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Factors Influencing the Safety Enhancement and Cost Reduction in Site Layouts of Construction Projects

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Abstract: As the foundation of national development, the construction industry is one of the most hazardous industries in the world, facing safety challenges and high rates of work-related accidents, especially in developing countries such as Iran, where 35% of all industrial accidents are related to construction accidents. In the meantime, construction site layout (CSL) design is vital in improving safety and cost efficiency, but the lack of comprehensive frameworks has limited its effective application. Traditional methods also create inefficiencies and additional costs due to the lack of flexibility in the face of project-specific constraints and unpredictable conditions. Significant research gaps exist, especially in Iran, where socioeconomic and cultural factors affect construction methods. This study aims to identify and analyze the critical factors affecting CSL in developing countries and provides a comprehensive framework that integrates regional constraints with global best practices. The main criteria identified in order of priority are hiring skilled professionals (weight: 0.32), hazardous materials management (weight: 0.25), and using advanced technologies (weight: 0.18). We first conducted a Delphi survey with domain experts using a hybrid approach to identify and refine key factors. Next, we utilized the Decision-Making Trial and Evaluation Laboratory (DEMATEL) and fuzzy logic to examine causal relationships among the factors. Additionally, we prioritized the factors based on their relative importance using the fuzzy analytic network process (FANP). This research provides a practical framework for CSL optimization that helps improve safety and reduce costs in construction projects.

Keywords: construction site layout; safety; cost; FANP-DEMATEL; Iran

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1. Introduction

The construction industry, a cornerstone of national development and prosperity, is paradoxically among the most hazardous industries globally, known for its high rates of workplace accidents and safety challenges [1]. Safety risks continue to dominate the concerns of practitioners and researchers, particularly in developing nations like Iran, where construction site accidents constitute 35% of all industrial incidents [2]. Unlike other industries, construction sites are dispersed, and their dynamic nature amplifies the difficulty of ensuring safety, requiring innovative and tailored strategies [3]. Despite increasing awareness of health, safety, and environmental practices, the construction sector struggles to balance productivity with accident prevention, underscoring the need for strategic planning to mitigate risks and optimize outcomes [4].

Recent research suggests that improving construction site layout can greatly improve worker safety and reduce project costs. The latest study on Construction Site Layout (CSL) emphasizes the use of technologies such as Building Information Modeling (BIM), drones for site monitoring, and artificial intelligence for risk assessment. The study sought to examine the impact of these elements on increasing safety and reducing costs in construction site layout using the latest research in the area.

At the core of effective construction project management lies the Construction Site Layout (CSL), a critical yet challenging process influenced by the complexity and variability of projects. CSL dictates the spatial arrangement of resources and directly impacts safety performance and cost efficiency [5]. While the importance of CSL is widely acknowledged, its implementation is often hampered by inadequate frameworks that fail to integrate safety and cost considerations effectively [6]. Also, traditional ways of planning the layout of a site are not flexible enough to deal with unknown and site-specific limitations, which leads to wasted time and higher project costs [7].

Although advancements in safety protocols and technologies such as Building Information Modeling (BIM) have shown potential, significant research gaps persist. There are not many studies that look at how safety, cost, and CSL optimization are related, especially in Iran, where cultural and socioeconomic factors affect building methods [8]. Existing research often overlooks critical factors like hazardous material management, real-time adjustments to site conditions, and the integration of advanced technologies in layout planning.

This study aims to fill in the gaps by finding and analyzing the key factors that affect CSL practices in developing countries like Iran, where the construction industry faces unique legal and economic problems. It is hard to make safer and more cost-effective construction sites because there are not any comprehensive frameworks that combine regional constraints with global best practices [9]. This causes problems with managing hazardous materials, making sure workers are safe, and figuring out where to put temporary facilities in the best place. To address the gaps, a hybrid approach is used that combines expert input and advanced analytical techniques. We conducted a Delphi survey with experienced experts to identify and refine the critical factors influencing CSL practices. This iterative approach ensured a consensus-based selection of key variables. Decision Modeling and Evaluation Methodology (DEMATEL) was used to look at the cause-and-effect connections between these factors. Fuzzy logic was added to DEMATEL to account for the fact that expert opinions are not always clear. The fuzzy analytical network process (FANP) was also used to rank the factors by how important they were. This gave a complete framework for improving CSL practices and, in the end, gave useful information for making construction projects safer and more cost-effective [10].

2. Literature Review

2.1. Construction Site Layout (CSL)

Nowadays, attention has been increasingly paid to the importance of safety management in preserving and improving the efficiency of organizations [11]. We can predict that almost 90% of workplace accidents result in injuries [12]. Therefore, the application of the appropriate planning methods is of particular importance [13]. Construction sites are no stranger to risk, as they are enumerated among the riskiest workplaces that encompass a wide range of dangerous activities [14]. Numerous safety accidents occur in the construction industry, with their severity varying depending on the country [15]. While it is important to ensure safety on the construction site, it is crucial to account for proper safety management in the early phases of the construction project lifecycle. Construction Site Layout (CSL) is one of the processes that affect the effectiveness of safety management. Specifically, CSL outlines and shows the relationship between the intended site and its peripheral environment, considering the access routes' communications and available equipment [16]. It includes the following: (1) figuring out what temporary tools and instruments are needed for different building tasks and choosing the right ones; (2) describing their sizes, shapes, and dimensions; and (3) putting them in the best spot on the site or around the edges while the work is being conducted [17]. CSL is carried out through three substantial stages: (1) identification of the temporary instruments on the construction site; (2) determination of the dimensions and sizes of the temporary instruments on the construction site; and (3) establishment of the temporary instruments on the site [18]. The classification of temporary instruments into three groups is based on their exploitation period. (1) Long-term temporary instruments that are present during nearly the entire execution of the construction project are their location on the construction site rarely changes, such as the administrative offices; (2) mid-term temporary instruments that are present in the main stages of project execution and whose location on the construction site rarely changes, such as storehouses; and (3) short-term temporary instruments that are used in short-term periods and are relatively rapidly displaced on the construction site, such as operational storage [19].

Many considerations need to be accounted for while setting the layout of the construction site, such as site access, storage area, offices and accommodations, plants, temporary services, health and safety, and fencing. The objective of a site layout is to provide a safe and economical flow of materials and workers [20]. The absence of appropriate CSL imposes extra costs on the construction project. These costs can be categorized into direct and indirect costs. Ref. [21] argued that it is critical and logical to first select the proper site layout of the facilities to effectively manage the site and reduce CSL costs, resulting in better project implementation [22].

CSL is argued to directly and indirectly impact construction workers and their productivity, as well as the effective use of construction materials. A proper CSL plays a critical role in successfully executing the project, and a bad CSL can cause distress and waste resources, leading to unsuccessful execution [23].

Construction projects are characterized by their unique nature—several types, sizes, locations, resources, and activities. This one-off nature of the construction industry has resulted in the inability to outline predetermined and coded categorizations of equipment. Therefore, it can be stated that every project, hence its equipment, is unique. CSL is a continuous process lasting till the end of the project, with the sites constantly optimizing and updating the plans [24].

Proper CSL also decreases pollution and mitigates bioenvironmental risks. For example, air pollution stemming from the frequent displacement of temporary instruments on construction sites can be reduced by implementing a proper site layout that minimizes transport on the site [25], shortens access routes, and destroys natural resources [26].

2.2. Construction Site Layout (CSL) in Other Geographical Regions

One of the critical factors influencing safety in construction site layouts is the safety climate, which encompasses the shared perceptions of safety within a workgroup or organization. Research indicates that a positive safety climate is associated with better safety behaviors among workers, which can lead to reduced accidents and injuries on-site. Ref. [27] emphasizes that the relationship between the safety climate at work and the safety responses of workers is mediated by supervisors; this shows how important leadership is in creating a safety culture [28]. Another researcher discovered that among Latino construction workers, a strong work safety climate is linked to better individual and group safety behaviors. This suggests that cultural factors may also affect safety practices [29]. We cannot overlook the role of leadership styles in influencing safety outcomes within the social dynamics of the safety climate. Grill et al. found that different leadership styles, such as participative and rule-oriented leadership, have varying effects on safety outcomes in construction sites across different cultures [30]. This means that the effectiveness of safety leadership might depend on the situation, which means that safety management needs to be tailored to different places.

The physical and operational characteristics of construction sites also significantly impact safety and cost. Ref. [31] discusses the safety risk factors associated with tower cranes, emphasizing the need for proactive maintenance to ensure safety and efficiency on construction sites. This highlights the importance of equipment management in enhancing safety, which can vary based on the types of machinery and technologies employed in different regions. Another critical aspect is the integration of advanced technologies in site layout planning. The application of Building Information Modeling (BIM) and Geographic Information Systems (GIS) has been shown to improve safety management by facilitating better visualization of site layouts and potential hazards [32].

These technologies enable construction managers to identify risks and optimize site layouts dynamically, which can lead to significant cost savings and enhanced safety performance [33]. The sociodemographic characteristics of construction workers also influence safety perceptions and behaviors. Research by Mosly and Makki indicates that factors such as supervision, risk appraisal, and management commitment to safety significantly affect safety climate perceptions in the construction industry in Saudi Arabia [34]. This suggests that understanding the workforce's composition and their specific needs is essential for effective safety management [35].

