (40%), representing low to mid-rise housing; Commercial buildings (30%), including offices and shops; Institutional buildings (20%), such as schools and public facilities; and Mixed-use buildings (10%), which combine residential and commercial functions. This classification ensured a balanced distribution, enabling meaningful comparative analysis across both zones and building use types. Figure 1 illustrates the spatial distribution of the sampled buildings, while Table 1 details the classification of the sample by building use and zone.

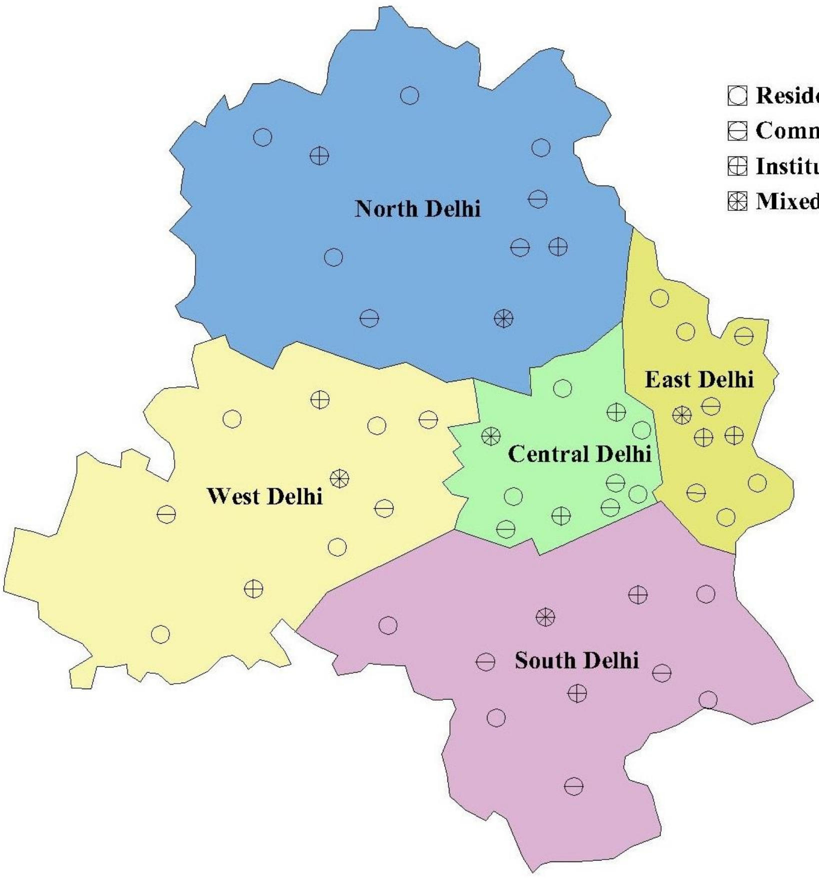

Fig. 1: Spatial Distribution of Survey Sample across Building Types and Zones in New Delhi

Table 1: Sample Distribution across Building Use and Zones

Category	Sub-category	No. of Samples	Percentage
Zonal Distribution	Central Delhi	10	20%
	North Delhi	10	20%
	South Delhi	10	20%
	East Delhi	10	20%
	West Delhi	10	20%
	Total	50	100%
Building Use Distribution	Residential	20	40%
	Commercial	15	30%
	Institutional	10	20%
	Mixed-use	5	10%
	Total	50	100%

The stratified approach facilitated a more in-depth analysis of fire safety trends across different building conditions, enhancing the contextual relevance of the findings. However, the sample size was limited, and the non-random selection method may restrict the broader generalizability of the results.

To explore the factors influencing fire safety compliance, the study employed both the Chi-square test and the Kruskal-Wallis H-test. The Chi-square test of independence was applied to examine the relationship between categorical predictors, such as building age and sustainability features (e.g., Eco-Friendly Norms, Solar-Powered Alarms), and the ordinal fire safety compliance variable (0 = Non-compliant, 1 = Partial, 2 = Full). This method was suitable for testing the independence of binary and categorical variables. In contrast, the Kruskal-Wallis H-test, which is ideal for non-parametric data, was used to assess differences in compliance levels across building age categories. However, since all sustainability features were binary

(0/1), the Kruskal-Wallis test was not applicable for these variables. Both tests were conducted at a significance level of $p < 0.001$, ensuring statistical rigor in evaluating the factors affecting compliance.

2.2 Development of the RVS Framework

The development and validation of the Rapid Visual Screening (RVS) framework followed a structured methodology that integrated a comprehensive literature review, expert consultations, and field-based evaluations. The literature review provided an extensive analysis of existing fire safety norms, identifying prevalent gaps and vulnerabilities, particularly in older structures. Expert consultations with fire safety engineers, urban planners, building inspectors, and fire protection specialists ensured that critical fire safety parameters were included in the framework.

