An Optimal Cost Estimation Practices of Fuzzy AHP for Building Construction Projects in Libya

Walid Alfaggi [1*], Sepanta Naimi [1]

[1] *Department of Civil Engineering, Altinbas University, Istanbul, Turkey.*

Abstract

This paper analysis and reviews the construction projects in Libya. In Libya, construction projects often face challenges due to the lack of proper information and data in cost-estimation methods. The primary goal of this paper is to demonstrate the estimation of construction costs using various methods. An optimization strategy based on a well-known robust algorithm The Fuzzy AHP technique is used to estimate the best roof structure choice based on cost rank among one or two-way flat slab, post-tension slab, pre-tension slab, waffle slab, and hollow core slab. The roofs were created employing five main factors that were implemented in a real-world situation in the Libyan building industry. The cost of materials, labor, machinery, transportation, and trash on site were all considered. Research findings show that the models can assist decision-makers in determining the cost rank of roof selection. When a range of methods are applied and compared to guarantee that this is the best option. This research study must be taken seriously when estimating and managing the contract and length of highway construction projects in the early stages of project development so that the time difference at the end of the project can be kept to a minimum by decision-makers when choosing the roof with the lowest cost.

Keywords: Cost Factors; Fuzzy; AHP; Slab Model; Construction Projects.

1. Introduction

Establishing a realistic duration at the early stage of infrastructure projects is important for both contractors and clients. An accurate determination of duration and cost at an early phase of project development can aid stakeholders to meet public expectations and avoid the public-related problems of time overruns. In addition, it can also be useful in the bid evaluation stage. In cases where bidders are requested to specify a construction period and cost, the expected project duration and cost can be used as one of the bid evaluation criteria. Accordingly, the costs of delays and safety problems during project implementation can be estimated and used as an input for the lifecycle cost analysis as well [1]. Therefore, it can be realized that the accuracy of the estimate is critical to guarantee the construction project's success.

The cost estimating process is a method for obtaining and analyzing historical data as well as forecasting future program costs utilizing quantitative models, approaches, tools, and databases. One of the most significant elements to consider during the early stages of the construction design process is cost. In order for a project to be successful, it is necessary to establish a useable model and approach for cost estimation in construction projects [1]. Furthermore, the estimating approach tends to become more complicated as the cost parts become more diverse, making it difficult for users who directly undertake cost estimation to apply recent research results to a building project in practice. Cost estimation is an important part of every building project. It represents the total cost of all resources required to finish the task [2].

The conceptual cost estimates developed during the early design stage are unique as a result of the two variables. To begin with, the estimations must rely on imprecise, incomplete structural information. Second, the ability to influence the building's features and cost early in the design phase is greater than later in the project. Both of these considerations stimulate research into development models that use a variety of methodologies and procedures to help with cost estimations when deciding the price of construction work. Direct costs involved with the realization of the work, overhead costs, and profit must all be taken into account. Contractors can use unit prices to calculate project costs. This procedure necessitates the contractor's extensive experience [3]. All of the above-mentioned costs must be included in the unit pricing. On the other hand, many studies revealed inaccurate estimation practices and proved that completing later than scheduled is a long-standing problem widely recognized. In the same way, Rivera et al. (2017) [2] have demonstrated global construction project performance. According to this study, 75% of projects in Africa experience schedule delays. Of the 75%, the project duration is delayed by 53% more than the original scope.

In several highway construction projects, the completion time of construction is set by the contract documents [4]. Estimation of the contract time duration of road construction projects at the planning stage serves as an important input for project planning, scheduling, and contract administration. On the other hand, there are various factors leading to time overrun, which becomes the most prime issue and hence induces turbulence in the time estimates [5]. In several previous studies, the various sets of factors that significantly affect the estimation accuracy of the duration of highway projects have been identified. Table 1 depicts the various factors impacting highway project duration and/or its estimation accuracy, which are deduced from a comprehensive literature review.

