CHAPTER 61

Enhancing Resilience in Construction Safety

Kartikey Bhatt[1], Abhishek Anand[1], Smriti Jaiswal[2] and Shinde Diksha Dilkhush[1]

ABSTRACT

The critical role of resilience in enhancing safety practices within the construction industry is characterized by high complexity and susceptibility to risks such as project delays, cost overruns, and safety incidents. Current related research mainly focuses on broader and traditional construction safety practices, but due to the advancement of technology in construction, it lacks a method to evaluate safety management. Therefore, this research identifies key elements that influence safety resilience on construction sites. Applying the 4M framework (Man, Machine, Media, Management) to identify critical indicators for enhancing safety resilience. Central to these findings are strategies such as money as an additional framework, and robust risk identification and assessment, which ensure potential hazards are effectively mitigated. Adaptive decision-making and clear communication channels further support dynamic responses to on-site changes and implementing real-time monitoring and feedback systems enables immediate identification and resolution of risks. The study adopts a multifaceted approach, including a systematic literature review, stakeholder interviews, and structured questionnaires, to identify and evaluate key factors influencing construction safety resilience. We expect the insights gained from this research to provide practical guidance for construction companies aiming to improve safety performance. By adopting resilience-focused measures, organizations can reduce the impact of accidents, enhance operation efficiency, and promote a safer, more sustainable work environment. This approach not only prioritizes worker well-being but also reinforces the construction industry's commitment to long-term safety and resilience.

Keywords: Resilience; Potential hazards; Safety performance; Sustainable work environment; Risk.

1.0 Introduction

The construction sector significantly contributes to global economic growth and job creation (Marsh, 2024). However, rapid expansion in this industry presents challenges related to resilience, safety, and risk management (Aidoo *et al.*, 2021).

[1]*School of Construction, NICMAR University, Pune, Maharashtra, India*
[2]*Corresponding author; School of Construction, NICMAR University, Pune, Maharashtra, India*
(E-mail: P2370657@student.nicmar.ac.in)

DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

Common issues such as uncertainties in project scope, cost overruns, and schedule delays can adversely affect project success (Zhang *et al.*, 2022). Implementing strategic solutions, particularly resilience models, is crucial to mitigate these risks and enhance safety throughout construction projects (Schafer *et al.*, 2008). A resilience framework enables construction companies to anticipate potential risks, adapt to unforeseen challenges, and implement robust safety measures (Construction Business Brokers, 2024). By integrating resilience principles into project management processes, businesses can improve their ability to handle disruptions, ensuring operational continuity and efficiency (Marsh, 2024). This structured approach facilitates proactive risk assessment and the development of contingency plans, embedding adaptability and flexibility into construction management (Eynce, 2023).

The construction industry involves a diverse range of stakeholders, each with distinct expectations and concerns. As teams navigate various transitions, project complexity increases, necessitating flexibility while adhering to established strategies (Canadian Construction Association, 2021). Adapting to evolving client expectations, regulatory changes, and external pressures adds another layer of complexity (Wall Street Journal, 2024). A systematic approach that balances risk reduction with operational efficiency is essential to maintain safety in this context (Time, 2025). Applying resilience measures in construction safety promotes long-term sustainability, enhances productivity, and leads to better project outcomes (Zhang *et al.*, 2022). By establishing robust risk management procedures, organizations can better withstand challenges, ensuring project success and the well-being of their staff (Aidoo *et al.*, 2021). Integrating resilience-based techniques into safety procedures is vital for creating a safe, adaptable, and efficient construction industry (Schafer *et al.*, 2008).

2.0 Literature Review

2.1 Understanding construction safety resilience

Resilience can be widely defined by the system's ability (e.g., ecological, organizational, psychological, etc.) to be aware of its surroundings and to adapt to recover once faced with disruptions (Folke, 2006). In engineering and construction, resilience is the ability to absorb or avoid damage without suffering complete failure. It is an objective of design, maintenance, and restoration of buildings and infrastructure, as well as communities (Bruneau *et al.*, 2003). Resilience is the capacity to bounce back from hardship, regain some semblance of normalcy following a shock or stressful event, or adjust to a new situation (Holling, 1973).