The RVS framework was designed to address six key areas: Fire Prevention, Fire Detection Systems, Fire Suppression Systems, Emergency Escape and Evacuation, Structural Fire Protection, and Emergency Preparedness. These areas were selected based on their importance in evaluating a building's fire safety readiness. Each area was further subdivided into specific parameters, each of which was assigned a weight reflecting its significance to fire safety and occupant protection. These weightings were informed by industry standards such as NFPA, NBC, and ISO, and by feedback from fire safety professionals. The Table 2 presents a comparative analysis of the proposed RVS framework categories against established international standards, including NFPA, NBC, and ISO.

The rationale behind the weight allocation was as follows:

- Fire Suppression Systems were assigned the highest weight (25%) due to their direct impact on controlling fire spread.

- Fire Detection Systems and Structural Fire Protection were given moderate weights (20% each) owing to their critical roles in early fire detection and passive safety measures.

- Emergency Escape and Evacuation was weighted at 15%, reflecting its importance in ensuring safe occupant evacuation.

- Fire Prevention and Emergency Preparedness were allocated lower weights (10% each), as they are preventative and preparatory measures, respectively, with indirect but essential contributions to overall fire safety.

This weighting rationale was guided by established fire safety standards and expert feedback.

Table 2: Comparison of RVS Framework Categories with International Standards

Category	Corresponding NFPA/NBC/ISO Elements
Fire Prevention	NFPA 1, Chapter 10 (General Fire Safety)
Fire Detection Systems	NFPA 72 (National Fire Alarm Code)
Fire Suppression Systems	NFPA 13 (Sprinkler Systems), NBC Part 4
Emergency Escape & Evacuation	NFPA 101, Chapters 7 & 8 (Life Safety Code)
Structural Fire Protection	NFPA 5000 (Building Construction)
Emergency Preparedness	ISO 22320 (Emergency Management)

The finalized RVS framework was pilot-tested on a sample of 10 buildings representing residential, commercial, and educational categories. On-site inspections were conducted to evaluate the presence and condition of the identified fire safety parameters. Feedback from fire safety inspectors, engineers and building owners was incorporated to validate the practical applicability and clarity of the assessment criteria. The RVS results were normalized on a scale of 0 to 5**,** with 5 indicating full compliance with relevant fire safety standards. This scoring approach facilitated consistent interpretation of fire safety performance across diverse building types.

The framework and scoring criteria were subsequently reviewed by a panel of five fire safety engineers and two building code experts to ensure both technical accuracy and practical applicability. This multi-expert validation strengthened the reliability and credibility of the RVS framework, reinforcing its suitability for real-world implementation in diverse urban contexts.

To derive a comprehensive Fire Safety Index, RVS scores were integrated with survey data, allowing for a holistic evaluation of fire safety performance across different building typologies. Data reliability was evaluated using Cronbach's Alpha, confirming acceptable internal consistency within the survey dataset.

Statistical analysis and visual representation were performed using IBM SPSS, Microsoft Excel, and AutoCAD, enabling pattern recognition and identification of critical compliance gaps. The overall methodological approach is illustrated in the flowchart in Figure 2.