Table 1. Factors impacting highway project duration and/or its estimation accuracy

Factors	Sources
Project type	Ahn et al. (2020); Rahman et al. (2021); Cao et al. (2019) [6-8]
Contract type	Camci et al. (2020); Rahman et al. (2021); Afolayan et al. (2020) [9-11]
Area location	Ali et al. (2019); Das et al. (2022) [12, 13]
Project location (districts)	Noorollahi et al. (2022); Rediske et al. (2020); Al-Abadi et al. (2020) [14-16]
Project scope	Ibrahim & Elshwadfy (2021); de Gracia et al. (2018) [17, 18]
Project length	Eskander (2018); Ashkezari et al. (2022); Gómez et al. (2020) [19-21]
Site topography (Terrain type)	Tang et al. (2021); Costache et al. (2022) [22, 23]
Project capacity (Number of lanes)	Feng et al. (2020); Meharie et al. (2019) [24, 25]
Design AADT	Jia et al. (2018); Sarraf & McGuire (2020) [26, 27]
Design speed	Liu et al. (2020); Galdiani et al. (2022) [28, 29]
Geometric design standard	Singh et al. (2019); Jovčić et al. (2019) [30, 31]
Curb, gutter and sidewalk	Gharebaghi et al. (2021); Raihan (2018) [32, 33]
Waterbody and storm drain extents	Sekovski et al. (2020); Banerjee et al. (2018) [34, 35]
Right-of-way (ROW) costs	Simanjuntak & Putro (2020); Dahim (2021) [36, 37]
Climate / weather conditions	Rezvani et al. (2022); Perosa et al. (2022) [38, 39]
Condition / type of soils	Doke et al. (2021); Zghibi et al. (2020) [40, 41]
Contractor's performance	Al-Saggaf et al. (2020) [42]

The traditional technique of cost estimation is based on the computation of each cost factor separately: direct cost (labor, materials, and equipment); indirect cost (labor, materials, and equipment); and profit. Proper cost control is a critical component of a successful project in this regard. As a result of insufficient cost control during the design and execution stages, several projects have encountered cost overruns. A bad plan, a bad budget, or a bad timetable can easily transform a profit into a loss [4]. The contractor does not experience losses when carrying out project operations when cost management is controlled using the finest methods and approaches. Poor project preparation, lapses in management and control, over budgeting, poor materials, labor shortages, increased material costs, delays in deliveries, material waste, unexpected weather changes, material loss, insecurity, and poor communication are among the issues that most project managers and contractors face when it comes to cost control on their construction sites [5]. In the realm of estimation, several previous studies have been conducted to identify the various critical factors affecting the accuracy of highway project duration estimation using different statistical techniques such as mean score, relative importance index [16-20, 43-45], principal component analysis [19, 20], stepwise regression [46], trial and error method of artificial neural network [47], sensitivity analysis [18], Likert scale analysis [18], as well as correlation analysis [4, 6, 21, 48]. There is no prior study in identifying and analyzing the critical factors that affect the estimation accuracy of highway project duration in a fuzzy environment because the qualitative attributes for expert evaluation are always imprecise and subjective. Uncertainties and fuzziness are often encountered in practice [22]. What's more, there is a lack of applying

a multi-criteria decision-making process to analyze the significant factors affecting highway project duration. This has motivated the authors of this paper to carry out a study to prioritize and rank the duration estimation accuracy factors by applying fuzzy set theory and the extent synthetic value analysis method on the fuzzy analytical hierarchy process (fuzzy AHP) approach as part of the decision-making process to capture the subjective and imprecise perspective data from experts and finally the most weighted factors influencing..

As a result, there are cost overruns, disagreements, and even project abandonments. In order to increase the accuracy and reliability of cost work, many studies have attempted to establish cost management strategies that maximize the practical utility of limited information [43]. The outcome was a variety of methodologies, both traditional and artificial intelligence-based, were researched and tested for their accuracy in estimating project costs at the conceptual stage. In recent years, a novel method based on computer system theory has gained traction. To regulate the cost, several methods such as ANN, Fuzzy NN, SVM, PSO, RBF, RA, PSO, Decision Tree, AHP, Monte Carlo, and fuzzy logic have been utilized. The qualitative model relies on expert judgment, heuristics, and mathematical rules for accurate building cost estimation [44, 49].