2.3. Factors Influencing the Safety Performance of Construction Sites

Safety is an issue that has always drawn the attention of construction practitioners and researchers due to historically poor safety records in the construction industry. In the construction body of knowledge, topics like the introduction of safety standards [36], the investigation of safety standards and regulations and their customization to various countries [37], the evaluation of safety management, and the development of models and frameworks for use on construction projects [38], and the exploration of environmental factors of safety [39] have been among the topics that have been discussed the most conducted extensive review of construction safety research and divided the existing work into three groups. The first group approached safety through the lens of safety management, which included the evaluation of safety and safety planning. The second group targeted the individual and collective properties of factors that impact construction safety, such as workers' attitudes, behaviors, and approaches toward safety. The third group deals with issues related to safety, health, and environmental management [40].

Numerous studies have also researched the analysis of safety costs on construction projects [41]. Some studies have offered models for calculating and analyzing the costs of lost days, insurance, and project completion delays [42]. For instance, safety indices were specified in a study by offering a new model for improving the safety of the construction site. The authors formulated the safety performance index for evaluating CSL based on a multidimensional safety model [43].

Pant et al. proposed a framework for evaluating safety risk based on the theory of safety cost and using the analytic hierarchy process (AHP). The framework offered a method for prioritizing safety risks in construction projects to create a reasonable budget and determine realistic goals [44].

Investigated the perceptions of a group of American contractors on various construction sites' safety practices. Results indicated that safety practices do not negatively impact project schedules when managed well. The majority of contractors surveyed indicated that they experienced project delays attributable to insufficient safety equipment. The author concluded that efficient safety practices are an area in need of improvement [45].

A study argued that full-scale management, including cost management, is crucial during project execution. The authors recognized that investigating the costs related to CSL is truly diverse and complicated. Therefore, they only considered the most significant costs of CSL. The results indicated that "supplying masonry and equipment", "non-specialized workforce", "cost estimation and control", and "environmental and atmospheric conditions" are the most important factors influencing the total costs of CSL [46]. Knowing that the supply of masonry and equipment is directly associated with the market and inflation being a concern, the authors further emphasized that changes in the prices of masonry and equipment have the greatest effect on the costs imposed on construction projects and CSL specifically.

To evaluate safety on construction projects, the various factors influencing safety performance need to be first identified. According to the literature review, the most frequent causes of work-related accidents are unsafe operations and conditions [47]. These findings are aligned with global statistics that show that 88% of accidents happen because of unsafe actions resulting from human behavior, 10% of the accidents occur as a result of unsafe conditions, and the remaining 2% are unpredictable accidents [48]. These numbers indicate the extent to which the creation of a safe workplace influences safety. It is considered that the level of acceptable risk increases with a lower safety level and vice versa [49]. Researchers noted that accidents and occupational diseases could be prevented on the sites through proper planning, which can also lead to improvement in productivity, morale, risk, quality, and environment [50].

Identification and investigation of the environmental factors influencing safety can be conducted in line with reducing and preventing the risks. Identifying factors that influence safety on the site plays a major role in better understanding safety and proposing frameworks to project managers to safely execute projects [51]. Numerous factors contribute to the safety of construction sites. One study categorizes 34 factors into seven substantial groups: historical, economic, psychological, technical, procedural, organizational, and environmental [52].

Previous studies have shown that building operations' safety is usually influenced by many factors, including CSL, safety-directed design, employees' manners, and staff members' education level. The important considerations that can enhance the safety of the building operations in CSL are (1) correct site layout of the temporary buildings for improving the safety performance of the crane and minimization of the accidents that occur when objects fall; (2) controlling dangerous materials and masonry in of the construction sites; and, (3) construction site' safety directly influences the time and also the costs related to construction site according to its involvement in designing plans for the CSL [53].

Finally, twenty-six influential factors on CSL were identified through the literature review. These factors are categorized into three different groups, which are (Table 1) safety, cost, and site layout.

Table 1. Safety, cost, and site layout criteria with description.

Category	Criteria	Description	Score
Safety	Objects' fall	The risk of items, tools, or materials falling from heights, which can pose serious safety hazards to workers and surrounding areas.	[54]
	Masonry displacement	The unintended movement or shifting of masonry components, which can compromise structural integrity and worker safety.	[55]
	Hazardous and flammable materials	Substances that pose risks of fire, explosion, or toxicity if not stored, handled, and disposed of properly.	[56]
	Use of standard equipment	Employing tools and machinery that meet safety regulations and quality standards to minimize risks during construction activities.	[57]
	Workers' safety equipment	Personal protective gear, such as helmets, gloves, goggles, and safety boots, designed to protect workers from potential hazards.	[58]
	construction site insurance	Coverage that safeguards against financial losses due to accidents, injuries, or damages on the construction site.	[59]
	Technical expertise	The specialized knowledge and skills required to plan, execute, and manage construction projects safely and efficiently.	[60]
Cost	Employment of skillful workers and specialized individuals	Hiring experienced and trained personnel who can perform tasks accurately and safely, reducing the risk of errors and accidents.	[61]
	Training and instructing the personnel	Providing comprehensive education and guidelines to workers regarding safety protocols, equipment usage, and emergency procedures.	[62]
	Quality of masonry and equipment related to construction site safety	Ensuring that construction materials and machinery are of high quality and meet safety standards to prevent failures and accidents.	[63]
	Use of novel technologies (like the use of automatic cutting machines)	Integrating advanced tools and equipment to improve efficiency, precision, and safety on construction sites.	[64]
	Up-to-date software	Utilizing modern software for project planning, safety management, and risk assessment to optimize site layouts and workflows	[65]

Table 1. *Cont.*

Category	Criteria	Description	Score
Site layout	Proper dumping of the hazardous masonry	environmentally compliant disposal of construction debris and hazardous materials.	[66]
	Proper CSL	Designing an organized and efficient site layout to minimize risks, enhance workflows, and ensure proper safety measures are in place.	[67]
	Places for providing services to the personnel	Establishing facilities for workers, such as rest areas, dining spaces, and first aid stations, to promote their well-being and productivity.	[68]
	Parking	Allocating designated parking areas to prevent traffic congestion and accidents within the construction site.	[69]
	Use of emergency equipment (like power generators)	Providing backup systems and equipment to ensure continuous operations and safety during emergencies or power outages.	[70]
	Masonry storehouses separated for construction material types	Organizing storage spaces for different materials	[71]
	CSL required for welding, woodworking, and the like	Allocating specific areas with appropriate safety measures for specialized tasks to minimize risks and maintain efficiency.	[72]
	Personnel's settlement place	Providing safe, comfortable, and compliant accommodations for workers to ensure their health, safety, and well-being.	[73]

3. Research Methodology

The present study aims to prioritize the CSL factors that lead to improved safety and reduced costs of construction projects. In this regard, a literature review was first conducted to identify CSL factors that influence the safety of construction sites. Three rounds of the Delphi technique were then conducted to screen the identified CSL factors. Next, to determine the cause-and-effect relationship between the CSL factors, the fuzzy decision-making trial and evaluation laboratory (DEMATEL) technique was employed. Finally, the factors were prioritized based on pairwise comparisons through the application of the fuzzy analytic network process (FANP). Throughout this research, questionnaires were used to gather the required data. The reliability and validity of the questionnaires were evaluated and confirmed using Cronbach's alpha coefficient and face and content validity tests.

In this study, safety, cost, and site layout are compared in detail using FANP and DEMATEL. Section 4.4 presents the methodology of this comparison, focusing on how to interpret and integrate the results of these techniques to provide insight into the interrelationship between these factors. This process evaluates the impact of each factor on safety, cost, and site layout and finally concludes with the optimal strategies for construction site layout.

The Delphi and DEMATEL methodologies are ideal for investigating complex, multi-dimensional aspects such as safety and cost in construction projects. The Delphi approach facilitates systematically collecting and refining expert perspectives, building consensus on crucial topics through iterative feedback. It is very good at managing ambiguity and identifying critical elements for prioritization, making it excellent for research with limited direct data. On the other hand, the DEMATEL technique excels at analyzing causal relationships between factors, assisting in distinguishing influential variables from those that are influenced. DEMATEL facilitates resource allocation and strategy planning by offering a clear framework for visualizing interdependencies and assigning weights to aspects. Together, these strategies provide a strong foundation for understanding and addressing the complexities of construction site layouts (CSL), resulting in better safety and economic efficiency through data-driven decision-making.

The selection of the final 20 factors was conducted using a three-round Delphi survey with 10 experts in construction safety, engineering, and management. Initially, 26 factors were identified from the literature review. In the first round, experts rated each factor on a 9-point Likert scale, and factors with a score below 7 were eliminated, resulting in the elimination of three factors. The second round involved re-evaluation of the remaining 23 factors, resulting in the elimination of three additional factors based on consensus. In the third and final round, the remaining 20 factors were added to the research.

3.1. Survey Questionnaire

The Delphi process in your study consists of a structured questionnaire created using the Analytic Hierarchy Process (AHP) method. This method ensures that criteria are evaluated systematically using pairwise comparisons, making determining their relative relevance easier. The Delphi study is carried out in three rounds, beginning with 26 criteria. In each phase, experts review and revise their responses based on feedback and insights from the larger group, eventually narrowing the criteria to 20. The structured feedback process promotes expert consensus while eliminating less significant criteria, allowing the focus to be on the most influential aspects.

The electronic delivery of surveys makes it easier to access while maintaining confidentiality, which is critical for gaining unbiased expert comments. Using pairwise comparison matrices, the procedure effectively extracts the relative weights of each criterion and assures appropriate prioritizing. This method is especially useful for investigations requiring a strong consensus-building approach.