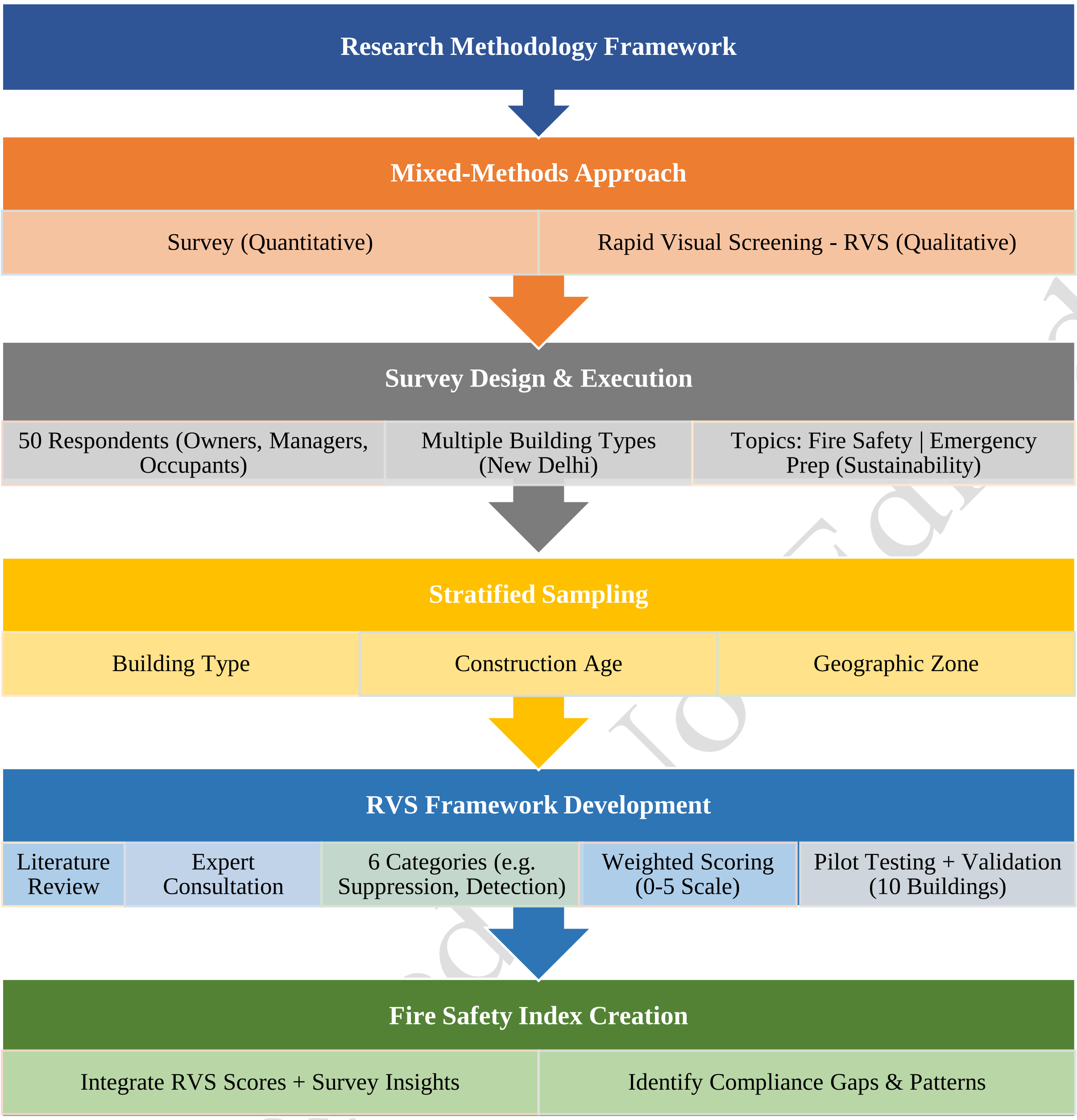

Fig. 2: Methodology - Flow Chart

Despite its contributions, the methodology has certain limitations. The reliance on visual inspections and self-reported data may introduce subjective biases and incomplete observations. Future research could benefit from the integration of sensor-based monitoring, IoT-enabled fire safety devices, and AI-powered risk detection models, offering greater accuracy and real-time insights into building safety.

The survey sample consisted of 50 respondents from New Delhi, India, selected based on convenience and accessibility. While the sample provides valuable insights into urban fire safety perceptions, it may not fully represent broader regional or national variations. The sample was not randomized, which introduces potential selection bias. Future studies should consider stratified or randomized sampling across diverse building typologies and locations for generalizable findings.

Ethical protocols were strictly followed throughout the research process. All participants were informed about the nature and purpose of the study, and their participation was entirely voluntary.

Informed consent was obtained prior to data collection. Respondents were assured of confidentiality, and all data were anonymized to protect personal and organizational identities. The survey avoided any sensitive personal questions and adhered to the ethical standards recommended for social research involving human subjects.

In summary, the developed RVS framework—anchored in international standards, supported by survey insights, and validated by domain experts—presents a robust, scalable methodology for assessing fire safety compliance and sustainability integration in existing buildings. The framework not only highlights areas requiring retrofitting and policy attention but also lays the groundwork for regulatory enhancement and future technological integration in fire safety assessments.

3. Results and Discussion

3.1 Results

This study presents a comprehensive investigation into the fire safety compliance of existing buildings, with an emphasis on identifying key barriers to improvement and evaluating the feasibility of adopting a Rapid Visual Screening (RVS)-based Fire Safety Rating system. Leveraging a combination of survey responses, expert evaluations, and the proposed RVS framework, the findings highlight significant patterns that illuminate both the challenges and opportunities for enhancing fire safety in urban environments.

One of the most critical observations from this analysis is the strong negative correlation between building age and fire safety compliance. As illustrated in Figure 3, the bar chart clearly shows that compliance rates are highest in buildings that are less than 10 years old, with a steady decline as buildings age.