2. Cost Estimation Methods

Due to advancements in cost estimation, project management has become an increasingly important discipline for achieving a balance between project working progress and project budget as early as feasible and reducing project overruns. This should be used to explain what the most effective monitoring-diagnosis cost estimating method [1]. To achieve the research objectives, the proposed strategy comprises three main steps: the first is computing the effective cost of various types of concrete slabs, and the second is recognizing the cost weight of each type of slab using appropriate methods. The third stage is to use the AHP approach to determine the best option based on cost and other project-related factors. The direct costs associated with the realization of the works, overhead costs, and profit must all be considered when determining the price of construction work [50]. Contractors can use unit price to calculate project costs. This procedure necessitates the contractor's extensive experience. All of the above-mentioned costs must be included in the unit pricing. The traditional approach of cost estimation is based on the computation of individual cost elements: the direct cost. This old method is accurate but time consuming, thus new approaches are still being explored through the use of new mathematical tools that can aid in the calculation's efficacy [43].

2.1. Analytic Hierarchy Process

AHP is a decision-making tool that decomposes a complex problem into a multi-level hierarchical structure comprising objectives, criteria, sub-criteria, and alternatives to better characterize the general choice operation. AHP can be used to make difficult, unstructured judgments involving several attributes. These criteria define decisions that do not fit neatly into a linear framework; they include both physical and psychological factors. AHP presents a mechanism for connecting that can quantify the decision maker's subjective assessment in a form that can be measured [48].

2.1.1. Implementation of the AHP

Creating a mathematical and computational model is the process of evaluating and selecting the appropriate stations for use in cost systems. In order to do so, the priority AHP approach was devised and used to specify the required stations as follows [47]:

Stage 1: establishment of the pairwise comparison matrix,

$$AHP = \begin{bmatrix} a_{11} & a_{12} & ..... & a_{1n} \\ a_{21} & a_{22} & ..... & a_{2n} \\ a_{n1} & a_{n2} & ..... & a_{nn} \end{bmatrix} \tag{1}$$

Stage 2: calculation of the weights of the criteria.

$$AHP_{sum\_1} = \left| \sum_{i=1}^{n} i1 \quad \sum_{i=1}^{n} i2 \quad \sum_{i=1}^{n} in \right| \tag{2}$$

$$AHP = \begin{bmatrix} a_{11} & a_{12} & ..... & a_{1n} \\ a_{21} & a_{22} & ..... & a_{2n} \\ a_{n1} & a_{n2} & ..... & a_{nn} \end{bmatrix} \times \left| \sum_{i=1}^{n} i1 \quad \sum_{i=1}^{n} i2 \quad \sum_{i=1}^{n} in \right|^{-1} \tag{3}$$

$$AHP_m = \begin{bmatrix} AHP_{m\_11} & AHP_{m\_12} & ..... & AHP_{m\_1n} \\ AHP_{m\_21} & AHP_{m\_22} & ..... & AHP_{m\_2n} \\ AHP_{m\_n1} & AHP_{m\_n2} & ... .. & AHP_{m\_nn} \end{bmatrix} \tag{4}$$

$$AHP_{sum\_2} = \begin{vmatrix} \sum_{j=1}^{n} j1 \\ \sum_{j=1}^{n} j2 \\ \sum_{j=1}^{n} jn \end{vmatrix} \tag{5}$$

$$AHP_{prio} = \frac{AHP_{sum\_2}}{\sum AHP_{sum\_2}} \tag{6}$$

$$AHP_{prio} = \prod_{St=1}^{n} St \tag{7}$$

2.1.2. FUZZY Logic Design

This section's major goal is to create a fuzzy classifier based on construction factors. The first goal is to encode data in fuzzy set format, followed by selecting appropriate fuzzy sets and designing a fuzzy inference system that classifies a fully formed cost system[46, 51].Steps in the creation of a preliminary heuristic fuzzy classifier are shown in Figure1.
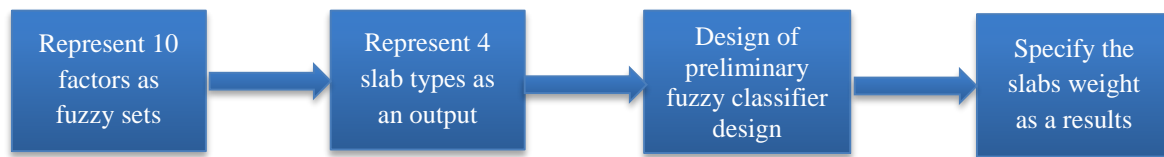