Resilience also refers to the ability of communities and structures at all levels and degrees of development to continue to function as habitable environments in the face of worsening or even catastrophic situations (Cutter *et al.*, 2008). Resilience thinking can help projects maintain their performance through flexible, systemic, and context-specific approaches once faced with disruptive events (Walker & Salt, 2006).

DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

Figure 1: Systematic Literature Review

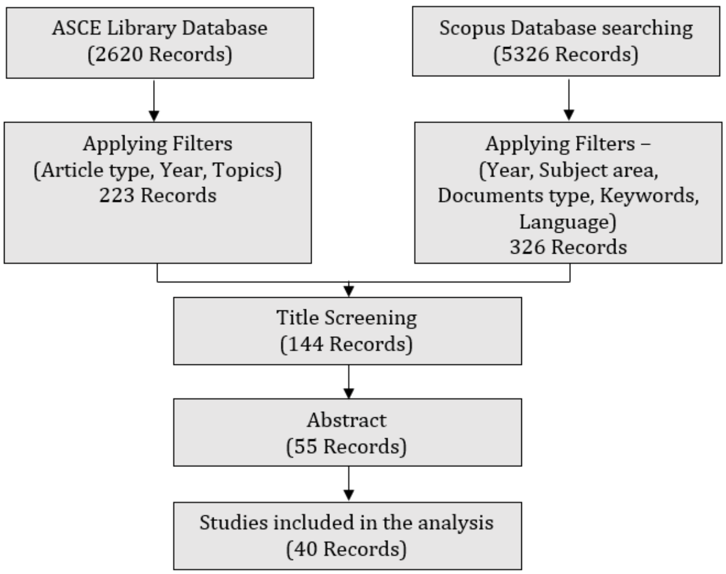

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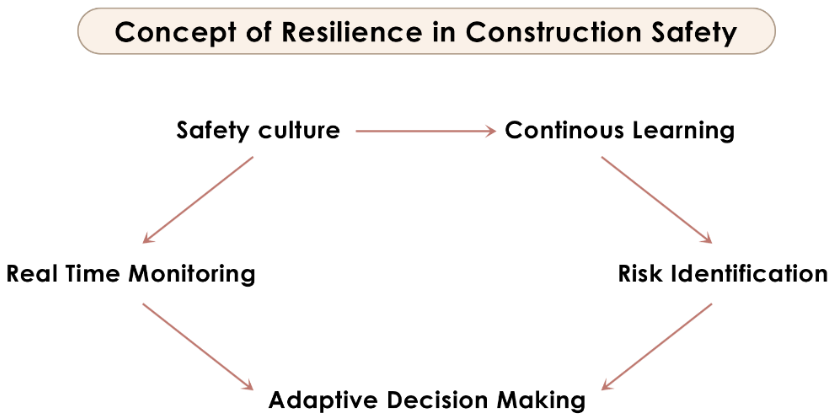
Figure 2: Concept of Resilience in Construction Safety



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2.2 Resilience-based safety management approaches

Resilience-based safety management highlights proactive risk control, ongoing learning, adaptive safety measures, and real-time tracking to enhance safety on construction sites. In contrast to conventional strategies, this model prioritizes predicting risk, modifying

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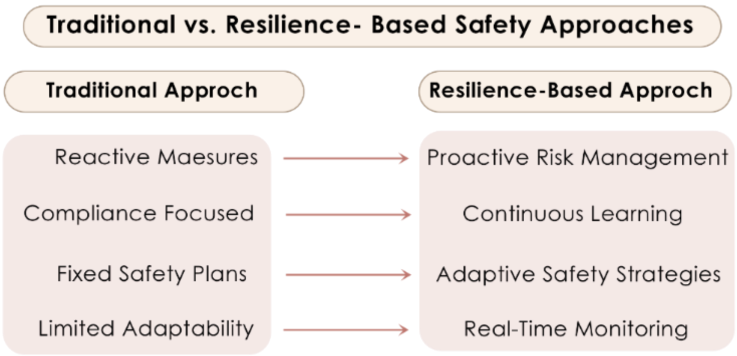
responses to varying conditions, and reacting quickly to incidents. By incorporating real-time information and supporting adaptive decision-making, resilience-based approaches develop a more adaptable and resilient safety framework, which adds to overall project stability and the protection of workers. (Qian, 2023).