3.2. Experts' Selection

A total of 10 experts were selected for the Delphi survey, all of whom had significant experience in the construction industry, particularly in safety, engineering, and project management, whose expertise was directly related to the objectives.

The experts consisted of eight men (80 percent) and two women (20 percent), with three experts between 30 and 40 years of age, five between 40 and 50 years of age, and two over 50 years of age.

Six had PhDs in civil engineering, construction management, and safety, and four had master's degrees in related fields. Each expert had at least 10 years of professional experience in construction site management, safety regulations, and cost optimization. Areas of expertise included health and safety (4 experts), construction site planning and management (3 experts), innovative construction technologies (2 experts), and cost strategies (1 expert).

The Delphi method is a well-known qualitative research strategy that uses an iterative process of obtaining expert viewpoints to reach a consensus on a certain topic. While the Delphi process's modest sample size of n = 10 may be regarded as a restriction, it is worth noting that this is consistent with standard Delphi study recommendations. A panel of 10 to 15 experts is generally sufficient for qualitative research, particularly in Delphi surveys, where the purpose is to synthesize expert knowledge rather than statistical representativeness [74].

While the Delphi process's tiny sample size of n = 10 may appear to be a drawback, it aligns with recognized Delphi methodology norms. The emphasis on expert consensus, the iterative nature of the approach, and the quality of the expert panel all add to the robustness of the findings. Therefore, this sample size is appropriate for the study's objectives.

3.3. Delphi Survey Technique

In the first step of this study, three rounds of the Delphi technique were conducted to consolidate the CSL factors identified through the literature review. A 9-point Likert scale was used to screen and evaluate each factor. When using the Delphi technique, it has been recommended that the Delphi panel be heterogeneous, consisting of individuals with diverse expertise [75]. Research suggests that six to 12 members are ideal when using the Delphi technique, while some scholars indicate that five to ten individuals suffice if the panel includes experts with different areas of expertise [76].

For this research, 10 subject matter experts in safety, engineering, and management in the Iranian construction industry were identified and contacted to participate in the research.

3.4. Decision-Making Trial and Evaluation Laboratory (DEMATEL) Technique

The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique is a commonly used method to obtain a cause–effect diagram of interdependent factors. Fuzzy linguistic modeling is also used to describe and represent the relationship between the factors. The fuzzy DEMATEL technique was employed to analyze the interrelationships among the various CSL factors identified in Section 4.2. Specifically, the analysis aimed at understanding the cause-and-effect relationships among these factors within the categories of safety, cost, and site layout. The following sections outline the key steps involved in the Fuzzy DEMATEL approach.

Forming the direct relation matrix: Once the list of CSL factors had been refined, a matrix was constructed to investigate the mutual effects (direction and intensity) between the various CSL factors that impact construction projects' safety and costs. A questionnaire was developed to distribute between the same group of experts during the Delphi survey stage. The questionnaire was prepared based on the fuzzy spectrum outlined in Table 2, recommended by [77].

Table 2. Fuzzy spectrum used for the DEMATEL survey questionnaire.

Lingual Variable	Quantitative Equivalent	Fuzzy Quantitative Equivalent		
		l	m	u
Without effect	0	0.0	0.1	0.3
Low effect	1	0.1	0.3	0.5
Intermediate effect	2	0.3	0.5	0.7
High effect	3	0.5	0.7	0.9
Very high effect	4	0.7	0.9	1.0

The product of this stage is denoted by A, and its factors are designated by a_{ij}, with every member of a being the degree of the effect factor i exerts on factor j (Equation (1)). Experts' feedback on pairwise comparisons was recorded.

$$A = [a_{ij}] = \frac{1}{H}\sum_{K=1}^{H} X, \tag{1}$$

Normalizing the direct relation matrix: Once data were collected from the previous step, Equation (2) was used to transform the direct relation matrix of A into the normalized direct relation matrix as follows:

$$D = m \times A, \tag{2}$$

$$m = \min\left[\frac{1}{max_i\sum_{j=1}^{n} a_{ij}}, \frac{1}{max_i\sum_{i=1}^{n} a_{ij}}\right], \; i,j \in \{1,2, \ldots, n\}$$

Calculation of the total relation matrix: When matrix D, i.e., the normalized direct relationship matrix, was calculated, matrix T of the total relationships was computed using Equation (3) [78].

$$T = \lim\left(D + D^2 + \ldots + D^m\right) = \sum_{m\to\infty}^{\infty} D^i,$$

$$the \sum_{m\to\infty}^{\infty} D^i = D^1 + D^1 + \ldots + D^m = D\left(1 + D^1 + D^2 + \ldots + D^{m-1}\right)$$
$$= D(1-D)^{-1}(1-D)^m$$
$$T = D(1-D)^{-1}, \tag{3}$$

Creation of the causal diagram: To build the cause-and-effect diagram, the sums of the elements in each row and each column of matrix T are termed vectors r and c (Equations (4) and (5)), respectively. The horizontal axis of the diagram labeled "importance axis" indicates the level of importance for each factor, which is calculated by summing vectors r and c ($c + r$). The vertical axis of the diagram labeled "dependence axis" is calculated by subtracting vectors r and c ($c - r$). The factors are divided into two groups of causes and effects according to their location on the dependence axis: when "$c - r$" is positive, the factor belongs to the group of causes; and when "$c - r$" is negative, the factor belongs to the group of effects. The causal diagram can thus be obtained by delineating spots with ($c + r$, $c - r$) coordinates [79].

$$r = [r_i]_{n\times 1} = [\sum_{j=1}^{n} T_{ij}]_{n\times 1} \tag{4}$$

$$c = [c_i]_{n\times 1} = [\sum_{i=1}^{n} T_{ij}]_{1\times n} \quad (5)$$

Creation of network relationship map: It is possible to create a network relationship map (NRM) between several factors. To calculate the network relationships, a threshold value a is calculated using the average values of matrix T (Equation (6)). This can help eliminate partial relationships (all relationships with values below the threshold value) from the causation relation, while significant relationships (relationships whose values in the matrix are higher than the threshold value) are shown [80].

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} Ta_{ij}}{N} \quad (6)$$

3.5. Fuzzy Analytic Network Process (FANP) Technique

Multi-Criteria Decision Making (MCDM) can be used to find a balanced solution because CSL has different aspects that affect safety, cost, environment, and management [81]. MCDM models are generally categorized into Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM) [82]. MADM techniques are used to select the most suitable options from among the available ones by evaluating and prioritizing them based on specific indicators [83].

The Fuzzy Analytic Network Process (FANP), as an MADM method, was employed to prioritize the identified CSL factors using pairwise comparisons. This method first creates a network, where different groups within it represent objectives, criteria, and options based on the requirements of the problem. The direct vectors connecting these nodes indicate the direction and presence of interactions between them. In the modeling phase, the objectives, indicators, and decision options are determined. Pairwise comparisons are performed to determine the weight of criteria and factors, following a hierarchical approach that uses a relative preference scale from one to nine [84]. Table 3 illustrates this scale [85].

Table 3. Fuzzy spectrum used for the DEMATEL survey questionnaire.

Value	Priorities	Explanations
1	Identical preference	Factors i and j possess equal importance, or they are not preferred to one another
3	A little preferred	Factor i is a little more important than factor j
5	A lot preferred	Factor i is more important than factor j
7	Very much preferred	Factor i is a lot more preferred to factor j
9	Completely preferred	Factor i is absolutely more important than factor j and they are incomparable in terms of importance
2, 4, 6 and 8	Intermediate values	Respondents designate values between the six preferred values; for example, 8 denotes a preference higher than 7 but lower than 9 for factor i

Before conducting a more in-depth examination of the CSL sub-elements within each category, the FANP analysis method is designed to prioritize variables at the category level, such as safety, cost, and site layout. In this step, pairwise comparisons and fuzzy measures are used to fine-tune the factor priority. This technique not only allows for determining the overall priority of each category but also provides detailed insights into how various CSL elements influence each other.

In the next stage, the internal weights of the indices and sub-indices specified during the modeling stage are calculated. In this stage, the internal and feedback affinities and interdependencies matter. The important point in pairwise judgements and comparisons is controlling their consistency. This critical issue is of particular significance in macro-level decision-making because individuals may act paradoxically in their judgements. In a general state, inconsistency below 0.1 is acceptable in the pairwise comparison matrices. The consistency ratio (CR) of every matrix is calculated with CI being the consistency index of the pairwise comparison matrix therein, and it is estimated using the highest value of the eigenvector (λ_{max}) and its dimension (n). Inconsistency rate is computed and offered by software for every pairwise comparison matrix, and the related judgement is inconsistent if it exceeds 0.1, and revisions should be made in the judgement method [86].

One way of doing the calculations in the FANP method is putting the weights obtained from the pairwise comparisons in a matrix termed supermatrix, which is a matrix of the relations between the network components, and it is obtained from the eigenvectors of these relations. The supermatrix can be divided into different blocks, each of which indicates the weight obtained from the pairwise comparison of the lines (for instance, indices) according to the columns (saying, options, or indices). After the formation of the initial supermatrix, which is called an unbalanced supermatrix, the columns of this matrix are normalized, if necessary, to obtain the weighted supermatrix. Using the probability matrices and Markov chains, Saaty proves that the final weights of the elements can be obtained from the relation [87].

$$W = \lim_{k \to \infty} w^{2k+1} \pi r^2 \tag{7}$$

In Equation (7), k is an odd number. The final matrix, or the definite matrix, is acquired by solving the above-presented relation. All the amounts in each line of this matrix have the same value and amount to the weight of the creation mentioned in the same line.