Figure 1. Basic steps in heuristic base fuzzy classifier

The method for scaling and mapping the values of process input variables to the area of fuzzy variables using the finding degree of membership function. For evaluating, creating, and simulating systems based on fuzzy logic, the Fuzzy Logic Toolbox includes MATLAB® functions, apps, and a Simulink® block. The software walks you through the process of creating fuzzy inference systems. Many standard methods, such as fuzzy clustering and adaptive learning, have functions. It can evaluate and visualize the fuzzy inference system once it has been developed. If the alter the names of the membership functions in the Membership Function Editor, for example, the changes are mirrored in the Rules Editor [52, 53]. The UIs can read and write variables to the MATLAB® workspace as well as to a file (the read-only viewers can still exchange plots with the workspace and save them to a file). For any particular system, you can have any or all of them open, or you can have several editors active for any number of fuzzy systems. This step represents the primary goal, and the outcomes are used as a selection strategy. The research process depicted in Figure 2 consists of two basic components, each of which has been confirmed using past industrial data.
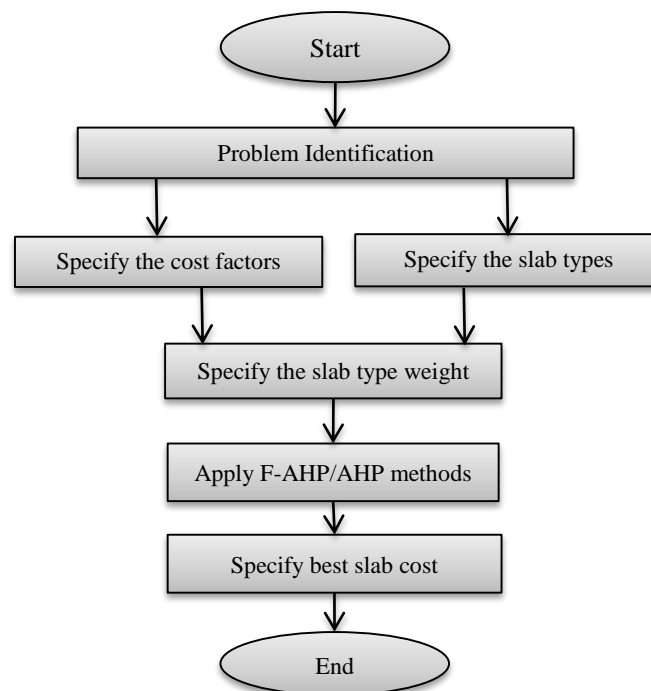

Figure 2. Methodology flow chart

3. The Case Study

The selected case study is to select one of the different types of slabs in construction. Bridges, roofs, foundations and driveways all rely on durable concrete for a firm base and dependable structure. Find out how to compare the four common concrete slab types before planning a construction project. Assess the concrete slab needs the right way with professional measuring devices and construction tools from Engineer Supply. The types of concrete slabs used in Libya are the one-way or two-way flat slab employs 4 to 6 inches of concrete to sustain large loads and is one of the most prevalent slab types in construction projects. The support structure is referred to by the slab's name. It's intended for use in situations when one direction is supported while the other requires less support. This slab is a cost-effective and straightforward option for commercial or residential construction. It's less expensive than other slab kinds, especially for a ground-level structure. One of the biggest drawbacks of one-way flat slabs is that they can't span as much as other slab kinds. As a result, they are inappropriate for a variety of bridge and ceiling applications. The Post-Tension Slab is the second type of concrete slabs. The features of the post-tension slab are similar to those of the pre-tension slab. This technique occurs after the concrete has been poured, rather than before the cables are tightened and tension is created. It produces a lightweight, long-lasting effect. If you choose this option, be cautious because an untrained concrete crew may leave air spaces in the slab. Steel cable corrosion is encouraged in these areas, which increases the likelihood of a sudden slab fracture.