Figure 3: Traditional vs Resilience based Safety Approach



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3.0 Research Gap and Rationale

Sufficient financial resources are critical for increasing safety resilience on construction sites because they enable risk-reduction methods, training programs, and technology developments. Adequate financing allows access to high-quality personal protective equipment (PPE), innovative safety monitoring systems, and technical controls that reduce workplace dangers. It also promotes thorough safety training, which provides managers, supervisors, and employees with the ability to evaluate hazards, resolve crises, and make sound decisions. A well-funded safety framework encourages frequent site inspections, constant safety exercises, and the use of new technology like automated reporting and real-time danger detection systems to develop a proactive safety culture.

4.0 Research Methodology

4.1 Data collection

Once the survey instrument was finalized and the sample was selected, the data collection process began. Respondents were asked to complete the survey. The goal was to collect enough data to ensure meaningful analysis, with a focus on obtaining responses that reflected both the breadth and depth of project complexity.

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4.2 Data entry and management in SPSS

Data entry: Once the primary data (e.g., survey responses) was collected, it was entered into SPSS either manually or by importing files like Excel or CSV (Pallant, 2020). Each respondent's answers were entered as rows (cases), and variables (survey questions) were arranged as columns (Field, 2018).

Variable setup: For each survey question, variables were properly defined. In SPSS, variables were set up to reflect the type of data they represented (nominal, ordinal, interval, ratio) (Bryman & Cramer, 2011). Their properties, such as labels, values, and measurement levels, were defined accordingly (Tabachnick & Fidell, 2019).

Descriptive statistics: Descriptive statistics were used to summarize the basic features of the data and provide a straightforward overview of the sample (Hair *et al.*, 2020). In SPSS:

Frequencies: Frequency distributions were created to count how many times each response appeared in the data (Pallant, 2020). This helped identify trends in categorical data, such as the number of respondents who selected a particular answer (Field, 2018).

Measures of central tendency: SPSS computed mean, median, and mode to provide an understanding of the central point of the data, especially for Likert scale or numerical questions (Tabachnick & Fidell, 2019).

Measures of dispersion: SPSS computed standard deviation and variance, giving insights into the variability of the data (Hair *et al.*, 2020). For example, it showed how consistent or diverse the responses were regarding the complexity factors (Bryman & Cramer, 2011). SPSS was a robust tool that proved invaluable in the research on identifying and evaluating the key variables influencing the complexity of construction projects (Pallant, 2020). By using SPSS for tasks such as data entry, descriptive analysis, factor analysis, regression, and testing relationships between variables, reliable insights were obtained, and conclusions were drawn based on statistical evidence (Field, 2018). The software's ability to handle both quantitative and qualitative data made it an ideal choice for this study, providing a comprehensive analysis of the factors contributing to complexity in construction projects (Hair *et al.*, 2019).

5.0 Data Analysis and Findings

5.1 Relative Importance Indices (RII)

The Relative Importance Index (RII) is a widely used statistical tool for ranking and prioritizing various factors based on survey responses. It is extensively applied in fields such as construction management, project management, and social sciences to assess the relative significance of different parameters (Holt, 1998; Chan & Kumaraswamy, 2002). The formula for the Relative Importance Index (RII) is expressed as follows (Tam *et al.*, 2000; Assaf & Al-Hejji, 2006):

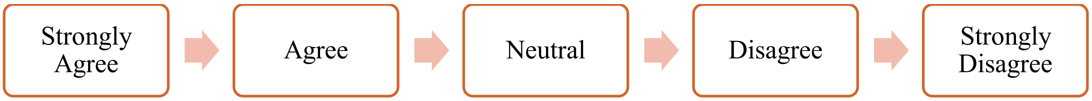
$$\text{Relative Importance Index(RII)} = \frac{\sum W}{A*N} = \frac{5n_5+4n_4+3n_3+2n_2+1n_1}{5*N}$$