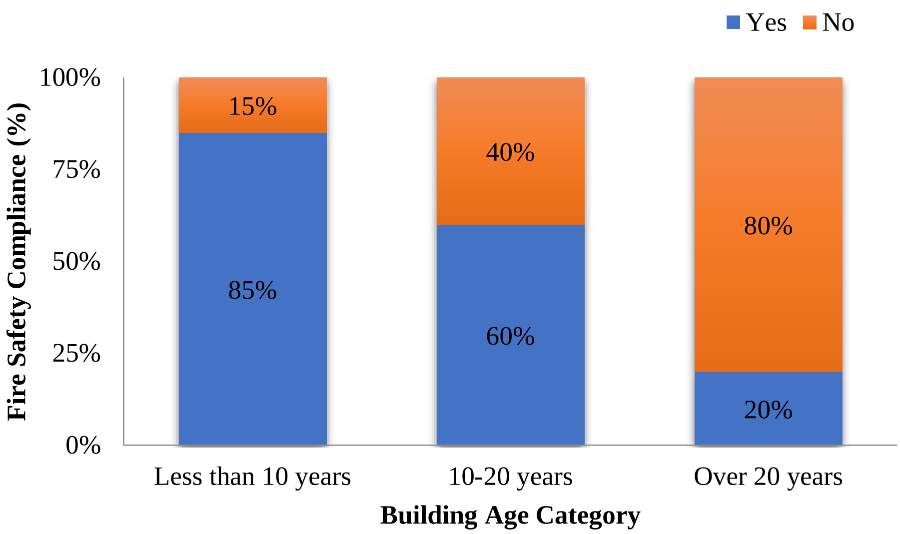

Fig. 3: Fire Safety Compliance across Building Age Categories

A marked decrease in compliance is evident in buildings over 20 years old, where non-compliance is disproportionately higher. These results suggest that older buildings are likely to lack modern fire safety measures and may not have undergone necessary retrofitting or updates to align with contemporary fire safety regulations. This pattern highlights the pressing need for prioritizing retrofitting efforts in aging structures to address this gap.

The breakdown of compliance levels by age category further reinforces this trend. Buildings constructed within the last 10 years exhibit a compliance rate of 85%, which drops to 60% in those aged between 10 and 20 years, and further declines to a concerning 20% in buildings older than 20 years as shown in Table 3. These findings support the notion that as buildings age, the likelihood of them meeting modern fire safety standards decreases, likely due to the absence of ongoing updates or necessary fire safety improvements.

Table 3: Fire Safety Compliance across Building Age Categories

Building Age Category	% Compliance (Yes)	% Non-Compliance (No)	Mean Compliance
Less than 10 years	85%	15%	0.85
10-20 years	60%	40%	0.60
Over 20 years	20%	80%	0.20
Correlation (r)	-0.792	$p < 0.001$	-
Chi-Square (χ^2)	50.000	$p < 0.001$	-
Kruskal-Wallis (H)	37.58	$p < 0.001$	-

To confirm the robustness of this observation, the Pearson correlation ($r = -0.792$, $p < 0.001$) was applied, which reveals a strong negative relationship between building age and fire safety compliance. This suggests that as buildings become older, the likelihood of them meeting current fire safety standards diminishes. The Chi-square test ($\chi^2 = 50.000$, $p < 0.001$) further supports this, providing statistical evidence of a significant association between building age and fire safety compliance, reaffirming that older buildings are more likely to exhibit non-compliance.

Moreover, to ensure that the analysis was appropriate for the ordinal nature of the compliance data (0 = Non-compliant, 1 = Partial, 2 = Full), Kruskal-Wallis Tests were used to confirm these trends. The Kruskal-Wallis test is a non-parametric method that compares multiple independent groups and is particularly suited to ordinal variables like fire compliance ratings. The results showed a statistically significant difference in compliance levels across the three building age categories ($H = 37.58$, $p < 0.001$), thereby confirming and strengthening the hypothesis that compliance decreases significantly with building age. This reinforces the earlier findings and validates the observed trend through a more statistically appropriate method.

The inclusion of the Kruskal-Wallis test not only complements the correlation and chi-square results but also enhances methodological rigor by ensuring compatibility with the data's ordinal scale. This added layer of statistical validation increases the reliability of the conclusions and supports policy arguments for targeted retrofitting of older buildings.

The correlation between building age and compliance can also be visualized in Figure 4, which demonstrates a clear downward trend in compliance as building age increases. This figure highlights a particularly stark concentration of non-compliant buildings (marked as 0) within the older age categories, further emphasizing the critical nature of retrofitting older structures.