4. Results and Discussion

4.1. Inviting Delphi Panel for Identifying the Major Factors

After extracting twenty-six factors that impact CSL from the literature, each member of the 10 Delphi panelists was provided with a questionnaire containing the 26 CSL factors. The factors were grouped into three categories: safety factors, cost factors, and site layout factors, resulting in three factors (safety, cost, and site layout). The experts then reviewed each of the twenty-six factors and were asked to rate the factors on a scale from 1 to 9. Factors with a score below 7 were eliminated. Three rounds of the Delphi technique were carried out. After the first round, the factor “protection and scaffold” from the safety category, the factor “employment of Health, Safety, and Environment (HSE) individuals or personnel specialized in safety” from the cost category, and the factor “scaffold-construction site” from the site layout category were eliminated. For the second round, the 23 factors kept after round one were discussed again with the experts. After the second round, three other factors were omitted, namely, the factor “the skillfulness in using devices” from the safety category and the factors “performing calculations on guarding and supporting structures and scaffolds” and “contractor rate” from the cost category were eliminated. A third round of the Delphi technique was conducted to refine the factors further. The twenty factors resulting from the second round were provided to the experts, who unanimously agreed that no other factors needed to be removed. Thus, the third round was the last round, and 20 factors were included in this study. Kendall’s agreement coefficient was calculated for each round to assess coordination and agreement among the experts. The Kendall’s agreement coefficient values are reported in Table 3, and the significance values in the right most column indicate that there is agreement. The 20 factors resulting from the Delphi technique are outlined in Table 4.

Figure 1 illustrates a composite of the relationship between the number of items examined every round (bars) and the Kendall concordance coefficient (line). This demonstrates how reducing the number of items every round increases expert agreement, as evidenced by an increase in the concordance coefficient. Table 5 shows the criteria based on abbreviations.

Table 4. Test results of Kendall's coefficient of concordance.

	Number of Items	Number of Experts	Kendall's Concordance Coefficient	Degree of Freedom	Significance Value
Round one	26	10	0.311	25	0.000
Round two	23	10	0.394	22	0.000
Round three	20	10	0.462	19	0.000

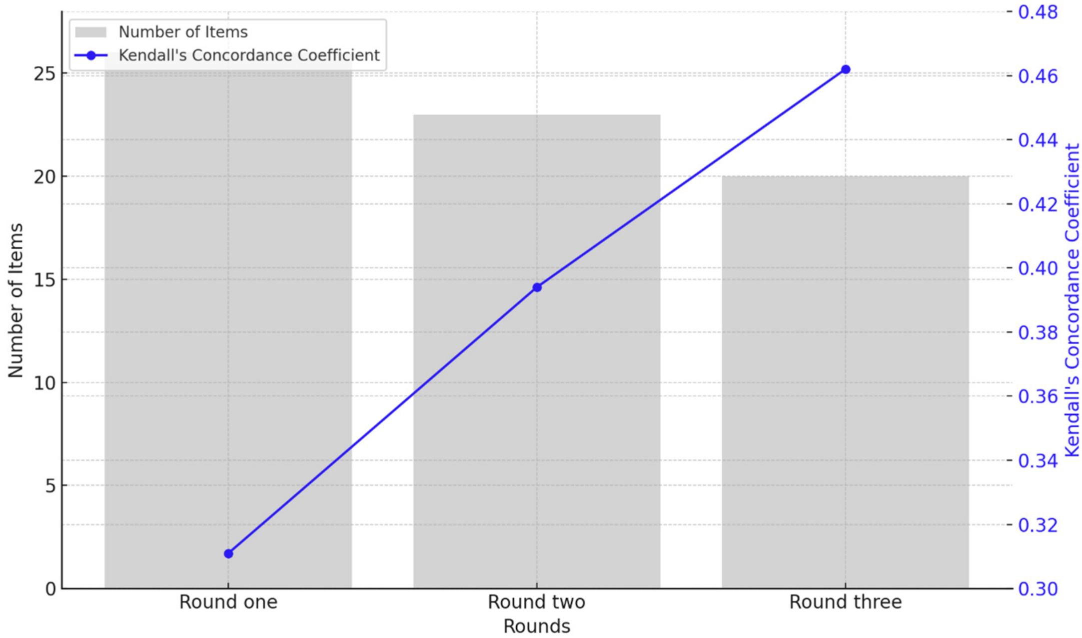

Figure 1. Number of items and Kendall concordance coefficient.

Table 5. Factors influencing CSL.

Category	Factor	Code
Safety (C1)	Objects' fall	S11
	Masonry displacement	S12
	Hazardous and flammable materials	S13
	Use of standard equipment	S14
	Workers' safety equipment	S15
	construction site insurance	S16
	Technical expertise	S17
Cost (C2)	Employment of skillful workers and specialized individuals	S21
	Training and instructing the personnel	S22
	Quality of masonry and equipment related to construction site safety	S23
	Use of novel technologies (like the use of automatic cutting machines)	S24
	Up-to-date software	S25
Site layout (C3)	Proper dumping of hazardous masonry	S31
	Proper CSL	S32
	Places for providing services to the personnel	S33
	Parking	S34
	Use of emergency equipment (like power generators)	S35
	Masonry storehouses separated for construction material types	S36
	CSL required for welding, woodworking, and the like	S37
	Personnel's settlement place	S38

4.2. DEMATEL Analysis for Investigating the Cause-and-Effect Relationships Between the Factors

Calculating the direct relationship matrix (M): Since the data for the DEMATEL technique were collected from ten experts, a simple arithmetic mean was used to form the direct relationships matrix denoted as M. Expert's feedback was collected using the fuzzy spectrum identified in Table 1. The values of the direct relationship matrix M are presented in Table 6.

Table 6. Fuzzified direct relationships matrix (M).

	Safety			Cost			Site Layout			Row Summation
Safety	0.300	0.100	0.000	0.520	0.320	0.170	0.560	0.360	0.210	1.380
Cost	0.660	0.480	0.320	0.300	0.100	0.000	0.600	0.400	0.250	1.560
Site layout	0.630	0.440	0.270	0.560	0.360	0.180	0.300	0.100	0.000	1.490

Figure 2 shows a dual depiction of the data to help understand the factor interactions. The bar graph displays the row summation and illustrates the total influence of each category (safety, cost, and site layout) based on their interactions with other variables. Simultaneously, the line graph displays the matrix's diagonal elements, demonstrating each factor's self-relationship or inherent relevance.

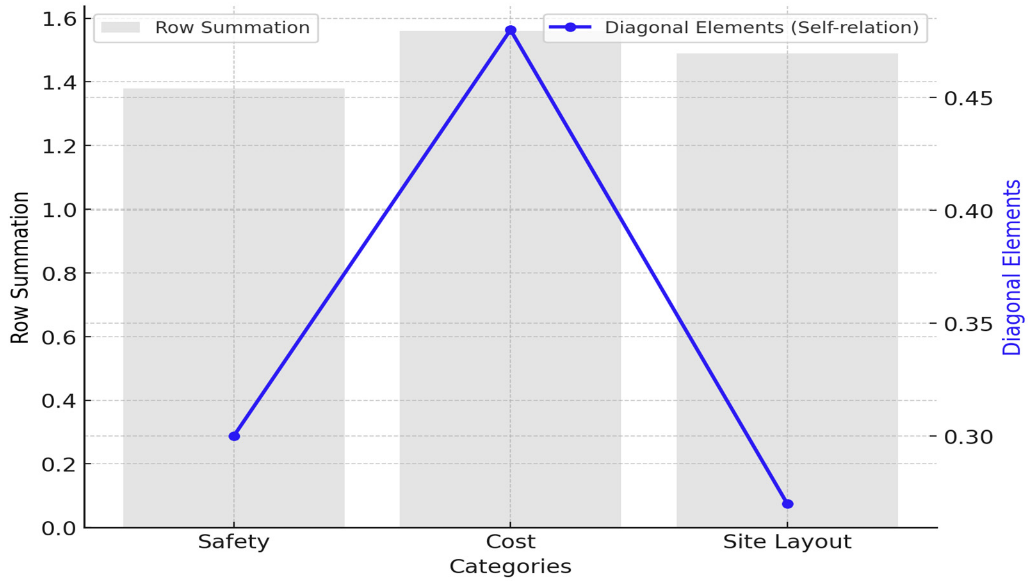

Figure 2. The overall effect and self-correlation of factors.

Finalizing the Total Relationship Matrix: To defuzzify the direct relationship matrix, the line mean of the fuzzy values of each factor was calculated to obtain the finalized values of the direct relationship matrix. Values are presented in Table 7.

Table 7. Total relationship matrix (T) for the finalized factors.

T	Safety	Cost	Site Layout
Safety	1.991	1.877	1.985
Cost	2.401	1.956	2.210
Site layout	2.293	2.009	1.975
Column summation	6.684	5.842	6.170
Threshold value			2.077

Figure 3 effectively combines two key aspects of the data: the column sum (represented by the bars) and the threshold value (represented as a dashed line). The bar graph shows the total impact of each category (safety, cost, site layout) based on the T values collected, allowing for a direct comparison of their overall impact. The threshold line provides a reference point and indicates whether the values in each category exceed or fall below the established criterion (threshold value = 2.077).