W: Weighting given to each factor by the respondent (e.g., 1 for strongly disagree to 5 or strongly agree)
A: the highest weight in the research (i.e. 5)
N: Total number of respondents

5.2 Questionnaire analysis (5 step approach)

- *Step 1:* We have listed the scale on a 1-5 scale by following-

Figure 4: Scale (Likert Scale)



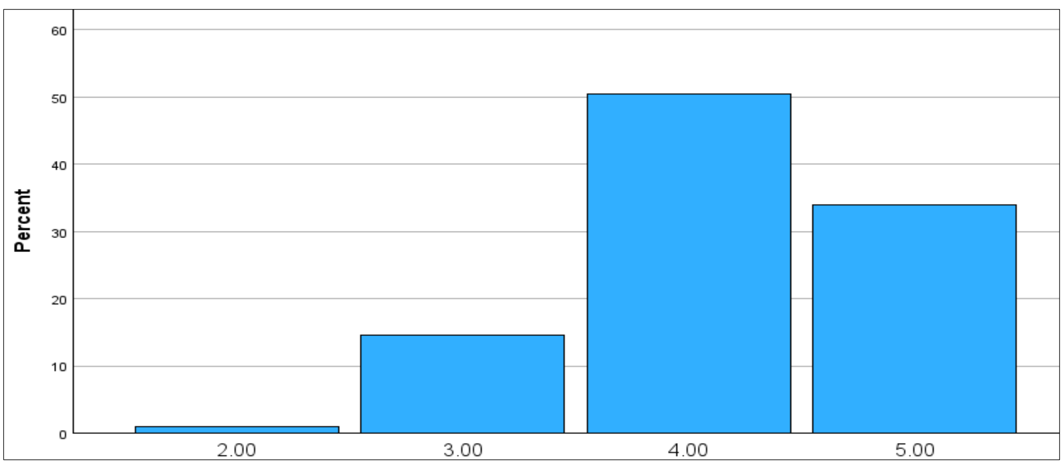
- *Step 2:* First, the data was converted to a numerical representation. With SPSS software, a frequency analysis was then carried out as part of the analysis. For example:

Table 1: Representation of Each Answer (in Percentage)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	1	1	1	1
	3	15	14.6	14.6	15.5
	4	52	50.5	50.5	66
	5	35	34	34	100
	Total	103	100	100	

Source: Compiled by authors

Figure 5: Representation of Each Answer (In Percentage Graph)



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DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

Table 2: Mean Score of Each Factor

Factors	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)	No. of Responses
Man	38.2	46.6	16.4	1.6	0.2	103
Media	34.25	42.5	24.5	1.5	0.25	103
Machinery	30.2	47.2	16	9.2	0.4	103
Management	37.8	43.8	17.4	2.4	1.6	103
Money	41.6	46.8	10	4	0.6	103

Source: Compiled by authors

Table 3: Relative Importance Index

Factors	Strongly Agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly Disagree (1)	Total	Total No of responses (N)	A*N	RII
Man	191	186.4	49.2	3.2	0.2	430	103	515	0.834951
Media	171.25	170	73.5	3	0.25	418	103	515	0.81165
Machinery	151	188.8	48	18.4	0.4	406.6	103	515	0.789515
Management	189	175.2	52.2	4.8	1.6	422.8	103	515	0.820971
Money	208	187.2	30	8	0.6	433.8	103	515	0.84233

Source: Compiled by authors

- *Step 3:* For each factor, five core questions were identified. These questions were then categorized, and the mean score for each category was calculated accordingly.
- *Step 4:* We have applied the relative index formula (Figure 4)
- *Step 5:* The factors have been ranked in order of importance based on the collected Relative Importance Index (RII) data.