The Pre-Tension Slab is another concrete slab used as a reinforcing framework for your concrete slab, lay tightened steel cables. Pre-tension slabs, like post-tension slabs, are used to prevent compression and increase overall strength. It accomplishes this by employing high-tensile steel cables. Before the concrete is poured into the structure, hydraulic jacks produce stress in the system. The tension of the wires prevents the concrete fragments from dangerously separating if the structure cracks. For a thinner result, use a pre-tension slab. The Waffle Slab offers an iconic aesthetic that is often utilized in restaurants, malls, and other commercial venues. This square-pod system can be used to house recessed lighting, modify acoustics, and provide a large span with minimum column support in a grand lobby. A waffle slab is exceptionally expensive and time-consuming to build and install. While the end result is a beautiful structure with a distinctive interior, the procedure can be too expensive for many commercial and residential projects. Finally, Hollow Core Slab is delivered to jobsite ready to use. This cuts down on the amount of time and effort required for your project. Simply lift and install the hollow core slabs on supporting columns with a crane. Hollow core slabs have a great span distance when compared to other slab alternatives. They also feature holes in them that are ideal for electrical and plumbing installation, reducing the construction project's time and cost even further. Make sure you get your hollow core slabs from a reliable contractor. Damage to these slabs might occur as a result of casting faults or incorrect transportation, resulting in a costly and time-consuming problem.

- Material prices / availability / supply / quality / imports. The factor such as shape and size correlated with gradation of material particle are hardly analytically linked to the mechanical behavior of materials. These factors have a major effect in terms of economy, all of which lead to loss of money and even lives [54, 55].

- Labor costs / availability / supply / performance / productivity

- Plant costs / availability / supply / condition / performance

Market conditions and external factors Owners and constructors are constrained by explicitly defined environmental responsibilities and obligations. One or more environmental challenges touch nearly every section and sector of the industry. The chosen characteristics can be summarized in Table 2.

Table 2. The cost factor matrix

	Cost factor	One/two Way Flat Slab	Post-Tension Slab	Pre-Tension Slab	Waffle Slab	Hollow Core Slab
F1	Cost of materials	H	VH	VH	VH	VH
F2	Cost of labor	VH	VH	H	VH	H
F3	Cost of machinery	H	H	VH	H	VH
F4	Transportation cost	M	M	H	M	H
F5	Waste on site	M	M	L	M	L

The situations were created in two stages. The first step is to identify effective value differences that can be used to rank the various roof types. To get to this point, the Fuzzy AHP was used to determine the optimum option. The researcher then put the established AHP algorithm to the test in order to determine the efficacy of roof cost parameters. The key issue with this project is figuring out how to cope with such massive amounts of data. The researcher organizes and classifies the data in order to provide a good depiction of the current methods.

4. Results and Discussion

Choosing the least expensive cost factor isn't always the greatest solution. If the merchandise is of poor quality, then the creation of a model that uses the Fuzzy AHP technique could help to eliminate time scheduling delays. Giving other factors the attention they deserve in order to select the cost component by focusing on its financial stability, history, and other criteria may be the best option. You'll need to acquire the right pricing, the right time, and the right specification to choose the ideal roof for the right building. Given equal weight to each criterion, one criterion may be deferred from another based on its value. In the Fuzzy AHP approach, this idea is employed to evaluate choices. Obviously, certain elements are more important than others. As a result, applying the appropriate amount of weight may be able to resolve the situation. Even if some managers believe certain criteria are more important than others, they may act in the opposite way in actuality. Managers appear to assume that quality is the most important characteristic, but when it comes to deciding on a cost element, they prioritize delivery performance and/or cost. The cost variables evaluated determined the priority weight of each criterion in each level. The relevant criteria were discovered using pair-wise comparison assessments. The purpose of pair-wise comparisons is to determine the relative relevance of the criteria, which are scored using Saaty's (1980) nine-point scale, as indicated in Table 3.