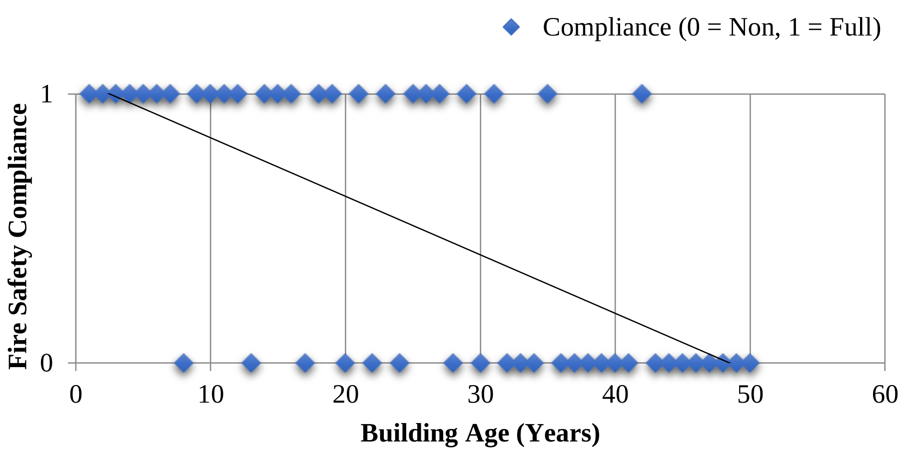

Fig. 4: Correlation between Building Age and Fire Safety Compliance

Descriptive statistical analysis, presented in Table 4, reveals the distribution of sustainability features across surveyed buildings and their relationship with fire safety compliance.

The analysis shows that Eco-Friendly Norms (Mean (M) = 0.66, Standard Deviation (SD) = 0.48) and Eco-Friendly Extinguishers (M = 0.64, SD = 0.48) are widely adopted, while Solar-Powered Alarms (M = 0.38, SD = 0.49) have a considerably lower implementation rate. These sustainability measures appear to influence the fire safety compliance of buildings, reinforcing the idea that integrating sustainability initiatives may have a direct impact on improving fire safety standards.

The variability in fire safety compliance (M = 1.20, SD = 0.83) indicates that a significant proportion of the surveyed buildings fall into non-compliant or partially compliant categories, which sets the stage for deeper inferential analysis exploring the interplay between sustainability measures and fire safety compliance.

Table 4: Descriptive Statistics

Variable	Mean (M)	Standard Deviation (SD)
Eco-Friendly Norms	0.66	0.48
Eco-Friendly Extinguishers	0.64	0.48
Energy-Efficient Lighting	0.45	0.50
Solar-Powered Alarms	0.38	0.49
Fire Safety Compliance	1.20	0.83

Chi-square tests **(**Table 5**)** were conducted to assess the statistical association between sustainability features and fire safety compliance. The results indicate a strong correlation, with Eco-Friendly Norms ($\chi^2(2) = 28.892$, $p < 0.001$) and Energy-Efficient Lighting ($\chi^2(2) = 20.852$,

$p < 0.001$) significantly influencing compliance levels. Similarly, Eco-Friendly Extinguishers ($\chi^2(2) = 18.932$, $p < 0.001$) and Solar-Powered Alarms ($\chi^2(2) = 13.392$, $p < 0.001$) exhibit a substantial association with compliance. A bar chart (Figure 5) illustrates these how sustainability-oriented buildings are more likely to comply with fire safety norms.

While the fire safety compliance variable is ordinal, Chi-square tests were deemed appropriate for this analysis due to the binary nature of the predictor variables and the objective of testing for independence. Kruskal-Wallis tests were considered; however, since all sustainability variables were binary (0/1), they do not fulfill the requirement of having three or more independent groups with ranked or continuous distributions. Hence, the Chi-square test of independence was deemed more suitable for evaluating associations with the ordinal outcome.

To further assess the predictive strength of sustainability measures on fire safety compliance, a binary logistic regression analysis was conducted. For this model, the fire safety compliance variable was re-coded into a binary outcome (0 = Non-Compliant, 1 = Compliant) to satisfy the assumptions of logistic regression.

Table 5: Fire Safety Compliance across Building Age Categories

Sustainability Feature	**χ^2 Value**	**df**	**p-value**
Eco-Friendly Norms	28.892	2	<0.001
Eco-Friendly Extinguishers	18.932	2	<0.001
Energy-Efficient Lighting	20.852	2	<0.001
Solar-Powered Alarms	13.392	2	<0.001