Table 4: RII Data and Ranking

Factors	RII	Ranks
Money	0.84233	1
Man	0.834951	2
Management	0.820971	3
Media	0.81165	4
Machinery	0.789515	5

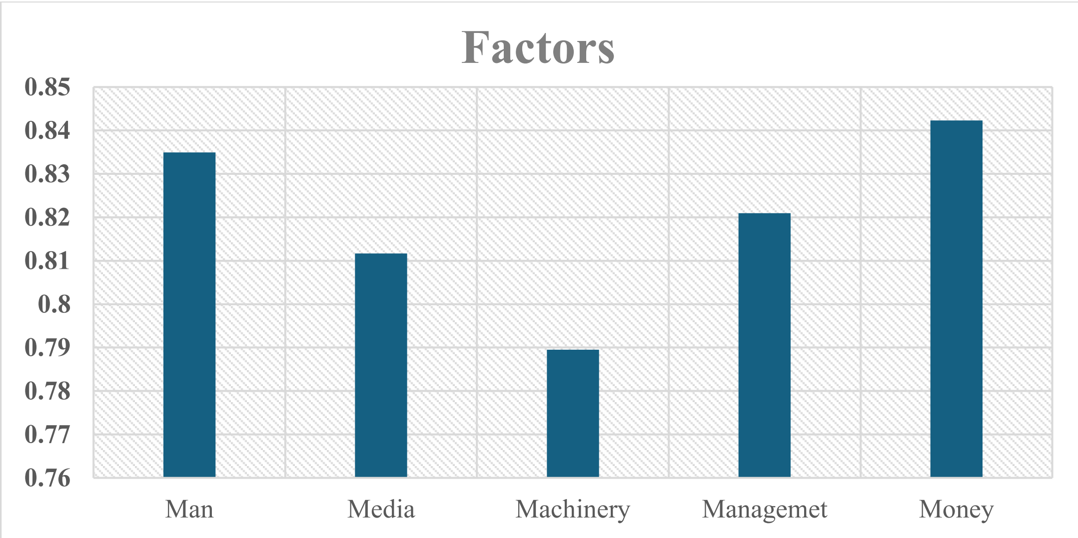
Source: Compiled by authors

5.3 Interview analysis

- *Step 1:* Data collection
- *Step 2:* Selection of best qualitative data analysis approach

DOI: 10.17492/JPI/NICMAR/2507061 ISBN: 978-93-49790-54-4

Figure 6: Factors Ranking



Source: Compiled by authors

Table 5: Qualitative Approach

Responded	Experience (in years)	Domain	Designation
1	6 years site 20+in academia	Execution & Planning	Assistant prof.
2	8+ years	Real estate, Interior, Industrial projects	Quantity surveyor & techno commercial associate
3	2+	Infrastructure, Heritage & Building projects	Safety Engineer in Consultancy
4	3+ years	Infrastructure Metro projects	Site engineer under Consultancy
5	5+ years	Real estate and commercial projects	Site engineer under Contractor Party
6	12+ years	National Highway Infrastructure	Safety Engineer under Client party
7	5 years	Infra Metro Projects	Site Engineer under Client party
8	6 Years	Metro projects	Site Engineer under Contractor
9	31+ years	Real Estate, infra-highway projects	General Project Manager
10	12 years	Real Estate and commercial projects	Planning and costing engineer