Table 3. Fuzzy AHP Pair wise comparison matrix

	One/two Way Flat Slab			Post-Tension Slab			Post-Tension Slab			Waffle Slab			Hollow Core Slab			Weight (%)
One/ Two Way Flat Slab	1	1	1	0.5	0.3333	0.25	0.2	0.2	0.2	0.33	0.3	0.33	0.3	1	0.3	7
Post-Tension Slab	2	3	4	1	1	1	1	0.5	0.333	0.33	0.3	0.25	0.3	0	0.2	10
Pre-Tension Slab	5	5	5	1	2	3	1	1	1	0.2	0.2	0.2	0.1	0	0.1	13
Waffle Slab	3	3	3	3	3	4	5	5	5	1	1	1	0.3	1	0.3	25
Hollow Core Slab	3	2	3	4	4	6	7	7	7	3	2	3	1	1	1	45
Col. Total	14	14	16	9.5	12.33	14.25	14.2	14	13.53	4.87	3.8	4.78	2.1	2	2	

The relative numbers 1, 3, 5, 7, and 9 represent equal, moderate, strong, extremely strong, and extreme levels of importance, respectively. 2, 4, 6, and 8 were used to represent intermediate values between two neighboring arguments. The one/two-way slab is clearly the heaviest among the other criteria. The first three rows illustrate how the one-way/two-way slab weight (i.e. the relative importance of each criterion) stacks up against the competition. Quality is slightly more important than delivery, management and organization, and financial performance in the second row and column. Because delivery (row) and delivery (column) are equally favored, the diagonal elements are assigned a value of 1. (column). After obtaining the pair-wise assessments, the next step is to calculate the weighting of the elements in the matrix. Divide the column's items by the column's total after calculating the total for each column. Finally, multiply this by the number of rows in each column. After calculating the total for each column, divide the column's items by the column's total. Finally, to calculate the average, add the elements in each resulting row and divide the total by the number of elements in the row. Illustrates the matrix's calculations. Table 4 shows the results of the priority weights (i.e. the relative importance of each criterion).

Table 4. Fuzzy weight (i.e. the relative importance of each criterion) of roofs

	Fuzzy Weight		
One/two Way Flat Slab	0.31387	0.3749	0.4927
Post-Tension Slab	0.05633	0.07654	0.1467
Pre-Tension Slab	0.05285	0.07564	0.1874
Waffle Slab	0.0473	0.05345	0.07456
Hollow Core Slab	0.3195	0.45437	0.5458