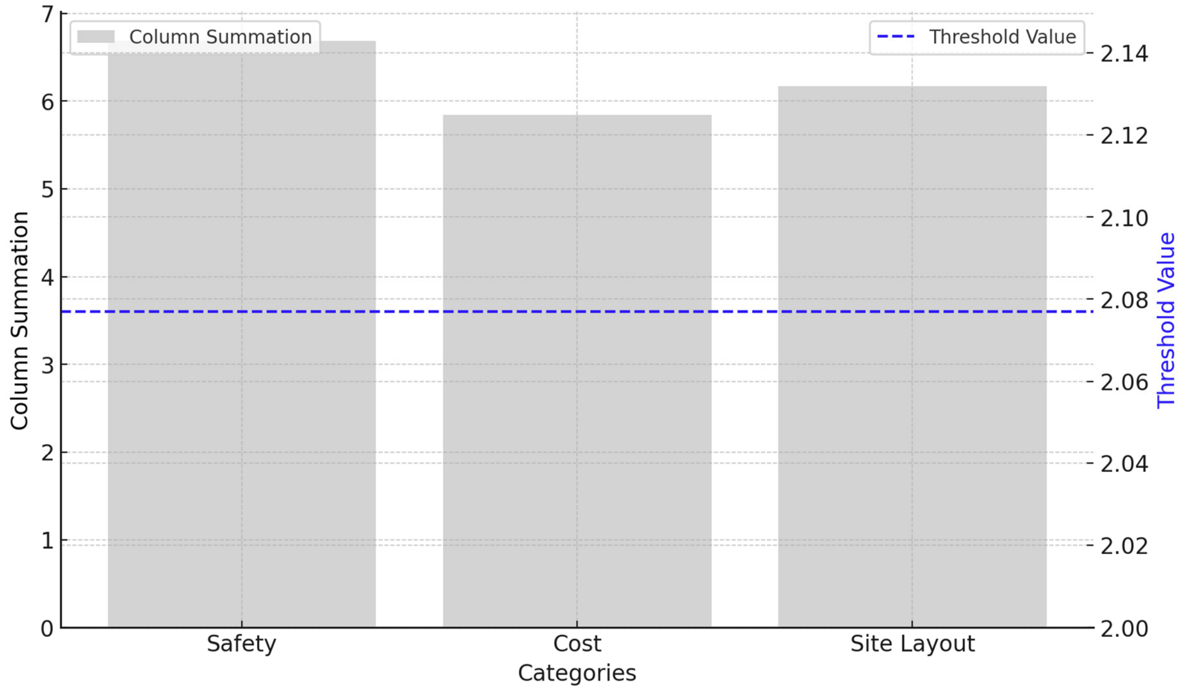

Figure 3. Comparison of column summation and threshold value.

Exhibiting the map of the network relations: To determine the network's relations map (NRM), the accountable threshold value should be computed. The trivial relations can be disregarded in this method, and the notable relation networks can be drawn. Relations with values larger than the threshold amount in Matrix T will be only displayed on NRM. The threshold value of the relations is calculated by obtaining the mean value of matrix T, which was found to be equal to 2.077. After the threshold intensity was determined, all the values of Matrix T that are below the threshold are zeroed, indicating that the causal relation will not be considered. Table 7 displays the results revealing the pattern of the significant relationships between the primary factors. The results reported in Table 8 delve into the pattern of the causal relationship between the three factors. The values in column (D) indicate the extent to which a factor influences the other factors in the system. Thus, the factor "cost" has the highest influence, with a value of 6.567. The values in column (R) are reflective of the extent to which a factor is influenced by the other factors of the system. Based on the results, the factor "safety" has been intensively influenced. The interaction between the factors is the function of columns (D) and (R). The higher the factorial (D+R) amount, the higher the interaction between one factor and the other factors. The difference between D and R (D-R) shows the power of the influence of each factor. If the value of (D-R) is positive, then the variable is used as causal. If the difference has a negative value, the variable is then described as an effect. Based on the results reported in Figure 4, "safety" is an effect variable. The variables "cost" and "site layout" are causal variables.

Table 8. The pattern of the significant relationships between the studied factors.

	Safety	Cost	Site Layout
Safety	*	*	*
Cost	2.401	*	2.210
Site layout	2.293	*	*

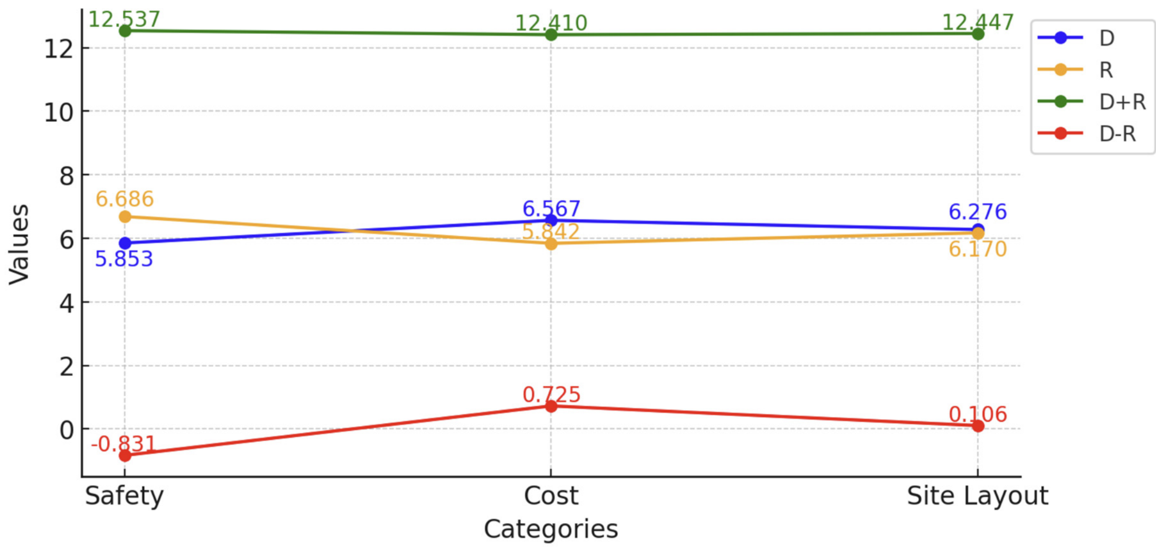

Figure 4. Trend analysis of D, R, D+R, and D-R across categories.

Table 8 represents the relationship between three categories: safety, cost, and site layout, with some values missing (denoted as *). The non-missing values indicate the strength or magnitude of the relationship between specific categories. For example, the value 2.401 shows the relationship between cost and safety, and 2.210 represents the interaction from cost to site layout. The diagonal and certain off-diagonal cells are missing, implying no recorded or meaningful interaction in those cases.

In Figure 4, the advanced multi-line plot shows D, R, D+R, and D-R values across categories (safety, cost, site layout) using distinct, visually appealing colors. Each line represents a unique dataset, allowing for clear comparisons and trend analysis. Gridlines and fixed markers improve readability and make spotting changes and relationships between data points easier.

4.3. Determination of the Factors' Priority Based on the Project Goals Using FANP Technique

The model's network pattern has been designed using ANP in the Super Decisions software V3.2, where factors were compared based on the goal through a structured network analysis. Initially, the perspectives of ten experts were gathered using Saaty's 9-point scale of relative preference. The geometrical means were then employed to aggregate expert opinions in the fuzzy ANP approach.

To further explore the relationships among these factors, the DEMATEL analysis was conducted, focusing on the interactions between the categories of safety, cost, and site layout, which encompass the 20 CSL factors identified earlier. This analysis provides valuable insights into how these categories influence each other. For clarity and better interpretation, individual factors were aggregated into their respective categories, facilitating a more structured presentation of the results. Table 9 illustrates the pairwise comparison matrix of these factors.

Figure 5 shows the trend of the non-fuzzy, normalized weights across categories: safety, cost, and site layout. Each line shows how the corresponding values change across categories, with clear markers to identify data points accurately. The graph shows higher values for cost compared to safety and site layout, providing insight into the relative importance of these factors.

Table 9. Pairwise comparison matrix for factors.