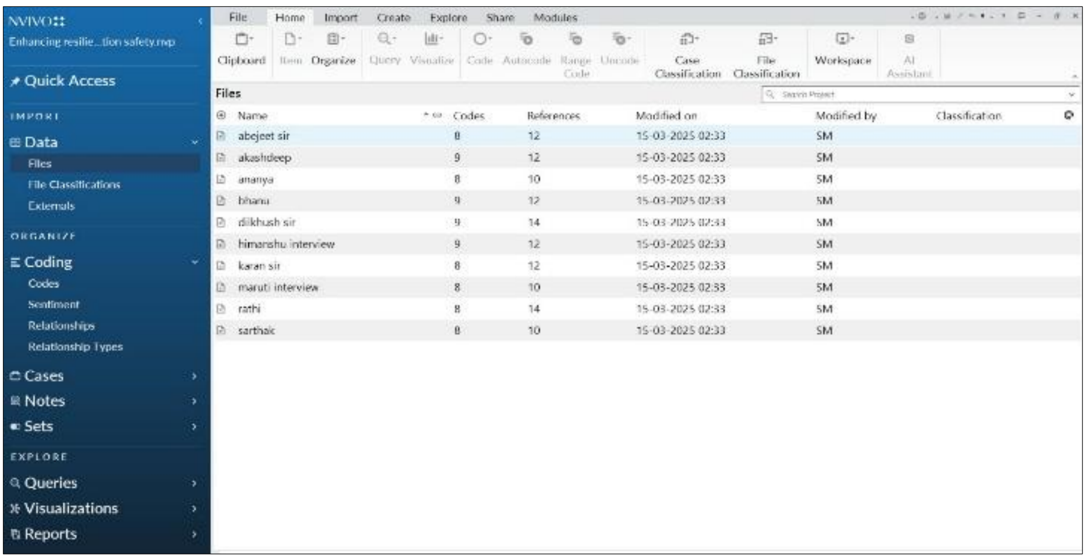
Source: Compiled by authors

DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

Thematic analysis is an agile and inclusive qualitative research method well suited for the identification of patterns and meanings in data. It provides a direct step-by-step procedure that guides researchers in investigating intricate experiences and social phenomena. It is a more precise and systematic way of analysis with the guarantee of coherence to pre-defined themes. It is also valuable in testing or developing already established theories and responding to targeted research questions, enriching the depth and applicability of findings. (Braun, V., & Clarke, V. 2006)

- *Step 3: NVIVO Software:* Reflexive Thematic Analysis (RTA) is a qualitative research approach that identifies, analyses, and interprets patterns (themes) in data. RTA, developed by Braun and Clarke (2006, 2019), is frequently utilized in several areas such as psychology, social sciences, and business research. It is a fluid, iterative technique that recognizes the researcher's active participation in topic development, rather than taking an objective, detached posture. The reflexive thematic analysis process included the following steps in analysing +qualitative data:
- *Familiarization with the data:* In the first step of reflexive thematic analysis, the researcher familiarized with the data by transcribing the interview transcripts.

Figure 7: Importing the Interview Files (Contain the Whole Details of the Interview)



Source: Compiled by authors

- **Generating initial codes:** After familiarizing with the data, the second step of reflexive thematic analysis, is generating initial codes. The initial codes generated in Nvivo 15 are shown in the table below: developed by Braun and Clarke (2006, 2019)

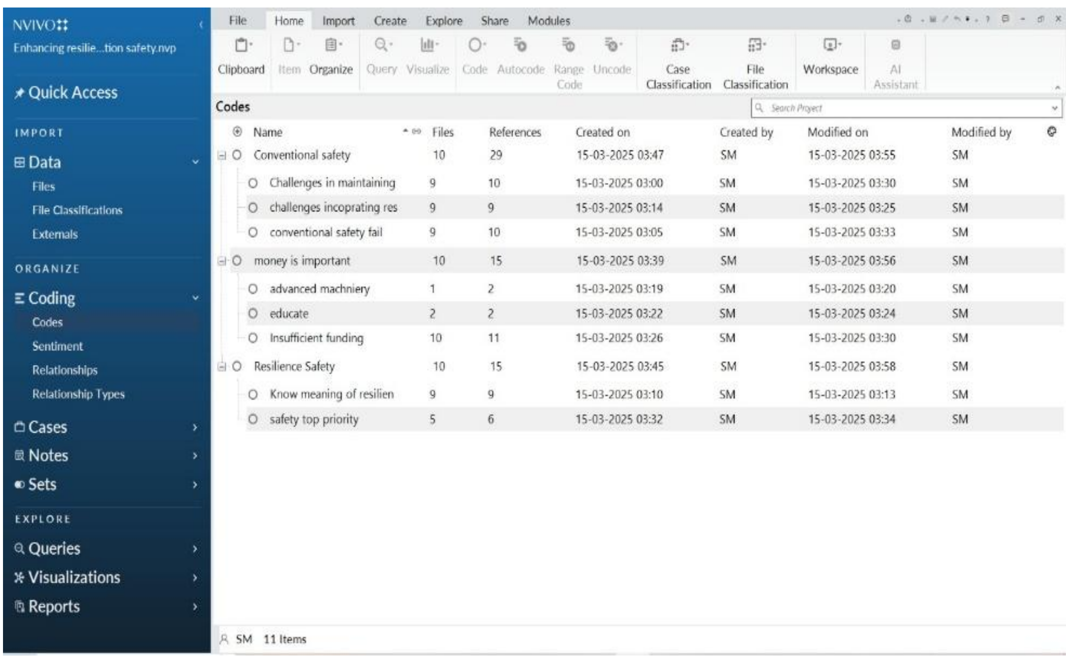
Table 6: Initial Coating

Name	Files	Reference
Challenges in maintaining	9	10
Challenges incorporating resilience	9	9
Conventional safety fail	9	10
Advanced Machinery	1	2
Educate	2	2
Insufficient funding	10	11
Knowing the meaning of resilience	9	10
Safety top priority	5	6