Alternative 3 of Hollow Core Slab has the highest total score based on this outcome. As a result, it is recommended as the best roof among the three, based on five factors and the decision makers' own preferences. This result should be compared to the Fuzzy approach used to the identical case study. In the effective design and simulation of a fuzzy logic system, input and output variables were formed, a membership function was created, fuzzy rules were defined, and results were produced. The model is required to select the appropriate input variable, partition the input space, and determine the number and kind of membership functions (MF). The input membership function is the Gaussian MF, while the output membership function is the Trapezoidal MF. The unit cost of product distribution is one of the input factors, the Mamdani model's architecture is ideal for successful facility design employing FIS as a membership function connected with the fuzzy inference system and variables (Figure 3).
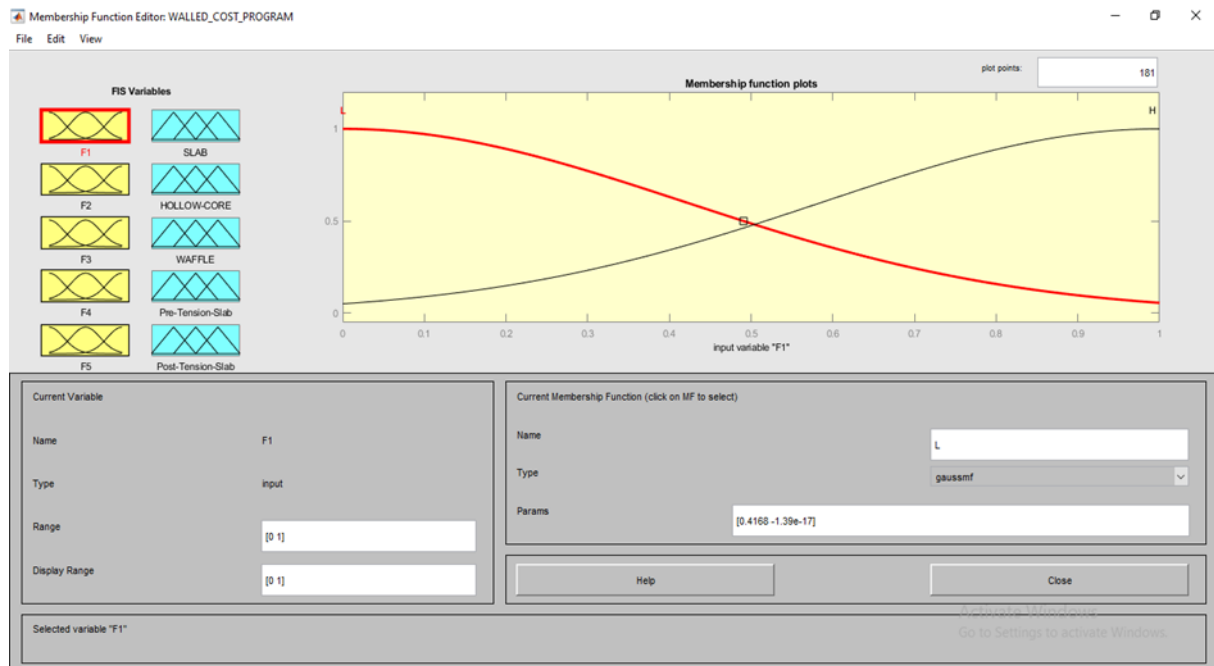
Figure 3. Membership function plot for input variables

The designed fuzzy model is highly efficient and creative; it includes a creative algorithm capable of fine-tuning parameters with good adjustments and resilient solutions using dataset provided by membership functions based on linguistic terminologies, as well as a creative algorithm capable of fine-tuning parameters with good adjustments and resilient solutions. A control surface map, shown in Figure 4 graphically represents all possible inputs and outputs in terms of cost. It's a three-dimensional case scenario because it has five input variables (materials cost, labor cost, machinery cost, transportation cost, trash on site) and five output signals (One/two Way Flat Slab, Post-Tension Slab, Pre-Tension Slab, Waffle Slab, Hollow Core Slab). The factors (F) that will affect the roof cost influenced all of the examples required in each situation.
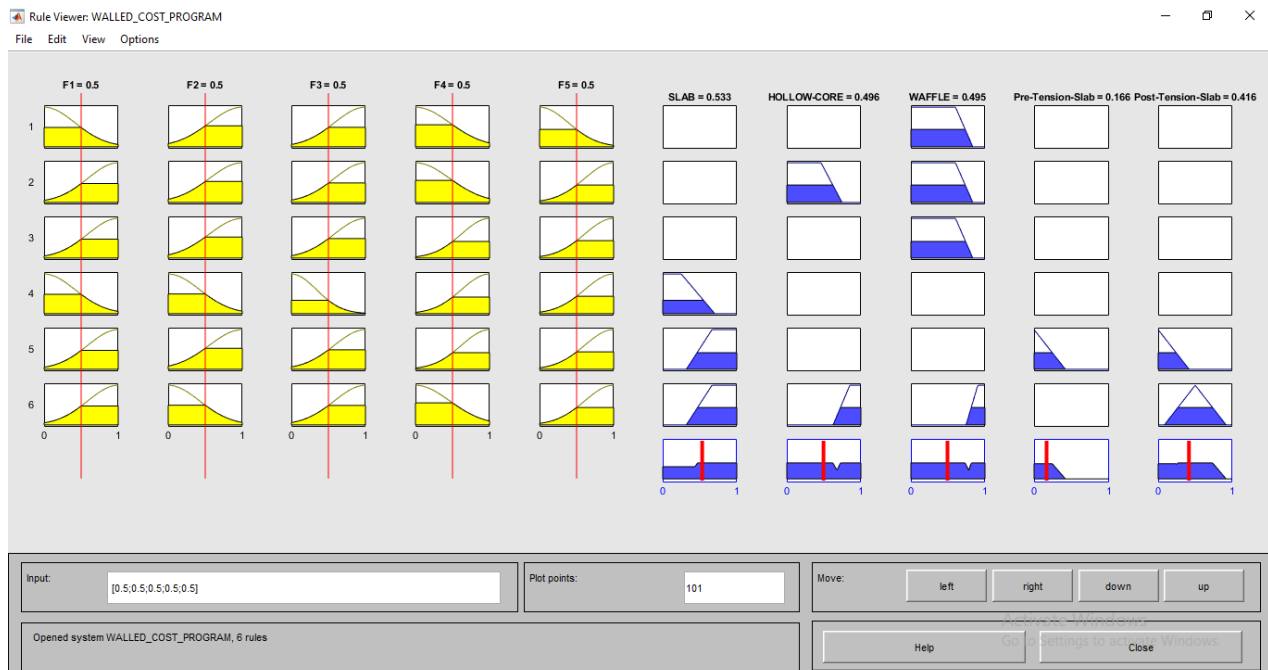