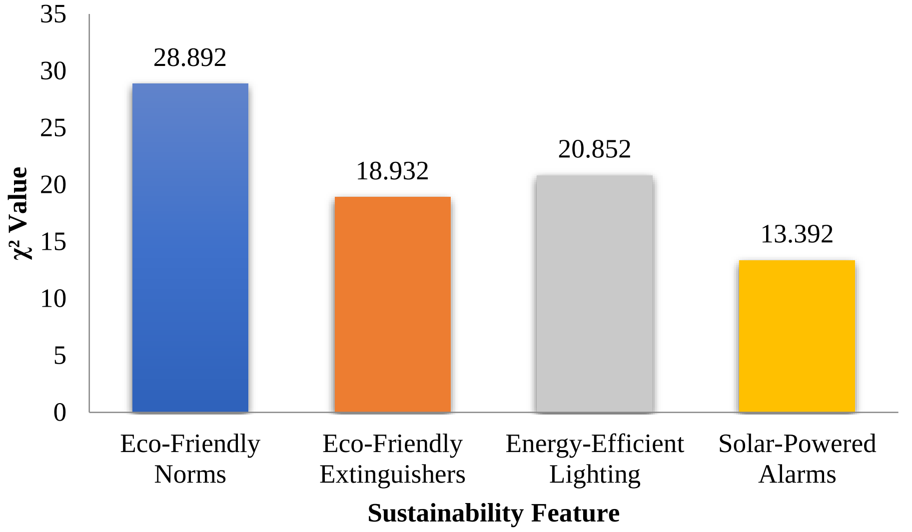

Fig. 5: Chi-Square Test Results for Sustainability Features and Fire Safety Compliance

The model demonstrated strong statistical significance ($\chi^2(4) = 38.260$, $p < 0.001$) and a Nagelkerke R^2 of 0.715, indicating that sustainability measures account for approximately 71.5% of the variance in compliance levels. Among the predictors, Energy-Efficient Lighting (Exp(B) = 16.379, $p = 0.004$) and Solar-Powered Alarms (Exp(B) = 6.055, $p = 0.058$) were statistically significant, confirming their contribution to improving compliance rates. The classification accuracy of the model (Figure 6) reached 76%, reinforcing the predictive strength of sustainability integration in fire safety measures.

Although the model's high Nagelkerke R^2 suggests strong explanatory power, the possibility of over-fitting was considered. However, given the theoretical grounding of the selected predictors and the limited number of independent variables, the model remains robust and interpretable within the study's scope.

Table 6: Logistic Regression Model Summary

Predictor	Regression Coefficient	Standard Error	χ^2 Value	p-value	Exp(B) (Odds Ratio)

Eco-Friendly Norms	22.382	20.95	0.000	0.999	5.25E9
Eco-Friendly Extinguishers	-19.106	20.95	0.000	0.999	0.000
Energy-Efficient Lighting	2.796	0.980	8.136	0.004	16.379
Solar-Powered Alarms	1.801	0.950	3.591	0.058	6.055
Constant	-5.111	1.675	9.314	0.002	0.006

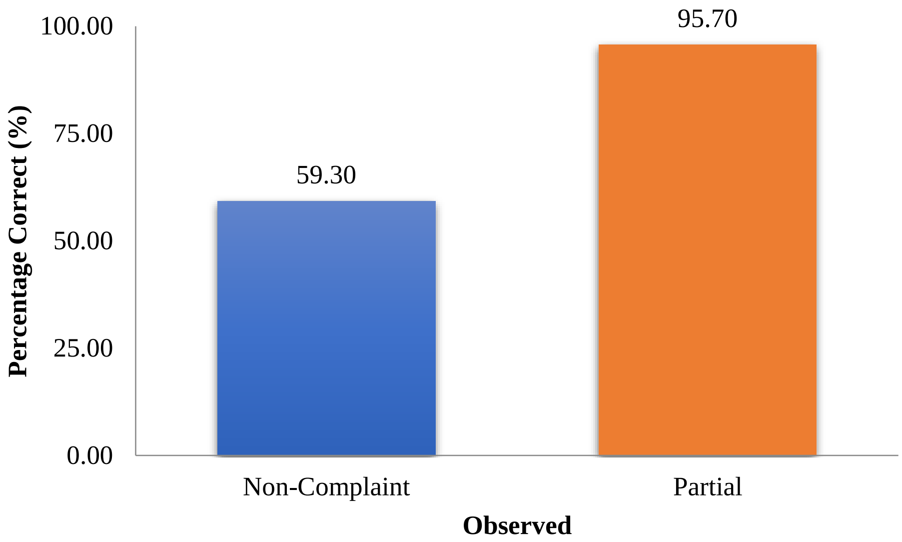

Fig. 6: Classification Accuracy for Fire Safety Compliance

A Principal Axis Factoring (PAF) analysis was conducted to identify underlying patterns among sustainability variables. Factor loadings (Figure 7) indicate that Eco-Friendly Norms (0.997) and Eco-Friendly Extinguishers (0.817) exhibit the highest contribution among sustainability features, reinforcing their critical role in fire safety compliance. These features demonstrate strong predictive capacity, suggesting that regulatory frameworks should prioritize their adoption. In contrast, Energy-Efficient Lighting (0.444) and Solar-Powered Alarms (0.454) show relatively weaker associations, implying that their impact on compliance is less pronounced. This highlights the need for targeted policy interventions to enhance their effectiveness in fire safety strategies.