Source: Nvivo software

- **Generating theme**: After generating the initial codes, the review the identify patterns and relationships, grouping related codes into broader themes. These themes were then refined and revised to ensure they effectively addressed the study's research questions. Finally, each theme was given a name that aligned with the research objectives, providing a clear and structured framework for analysis. As shown in (Figure 9).

Figure 8: Generating Theme



Source: Nvivo software

DOI: 10.17492/JPI/NICMAR/2507061 ISBN: 978-93-49790-54-4

Table 7: Exported Code Book (NVIVO)

Conventional safety	This includes the challenges faced in maintaining and incorporating resilience, justification for failure of conventional practices	10	29
Challenges in maintaining safety on-site	Timeline, OSHA rules not followed, unpredictable activities, budget constraints, lack of awareness of safety	9	10
Challenges incorporating resilience in conventional	Mindset, continuous monitoring, limited data from previous projects, absence of contingency funds	9	9
Conventional safety fail	Ignored instructions, Limited funding, Unavailability of resources (machinery)	9	10
Money is important	Money plays an important role	10	15
Advanced Machinery	Modern cranes, feature advanced mechanisms, reduce operational risks	1	2
Educate	Incentives for safety protocols, Toolbox talk, Safety training workshops	2	2
Insufficient funding	Contractor excludes budget for safety, builders struggle to secure optimal pricing, and developers see safety funds as an expense	10	11
Resilience Safety	Proactive approach important in safety	10	15
Know meaning of resilience	Safety resilience is effective ,1/3 of accidents reduced, effective implementation of safety	9	9
Safety top priority	Strict safety practices, advanced safety mechanisms, Modern machinery	5	6

- *Producing the report:* The final stage of the reflexive thematic analysis process involved producing the report. The report represented the different codes and how they came together to form themes that answered the research questions posed in the study. The report also included excerpts representing the statements of different interviewed participants as evidence of different codes and themes. The table below shows the final codes and themes. (Braun and Clarke (2006, 2019)

6.0 Result and Conclusion

6.1 Interpretation of research findings

The data in this study was analyzed using the Relative Importance Index (RII) and a structured questionnaire to determine the essential aspects impacting resilience in construction safety. The study also used statistical tools like SPSS (Statistical Package for the Social Sciences) to process, evaluate, and draw relevant conclusions from the acquired data. The results of both methodologies give a full assessment of critical safety resilience elements and their implications for building projects.

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1. *Relative Importance Index (RII):* Analysis was employed to rank the factors affecting safety resilience based on their significance. The formula used for RII calculation is as follows in (Figure 7) The calculated RII values for each factor were ranked accordingly to determine their relative importance in (Table 4) The most important component was money (financial investment in safety measures), demonstrating that adequate financing is vital to achieving safety resilience. The second most significant component was human engagement (man), which emphasised the need of competent labour, training, and awareness in reducing construction dangers.
2. *Questionnaire Analysis:* A five-step questionnaire study was carried out to confirm the relevance of these elements.
   - *Step 1:* The poll employed a Likert scale (1 to 5) to assess respondents' views on safety resilience variables.
   - *Step 2:* The obtained data was transformed to numerical values and frequency analysis was performed using SPSS.
   - *Step 3:* Each factor's mean score was calculated to determine the amount of effect.
   - *Step 4:* The RII method was used to rank the components based on statistical data.
   - *Step 5:* A final ranking of criteria was calculated, as seen in Table 4.