	Safety	Cost	Site Layout	Defuzzy	Normal Weights
Safety	1.000	1.987	0.449	0.364	0.351
	1.000	1.539	0.341		
	1.000	1.170	0.282		
Cost	0.855	1.000	0.286	0.548	0.528
	0.650	1.000	0.230		
	0.503	1.000	0.196		
Site layout	3.542	5.115	1.000	0.126	0.121
	2.930	3.349	1.000		
	2.229	3.495	1.000		

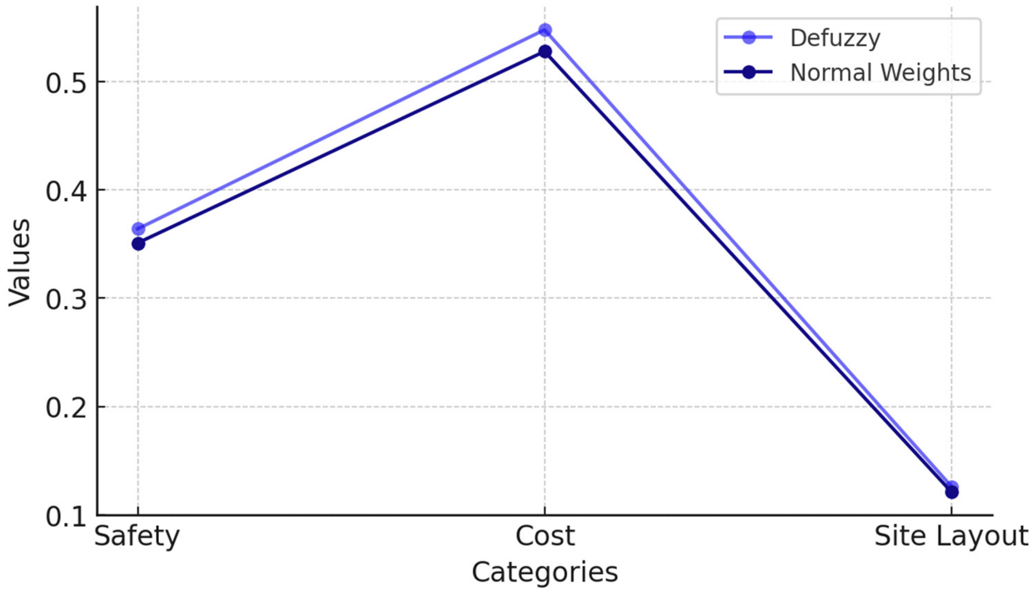

Figure 5. Analysis of defuzzy and normal weights across categories.

Based on the results, the factor "cost", with a normal weight of 0.528, was found to have the highest priority. The factor "safety", with a normal weight of 0.351, was found to have the second highest priority. Finally, the factor "site layout", with a normal weight of 0.121, came in third in terms of priority. To validate the pairwise comparisons, the inconsistency rate of the pairwise comparisons was calculated and had a value of 0.0001, which is smaller than 0.1, indicating that the comparisons are reliable.

For the second step in ANP, the factors corresponding to each factor were evaluated using pairwise comparisons. At first, the calculations performed to fuzzify the means of the experts' perspective in line with the determination of the factors' priorities were offered. After forming the matrix for the obtained pairwise comparisons, the fuzzy sum of each line is calculated. The inconsistency rate of the comparisons performed for the factors "safety", "cost", and "site layout" are equal to 0.051, 0.080, and 0.050, which are lower than 0.1, indicating that the comparisons are reliable.

The unbalanced (initial) supermatrix was obtained considering the calculations. Next, normalization was used to convert the unbalanced supermatrix into a balanced (normal) supermatrix. In the balanced supermatrix, the sum of the elements in all columns equals unity. The next step is the calculation of the limit supermatrix, which is acquired by raising all the elements in the balanced supermatrix to a given power. This action is frequently reiterated, such that all the elements of the supermatrix become similar. In this state, all the supermatrix's entries will become equal to zero, and only the entries related to factors will take values that are repeated in all the lines associated with them. The final priority weights of the factors are obtained and ranked, as shown in Table 10.

Table 10. Final weights of the factors.

Code	Factors	Normal Weight	Rank
S_{11}	Objects' fall	0.040	16
S_{12}	Masonry displacement	0.063	2
S_{13}	Hazardous and flammable materials	0.046	11
S_{14}	Use of standard equipment	0.042	13
S_{15}	Workers' safety equipment	0.044	12
S_{16}	construction site insurance	0.048	9
S_{17}	Technical expertise	0.051	8
S_{21}	Employment of skillful workers and specialized individuals	0.123	1
S_{22}	Training and instructing the personnel	0.056	4
S_{23}	Quality of masonry and equipment related to construction site safety	0.040	14
S_{24}	Use of novel technologies (like the use of automatic cutting machines)	0.055	6
S_{25}	Up-to-date software	0.059	3
S_{31}	Proper dumping of hazardous masonry	0.035	18
S_{32}	Proper CSL	0.040	15
S_{33}	Places for providing services to the personnel	0.056	5
S_{34}	Parking	0.046	10
S_{35}	Use of emergency equipment (like power generators)	0.037	17
S_{36}	Masonry storehouses separated for construction material types	0.033	20
S_{37}	CSL required for welding, woodworking, and the like	0.034	19
S_{38}	Personnel's settlement place	0.053	7

Figure 6 shows the variations in normalized weights across different factors, highlighting the relative importance of each factor. Each point on the line corresponds to a specific factor, the height of which represents its normalized weight. This visualization effectively identifies the most important factors, such as "Employment of skilled workers and specialists", which has the highest weight, and less important factors, such as "Masonry warehouses separate from the type of building materials".

Based on the above-performed calculations, considering the limit supermatrix and the output of Super Decision Software, the determination of the factors' final priority becomes feasible; thus, according to the calculations, the final weight of each of the model's indices was computed using the FANP technique. Based on the outputs of the FANP technique, it can be observed that when the internal relationships between the study variables are considered, the significance and rank of the studied indices are changed. The results indicate that factor S_{21} employment of the specialized and versatile individuals has the highest priority with a weight of 0.123. Factor S_{12} masonry dislocation is ranked second with a weight of 0.063. Factor S_{25} (i.e., up-to-date software) is ranked third significant with a weight of 0.059.

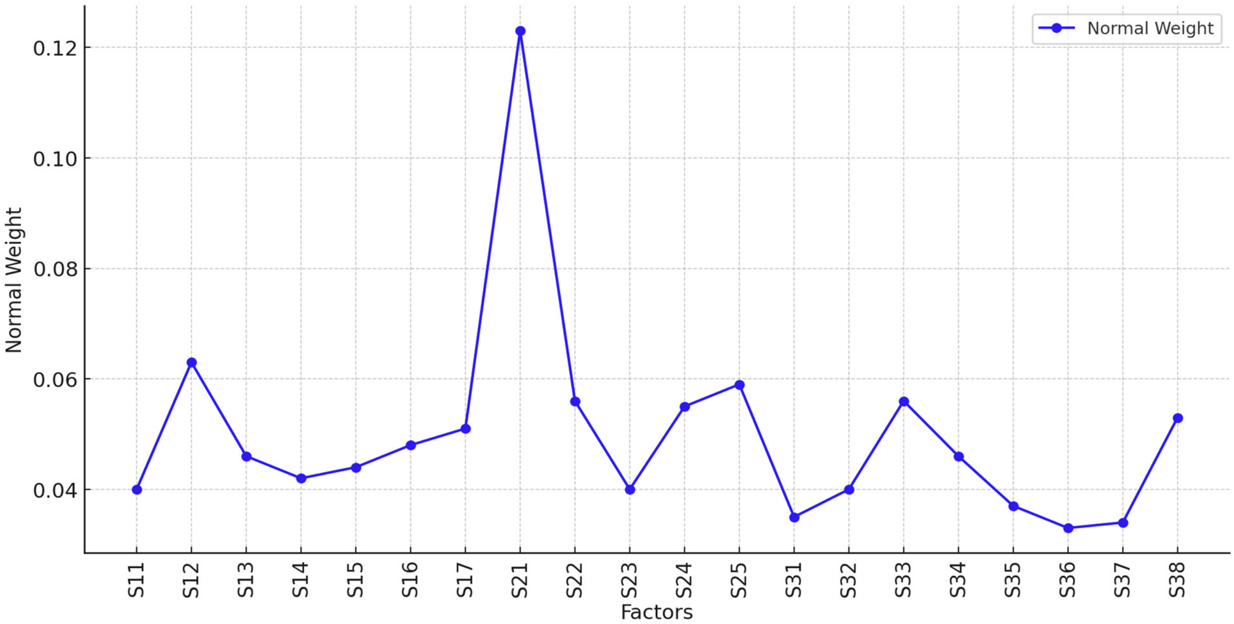

Figure 6. Normal weight across factors.

4.4. Comparing the Site Layout Prioritization with Respect to Cost and Safety

Knowing that the present study aims to evaluate the effect of site layout on the safety and cost of construction projects, the "site layout" is assessed in comparison to safety and cost. The means of the defuzzified site layout factors are reported in Table 11. The sum of the means, which is equal to 1 divided by the number of site layout factors (which is eight), equals 0.125, which is then used as a threshold for comparison. Now, factors of cost and safety that are close and superior must be identified. Table 11 shows the final fuzzy index.

Table 11. Mean scores of site layout factors.

Site Layout	Mean Scores
Proper dumping of hazardous masonry	0.105
Proper CSL	0.120
Places for providing services to the personnel	0.167
Parking	0.138
Use of emergency equipment (like power generators)	0.110
Masonry storehouses separated for construction material types	0.099
CSL required for welding, woodworking, and the like	0.103
Personnel's settlement place	0.158

Figure 7 shows the change in the mean scores for different site layout factors and highlights their relative importance. Each dot represents a specific factor, the height of which indicates its score. Factors such as "personnel service location" and "personnel location" show higher scores, indicating greater importance in site layout considerations. Meanwhile, factors such as "separate masonry warehouses for different types of building materials" have lower scores, indicating relatively less importance.