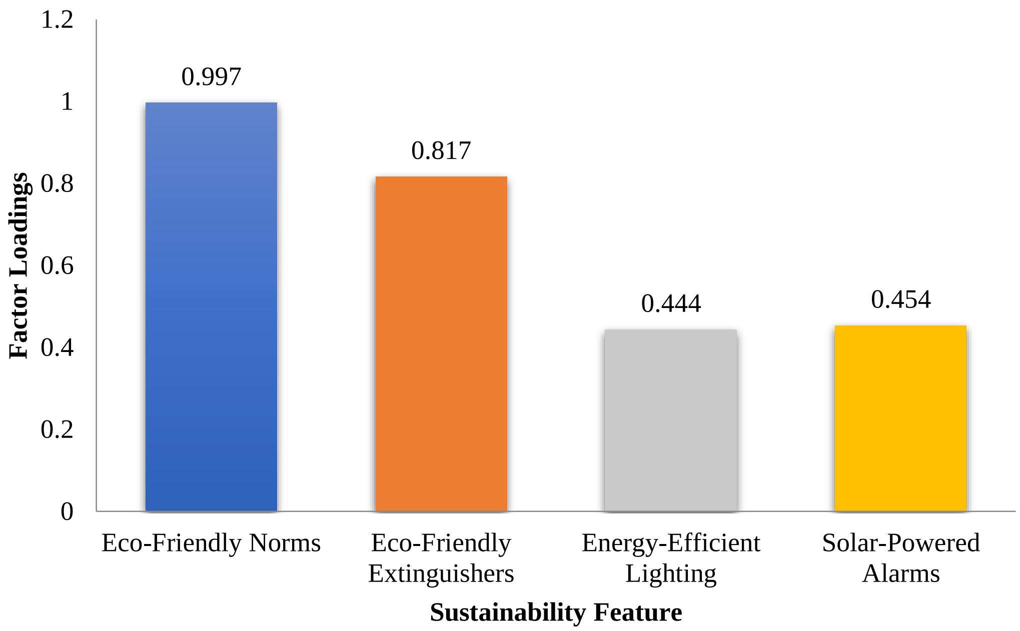

Fig. 7: Factor Analysis Loadings

The overall analysis establishes a significant relationship between sustainability-oriented fire safety measures and compliance levels. Logistic regression results confirm that sustainability features substantially influence compliance outcomes, with classification accuracy reaching 76%. Additionally, the factor analysis underscores the dominance of Eco-Friendly Norms and Extinguishers as primary drivers of compliance. These findings strongly advocate for the integration of sustainability-based fire safety measures within regulatory standards, ensuring a more resilient and environmentally responsible built environment.

The Rapid Visual Screening (RVS) framework was developed to evaluate fire safety across six critical areas using 20 weighted parameters, each scored on a normalized scale from 0 (non-compliant or not present) to 5 (full compliance). This framework was implemented across 20 buildings representing residential, commercial, and educational typologies to systematically assess fire safety performance.

Results from the RVS assessment revealed varying compliance levels across building types, with critical deficiencies observed in Fire Detection Systems and Emergency Escape provisions**,** particularly in commercial and educational buildings. In contrast, areas such as Fire Prevention and Structural Fire Protection scored relatively better. This variation highlights the importance of targeted, building-type-specific interventions to address high-risk domains.

The aggregated RVS scores provided a comprehensive overview of fire safety conditions. Buildings with lower total scores frequently exhibited severe shortcomings in Emergency Preparedness and Fire Suppression Systems, suggesting that a low overall rating corresponds with systemic vulnerabilities that could exacerbate fire risk.

To evaluate the internal consistency of the RVS tool, reliability testing using Cronbach's Alpha yielded a value of 0.720, indicating acceptable reliability for a newly applied evaluation framework. This supports the robustness of the instrument for use in rapid on-site evaluations. In addition, feedback from fire safety officers, engineers and building managers helped refine the practical aspects of parameter weightage and field implementation, further improving the framework's applicability.

The findings from this study provides valuable insights into fire safety compliance in existing buildings, emphasizing the influence of building age, sustainability features, and the effectiveness of the proposed Rapid Visual Screening (RVS) framework.

Correlation analysis reinforced the role of building age in predicting fire safety compliance. A strong negative correlation was found between building age and compliance ($r = -0.792$, $p < 0.001$), with compliance levels declining from 85% in buildings less than 10 years old to just 20% in buildings older than 20 years. This association was further validated by a Chi-square test ($\chi^2 = 50.000$, $p < 0.001$), highlighting the urgent need for retrofitting strategies to address the risks posed by aging infrastructure. Additionally, the Kruskal-Wallis test ($H = 37.58$, $p < 0.001$) confirmed and reinforced the hypothesis that compliance significantly decreases with building age.