   The questionnaire analysis results support the RII method's findings, reinforcing the idea that financial investment, human resource management, and effective leadership in safety programs all play an important role in building resilience.
3. *Interview Analysis (Qualitative Insights):* To supplement the quantitative study, structured interviews were undertaken with industry specialists (engineers, contractors, project managers, and safety officials) to acquire qualitative insights regarding construction safety resilience. The key conclusions from the interviews include: The importance of financial investment was emphasized by many experts, highlighting the need for major expenditure on safety measures, including equipment, training, and technology integration (Smith & Johnson, 2020; Patel *et al.*, 2021). Studies indicate that organizations that allocate sufficient financial resources for safety enhancements report fewer workplace incidents (Brown & Lee, 2019).

The need for trained labor was another crucial factor identified, as respondents stated that worker awareness and training programs significantly improve safety resilience. Poorly trained workers were found to be a significant risk factor in construction projects (Gonzalez *et al.*, 2018; Zhang & Kumar, 2022). Research suggests that continuous training and certification programs can enhance compliance with safety protocols and reduce accident rates (Williams & Turner, 2020). Additionally, management responsibility was highlighted as a critical component, with experts stressing that leadership plays a pivotal role in adopting effective safety measures and ensuring regulatory compliance (Davis & Clark, 2017).

Effective leadership fosters a culture of safety, where managers actively enforce protocols and encourage worker participation in safety initiatives (Robinson, 2021). These

DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

findings highlight the importance of a multimodal approach that combines financial resources, human experience, modern technology, and strong leadership to improve construction safety (Anderson *et al.*, 2019; Miller & Chen, 2023).

6.2 Summary of key findings

After analysing RII values, questionnaire responses, and interview insights, the following significant conclusions were reached.

- Financial investment (money) is the most important aspect in improving safety resilience since it dictates the ability to invest in technology, training, and processes.
- Human factors (Man) have an important role in construction safety, notably in skilled labor, danger awareness, and successful collaboration.
- Strong management (leadership) is required to guarantee compliance with safety requirements and the implementation of proactive safety policies.
- Communication (Media) enhances safety resilience by ensuring that safety regulations and danger warnings are delivered in real-time to all stakeholders.
- Machinery (automation and monitoring systems) helps to build resilience by decreasing manual mistakes and enhancing site safety through predictive analytics.

7.0 Recommendations

Integrating safety costs in initial rate analysis: During the initial rate analysis and budgeting phase of building projects, safety factors should be considered, and a separate budget allocation for safety measures should be made. Safety is a critical component of every construction project, and its expenditure should not be considered an accidental or supplementary expense. Instead, a distinct and well-defined budgetary allocation should be made to cover protective equipment, hazard prevention strategies, emergency response plans, and regulatory compliance. Organizations that incorporate safety expenditures from the start of a project can assure greater adherence to safety procedures, reduce cost escalations due to accidents or noncompliance, and improve overall project efficiency.

Shifting mindset and promoting a proactive safety culture: To build a proactive safety culture, construction professionals must first change their perspective and willingness to prioritize safety. Safety should not be considered as a simple statutory obligation, but as a critical operational characteristic that necessitates continual conversations and the execution of preventative actions. Encourage industry professionals, contractors, and workers to actively participate in safety-related discussions, which will result in increased awareness, accountability, and adherence to established safety measures. Organizations may drastically minimize worker accidents and increase construction project resilience by emphasizing the need for preventative measures, frequent safety exercises, and hazard awareness training.

DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*

Improving safety compliance through policy reforms: To increase organizational motivation to apply complete safety measures, incentive-based safety standards should be implemented, comparable to the recognition mechanisms used in sustainable building. Green construction programs such as IGBC (Indian Green construction Council) accreditation reward buildings that follow sustainable principles with benefits such as improved Floor Area Ratio (FAR), brand recognition, and increased market value. A similar strategy may be taken for construction safety compliance, with businesses who strictly follow safety regulations receiving government incentives, policy advantages, or industry recognition. Establishing a structured incentive framework would motivate enterprises to prioritize safety, resulting in a more secure and resilient construction sector while also enhancing compliance with safety requirements.

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DOI: 10.17492/JPI/NICMAR/2507061 *ISBN: 978-93-49790-54-4*