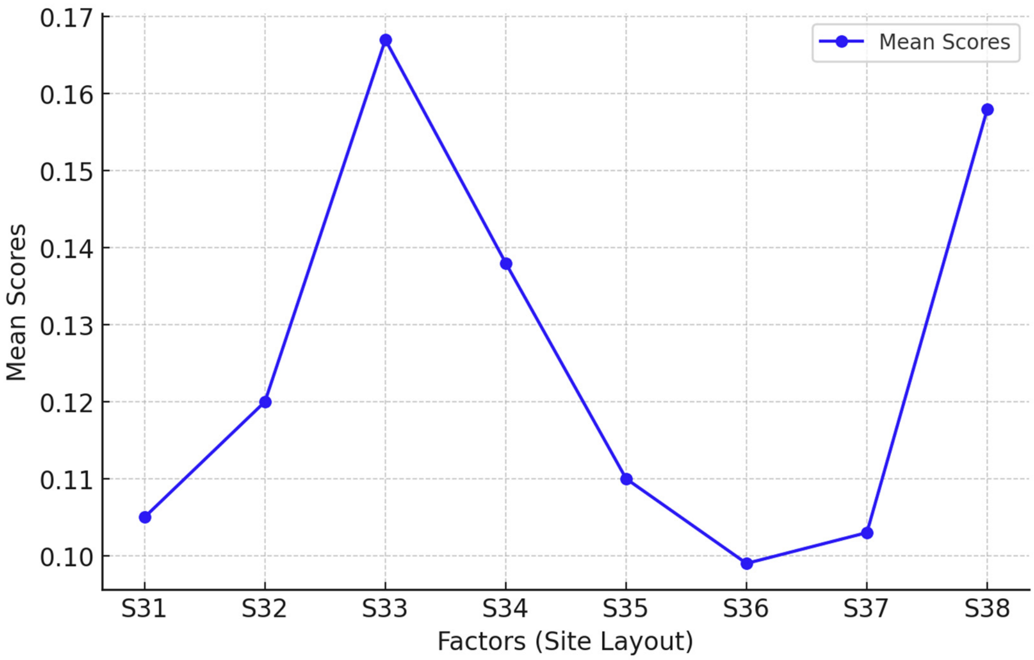

Figure 7. Scores for site layout factors.

Table 12 shows the safety indexes related to various factors such as objects' fall, masonry displacement, hazardous materials, and the use of standard equipment.

Table 12. Final fuzzy indexes of safety in contrast to site layout.

The Final Fuzzy Index of Safety in Contrast to Site Layout	Fuzzy Index
Objects' fall	0.120
Masonry displacement	0.188
Hazardous and flammable materials	0.138
Use of standard equipment	0.126
construction site's safety equipment	0.131
construction site insurance	0.145
Technical expertise	0.153

Figure 8 shows the fuzzy index of safety factors compared to the site layout. The line graph shows the variation in the values of the fuzzy index between factors such as "masonry displacement", which has the highest importance with a value of 0.188, and "falling objects", which has a lower value of 0.120. This graph effectively highlights the relative importance of each of the safety factors and enables a clear understanding of their impact on the safety and layout of the site.

Table 13 shows that the final fuzzy cost index is affected by various factors. The most important effect is from the employment of skilled workers and experts (0.370), which highlights the important role of skilled labor in cost management. Up-to-date software (0.176) and personnel training and education (0.168) also play an important role in cost optimization. The use of new technologies, such as automatic cutting machines (0.165), and the quality of stonework and construction site safety equipment (0.121) are also influential factors.

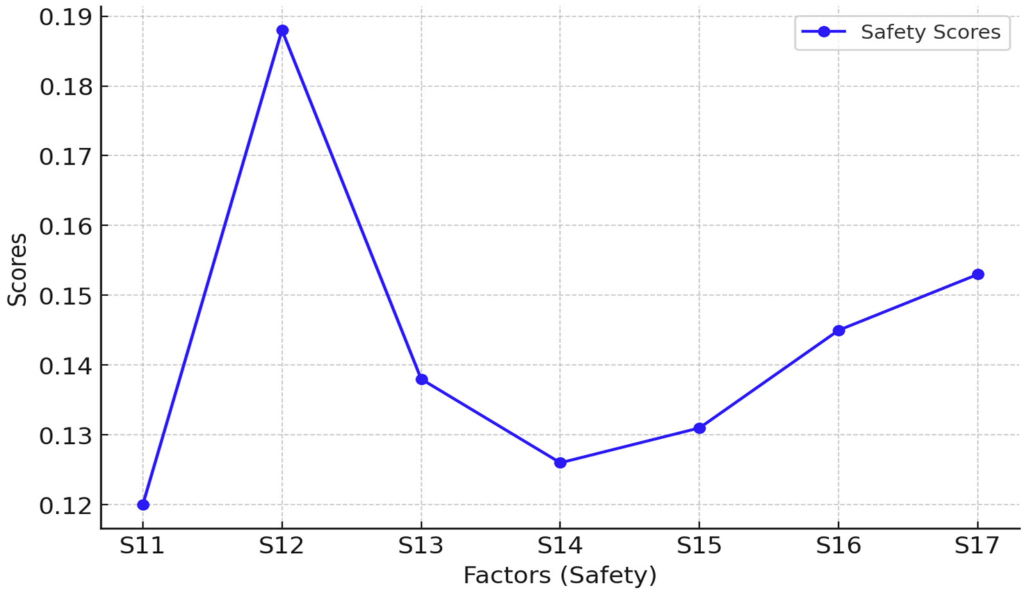

Figure 8. Final fuzzy indexes of safety.

Table 13. Final fuzzy indexes of cost.

The Final Fuzzy Index of Cost in Contrast to Site Layout	Fuzzy Index
Employment of skillful workers and specialized individuals	0.370
Training and instructing the personnel	0.168
Quality of masonry and equipment related to construction site safety	0.121
Use of novel technologies (like the use of automatic cutting machines)	0.165
Up-to-date software	0.176

Figure 9 shows the fuzzy index of various cost factors against site design. The green line highlights the differences between the factors, with “employment of skilled workers and specialists” having the highest index at 0.370, indicating its significant impact. Other factors, such as “quality of masonry and equipment related to construction site safety”, show lower fuzzy index values, reflecting their relatively smaller impact.

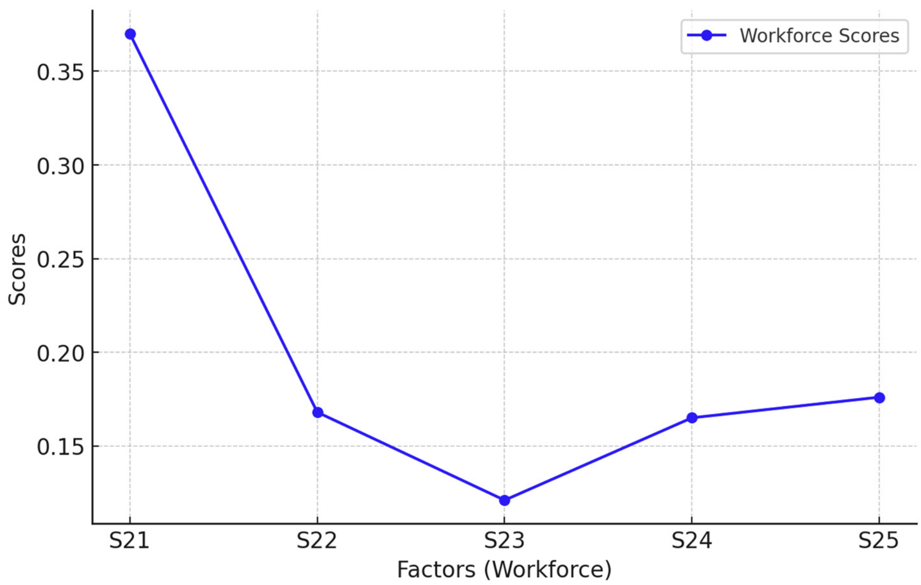

Figure 9. The final fuzzy index of cost.

Several studies have examined the factors influencing construction site layout and safety management. For instance, Choe and Leite (2017) [3] demonstrated that integrating spatial and temporal information into construction safety planning can significantly reduce potential hazards. This finding aligns with the present study's results regarding improving safety through optimizing site layout.

Nguyen (2020) [5] found that using a fuzzy-based optimization model enhances safety management in construction projects. However, the present study highlights differences in the application of advanced technologies for cost optimization. These differences suggest that the impact of emerging technologies depends on regional conditions and safety policies.

Mosly and Makki (2021) [34] investigated the construction industry in Saudi Arabia and found that the demographic characteristics of construction workers play a crucial role in safety perceptions. This finding is consistent with the present study's emphasis on the need for skilled and specialized labor in construction sites.

The findings of this study align with previous research on the impact of site layout on safety and cost efficiency. However, differences in optimization models, workplace culture, and regional requirements suggest a need for tailored approaches. These comparisons underscore the robustness of the study's conclusions and provide a deeper understanding of the factors influencing safety and cost optimization in construction sites.

5. Discussion of Results

In this section, the implications of the analysis are explored, and the relationships between safety, cost, and site layout are examined, considering the findings. This discussion aims to offer deeper insights into the significance of these relationships and their impact on optimizing construction site layouts for enhanced safety and cost-efficiency.

It becomes clear according to the factor "site layout" that the Proper dumping of the hazardous masonry, with a final weight of 0.105, and the Proper CSL, with a final weight of 0.120, should not be arranged on elevated sections for the objects' fall likelihood is increased; hence, they should be placed in locations with the highest safety.

The cost stemming from the CSL should be such that the quality of the equipment and masonry related to construction site safety, with a final weight of 0.121, can be preserved, and the lowest costs are spent on the equipment. The utilization of high-quality, appropriate masonry can also reduce CSL costs because such construction materials last for a long time and depreciate slowly.