Sustainability features were also found to have a statistically significant impact on fire safety compliance. Eco-Friendly Norms ($\chi^2 = 28.892$, $p < 0.001$) and Energy-Efficient Lighting ($\chi^2 = 20.852$, $p < 0.001$) emerged as key contributors. Logistic regression analysis confirmed that Energy-Efficient Lighting was a strong predictor of compliance (Exp(B) = 16.379, $p = 0.004$), while Solar-Powered Alarms showed a moderate yet notable association (Exp(B) = 6.055, $p = 0.058$). These findings suggest that the integration of certain sustainability measures can directly enhance compliance levels, while also pointing to the need for further promotion and policy support for underutilized features.

Overall, the combined results from the statistical tests and the RVS framework provide a comprehensive understanding of the multifaceted nature of fire safety compliance. The RVS tool, in particular, proves valuable not just for assessment, but also for prioritizing improvements based on a building's specific risk profile. Its integration with sustainability assessments and age-related risk analysis creates a holistic basis for developing proactive fire safety policies.

3.2 Discussion

The findings from this study offer critical insights into fire safety compliance among existing buildings in urban India, with a focus on New Delhi. While the logistic regression results show a strong model fit (Nagelkerke $R^2 = 0.715$), the high explanatory power may be partially influenced by the relatively small sample size.

This highlights the need for caution in generalizing the model across broader populations. Moreover, the use of chi-square tests provided an initial understanding of group-level differences; however, future research may benefit from employing Kruskal-Wallis or ordinal regression models to better handle the ordinal nature of compliance levels.

The Rapid Visual Screening (RVS) framework introduced in this study, although novel in the Indian context, warrants further benchmarking against established fire safety assessment tools such as NFPA 101 or ISO 16732. The current scoring system, based on a 0–5 scale, reflects stakeholder-informed prioritization but would benefit from empirical validation or Delphi-based weight assignments to reduce subjectivity.

Additionally, the cross-sectional design of the study limits the ability to infer long-term effects of retrofitting. Longitudinal studies tracking the impact of interventions over time would provide deeper evidence of causality.

Lastly, while the current study focuses on an urban context, future research should incorporate informal settlements and non-urban regions where fire risks are often higher and regulatory enforcement is weaker, to broaden the policy relevance of the findings.

4. Conclusions

This study offers a comprehensive analysis of fire safety compliance in existing buildings and evaluates the feasibility of a Rapid Visual Screening (RVS)-based Fire Safety Rating system. Key findings reveal a strong negative correlation between building age and compliance with modern fire safety standards, with older buildings (over 20 years) showing significantly lower compliance. This highlights the urgent need for retrofitting efforts to bring older buildings in line with current fire safety norms.

Sustainability-driven fire safety measures, such as Eco-Friendly Norms and Energy-Efficient Lighting, were identified as critical factors influencing compliance. The logistic regression model demonstrated a predictive accuracy of 76%, underscoring the positive impact of sustainability features on fire safety outcomes. These results emphasize the importance of integrating sustainability into fire safety regulations.

The application of the Rapid Visual Screening (RVS) framework demonstrated its effectiveness and reliability as a practical tool for assessing fire safety compliance in existing buildings. Statistical validation through internal consistency analysis yielded a Cronbach's Alpha value of 0.720, which indicates an acceptable level of reliability. This suggests that the components and indicators within the RVS checklist are well-correlated and measure a coherent underlying construct related to fire safety compliance. The consistency of responses across different items further reinforces the robustness of the framework in capturing essential fire safety parameters in a structured and replicable manner.

5. Future Scope

The results of this study open several avenues for future research and practical application:

- Simulation-Based Validation: Integrating fire simulation software like FDS (Fire Dynamics Simulator) or Pathfinder can help validate RVS parameters under realistic fire scenarios, improving its accuracy and reliability.

- AI-Driven Visual Inspections: Future applications may incorporate computer vision and AI tools to automatically detect fire safety deficiencies—such as blocked exits, missing alarms, or damaged fire doors—through photos or video footage.

- Sustainability-Fire Safety Interaction Modeling: Future models can quantify how sustainability features (e.g., passive design, green materials) contribute to fire safety performance, enabling dual-benefit evaluations.

- Longitudinal Retrofitting Assessment: Long-term studies should track fire safety compliance over time in retrofitted buildings to measure the sustained impact of interventions and validate the effectiveness of upgrades.

- Policy Integration and Automation: Collaborations with regulatory bodies can help incorporate the RVS framework into local building codes and automate compliance reporting through digital platforms.

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