Figure 4. Rule viewer for input and output signals

This is true in Libya, where the One/two Way Flat Slab was employed in the majority of homes. The increase in indirect cost will make the hollow car the preferred roof. As a result, it may be chosen as the best option for meeting the construction managers' aims and objectives. The ultimate score and ranking for each roof type may be found in the results. In terms of high direct cost, One/two Way Flat Slab As' score of (0.67) is higher than the scores of the other four roof kinds, such as Hollow Core Slab (0.369), Waffle Slab (0.424), Post-Tension Slab (0.316), and pre-tension slab (0.166). In all other cases, however, the hollow core slab is a viable option. , the general results are significant similarity as shown in Table 5.

Table 5. A comparison between Fuzzy AHP weight results and FUZZY weight results

	Fuzzy AHP weight results	FUZZY weight results
One/two Way Flat Slab	0.4927	0.4
Post-Tension Slab	0.1467	0.439
Pre-Tension Slab	0.1874	0.189
Waffle Slab	0.07456	0.5
Hollow Core Slab	0.5458	0.5

The outcomes of the two operations have a significant cost indicator. Finally, the built model assists in the selection of a suitable building roof. It comprises a number of steps, including designing building element selection criteria, identifying sub-criteria, structuring the hierarchical model, prioritizing the order of criteria, estimating roof cost, and determining roof priority and selection in that order.

5. Conclusion

It has investigated the role of fuzzy logic and the Fuzzy AHP technique in construction operations. Fuzzy logic applications could be valuable in the construction business, it's worth highlighting. Finally, this research emphasizes the difficulties in selecting construction elements. The most important contribution of the project was the development of crucial criteria for the roof selection process. A fuzzy multi-criteria decision model was then constructed for studying and selecting a roof type. In addition, for studying and selecting roof types, a fuzzy multi-criteria decision model was developed. A fuzzy decision model for selecting roof kinds was also developed. The fuzzy AHP model assesses decision-makers to identify and evaluate supplier selection using a multi-criteria decision model. Finally, the model is put to the test on five different types of roof selection challenges. The findings demonstrate that the models can help decision-makers evaluate the cost rank of roof choices. The major selection method has been achieved when a variety of ways were applied and compared to ensure that this is the best option.

6. Declarations

6.1. Author Contributions

Conceptualization, W.A., and S.N.; methodology, W.A., and S.N.; software, W.A.; validation, W.A.; writing—original draft preparation, W.A.; writing—review and editing, W.A., and S.N.; supervision, S.N. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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