Emergency equipment (such as power generators) with a weight of 0.110 should be used where the objects are less likely to fall because the largest weight closer thereto is that of the objects' fall, 0.120. Additionally, the employment of specialized and technical individuals can be a solution for reducing the costs of using power generators, for their spatial effects are reduced in this way, and the speed of action is increased at the same time.

The personnel settlement, with a weight of 0.158, is closest in score to their technical expertise, with a weight of 0.153 in each of the studied parts; that is because the placement of the personnel in their related section causes the enhancement in safety in operations (as an example, the welding personnel should be working in the vicinity of the welding construction site and direct supervising of them brings about an increase in the safety); the use of modern technologies, with a weight of 0.165, adds to the higher safety of the technical and specialized personnel and it is by the observance of safety hints that the ancillary costs of the project are reduced.

The proper place for building parking lots for heavy vehicles and civil reconstruction machinery (excavators, mechanical shovels, loaders, and the like) with a weight of 0.138 should be in the farthest distance from the flammable materials since it was found closest in score to the hazardous and flammable materials. The increase in the quality level of the construction site products (safety enhancement in the construction site) (reduction in the number of trips and movements in the construction site) depends on the type of site layout in various sections of the construction.

In comparison to the prior studies, the results of the present study are consistent with their findings. Approximately comparable results have been obtained. Based on the results obtained, among the factors, environmental quality and conditions fall in the first and second ranks, and time and cost fall in the next ranks. Furthermore, it was clear in the analysis of the factors that the CSL and implementation type, safety, routes of access to the construction site, project planning, and overall budget fall in the first ranks. In the present study, among the factors, safety was found in the first rank, and cost and proper site layout were found to belong to the second and third ranks. Considering the results, the factor “implementation type and safety” is of a higher rank in the study by Ansari, and this finding is in accordance with what has been found herein. That is because the highest scores for the site layout factors were closest to those for the safety factors.

Study Limitations

Despite the strengths of this research in identifying and prioritizing key factors influencing construction site layout (CSL), several limitations should be acknowledged.

Limited Sample Size of Experts: This study relied on ten experts for the Delphi survey, which, while sufficient for qualitative research, may not fully capture the diversity of perspectives in the construction industry. A larger expert panel could enhance the robustness of the findings.

Geographical Focus on Iran: The study specifically analyzes CSL factors in Iran, where socioeconomic conditions, regulations, and construction practices differ from other regions. The results may not be fully generalizable to countries with distinct industry standards.

Exclusion of Environmental Sustainability Factors: While the study focuses on safety and cost, sustainability aspects such as energy efficiency, waste reduction, and eco-friendly materials were not explicitly considered. Future research could integrate environmental sustainability into CSL optimization models [87–90].

6. Conclusions and Research Implications

Safety risks are among the most important dangers of building projects because the construction industry is prone to higher rates of injuries and casualties than the other industries. In the management of building projects, safety is significant regarding the CSL and its costs. The present study aimed to prioritize the factors influencing safety enhancement and cost reduction in construction projects through the proper CSL. For this reason, the study used a combined fuzzy ANP-DEMATEL technique. The study specifically looked at previous research and asked experts for their thoughts in order to lay the groundwork for writing down the assumptions needed to find and rate cost, safety, and site layout indicators in construction sites. In the first step, the factors were screened. In this section, the number of the final factors decreased from 26 to 20. In the second step, we used the fuzzy DEMATEL technique to investigate the internal relations among the study’s factors. The internal relations between the study’s factors strongly influence safety. The FANP method was then used to give the study’s factors weight. The results showed that the factor “cost” had a normalized weight of 0.528, the factor “safety” had a weight of 0.351, and the factor “site layout” had a weight of 0.121. These are the factors that came in first, second, and third, respectively. We also subjected the study’s factors to pairwise comparisons. The employment of specialized and skillful individuals falls as the first priority, with a weight of 0.123. Masonry displacement is the second priority, with a weight of 0.063. Up-to-date software falls in the third rank with a weight of 0.059.

Figure 10 shows the use of color intensity to depict the weights of factors, with darker shades indicating greater importance. The heat map highlights "cost" as the dominant factor over "safety" and "site layout". Among the priority factors, "expert recruitment" holds the highest weight, emphasizing its critical role. This visual tool effectively identifies key factors and their relative significance.

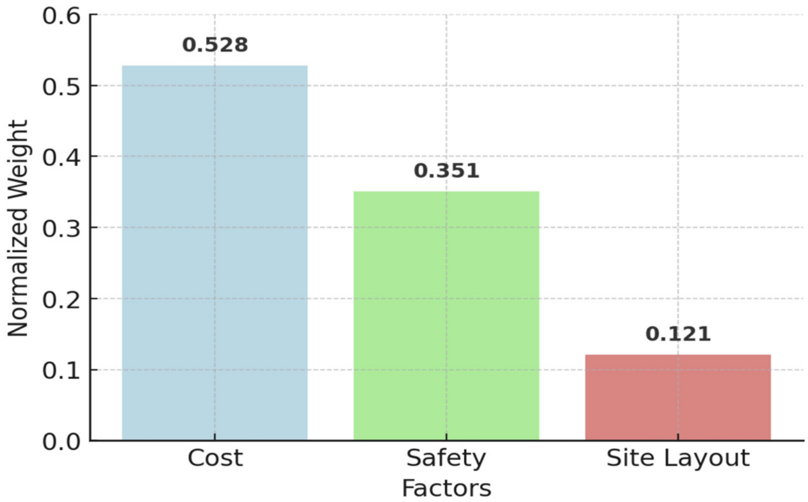

Figure 10. Weights for factors.

Figure 11 illustrates the priority factors influencing construction site safety and cost management using color intensities. Darker shades represent more critical factors, such as "Employing skilled personnel", with the highest weight. Lesser-weighted factors, like "Up-to-date software" and "Using new technologies", still significantly improve safety and efficiency.

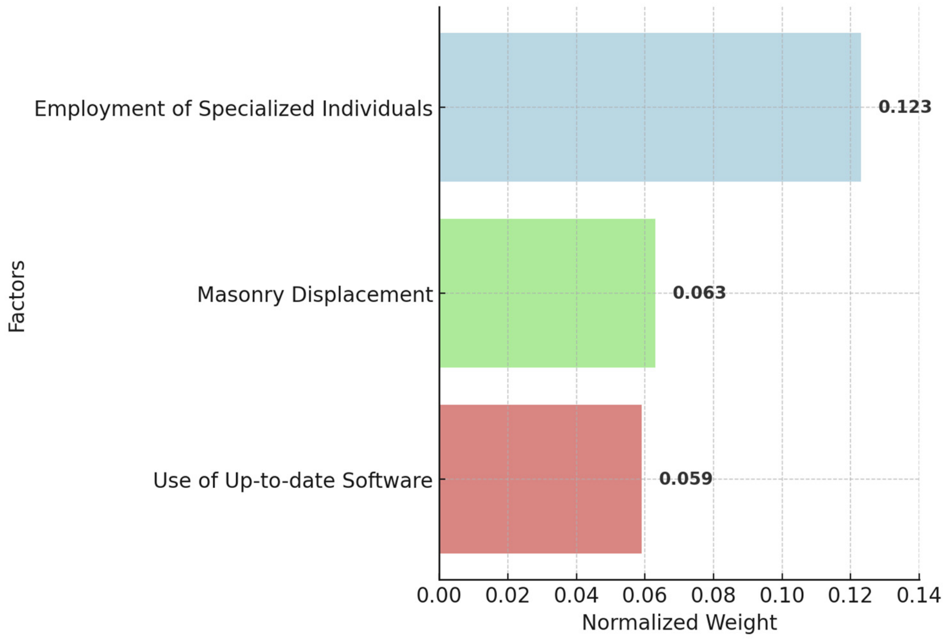

Figure 11. Priority factors weights.

The construction industry must prioritize proper design and planning for Construction Site Layout (CSL) to ensure safety for all project stakeholders. Hiring skilled and specialized individuals is paramount, emphasizing that site safety depends not only on strict regulation enforcement but also on fostering a safety culture among workers. Key strategies include employing talented professionals through rigorous recruitment and training programs and promoting continuous professional development. Advanced technologies like Building Information Modeling (BIM), drones, and automation enhance safety and efficiency.

This study highlights significant implications for Iran's construction sector. Improved safety and cost efficiency in CSL design can boost economic growth by reducing accidents, minimizing downtime, and increasing worker productivity. These measures lower costs and improve return on investment while fostering a culture of workplace safety. The findings underscore the critical role of hiring specialized personnel and leveraging innovative technologies in reducing costs and enhancing safety. The proposed ANP-DEMATEL model offers a novel approach for identifying and prioritizing key factors in developing countries like Iran, contributing practical solutions to safety and cost management challenges.

This study primarily focuses on safety and cost-effectiveness, and environmental sustainability was not explicitly addressed. Therefore, future research could explore the integration of environmentally friendly materials, energy-efficient site layouts, and waste management strategies to enhance the overall impact of CSL optimization. On the other hand, it is worth exploring the integration of artificial intelligence (AI) and the Internet of Things (IoT) in CSL planning to enhance real-time decision-making and safety monitoring. Extending the study to other residential, infrastructure, and industrial sectors could provide broader insights. Larger sample sizes in Iran and other developing countries would confirm the findings and provide regional perspectives. Examining the economic, social, and environmental impacts of modern technologies in CSL is essential to comprehensively address the evolving needs of the industry.

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