Notes on Intuitionistic Fuzzy Sets
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Ranking of factors affecting pricing in construction projects by intuitionistic fuzzy analytic hierarchy process with ordered pairs

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Abstract: The construction industry faces various challenges related to uncertainties in project bids and unstable pricing. These challenges include situations where uncertainties in bid documents can affect project pricing and performance. In order to resolve these uncertainties and clarify project requirements, risks and uncertainties within the document need to be identified early in the project life cycle. This study aims to rank the factors affecting project pricing. For this purpose, firstly, the parameters that have an impact on pricing are defined and then these factors are weighted by using Intuitionistic Fuzzy Analytic Hierarchy Process with Ordered Pairs.

The analysis of factors affecting construction pricing reveals some important insights. Environmental uncertainties and uncertainties in prices and labor costs are the most important factors influencing pricing, while past project experience is the least important factor. Overall, these findings shed light on the multifaceted nature of construction pricing, which is shaped by the complex interaction of environmental, economic and market factors.
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1 Introduction

In construction projects, pricing is a complex process, and it depends on several factors, such as the costs of materials used, labor costs, equipment costs, etc. Material prices vary depending on market conditions, the supply chain, and the characteristics of the project, while labor costs can vary according to the size, length, and complexity of the project. In addition, if construction equipment needs to be rented or stored, these costs also affect the pricing of construction projects. In addition, local market conditions, material supply, labor supply, local regulations, and permits in the region where construction projects are carried out can also directly affect the cost of the project. Apart from these factors, construction projects are often full of uncertainty and risk. Unexpected situations can increase project costs, so these risk factors are important elements that affect pricing.

All of these factors are key elements that reflect the complexity of pricing in construction projects. In addition, the construction industry faces challenges related to uncertainties and unbalanced pricing in project bids. Construction companies usually try to develop a competitive and sustainable pricing strategy by taking these factors into account. Therefore, bid pricing in construction projects has been the subject of several research papers. In this context, Shrestha et al. [10] emphasize pre-bid Request for Information (RFI) requests and use them as an important clue to quantify uncertainties in the project document. Furthermore, Alhyari and Hyari [1] evaluate the bidding regulations used to protect the interests of a number of subcontracting authorities by addressing the unbalanced pricing strategies adopted by contractors in participating in competitive tenders. Ribeiro et al. [9] apply a real options approach that has contributed for more than 40 years to research on finding the optimal bid value in construction projects, aiming to optimize the bid price. Furthermore, Kissi et al. [8] examine the challenges in pricing Ghanaian construction projects, highlighting the challenges for construction stakeholders in achieving an effective and efficient pricing system. Wong and Hui [11] evaluate several factors that influence bid prices, highlighting the differences between large and medium-sized contractors' perceptions of these factors. These studies provide valuable perspectives to practitioners, policymakers, and researchers, contributing to the understanding and management of uncertainties, unbalanced pricing, and risk factors in construction bidding.

The aim of this study is to define the significance levels of the parameters affecting the price bid in a tender. The intuitionistic fuzzy analytic hierarchy process with ordered pairs (IFSOP) is used to make calculations based on the decision makers' consistency by evaluating the decision makers' answers to functional and non-functional questions simultaneously.

The rest of the study is organized as follows. The second section presents the IFSOP and the steps of the analytic hierarchy process based on the IFSOP. The third section explains the parameters affecting pricing in construction projects. The fourth section presents the importance degrees of the factors affecting pricing in construction projects. Finally, the fifth section presents the findings and conclusions of the study.

2 Preliminaries

Experts may not be fully consistent in expressing their views on certain issues. Inconsistencies are particularly pronounced under uncertainty or when many factors are being considered simultaneously. Therefore, fuzzy sets were introduced by Zadeh to address uncertainty [12]. Since then, numerous approaches and theories dealing with imprecision and uncertainty have emerged. One of these concepts is intuitionistic fuzzy sets (IFS), which were introduced by Atanassov and are characterized by both a membership function and a non-membership function [2, 3]. Various terms, such as intuitionistic fuzzy pair, intuitionistic fuzzy couple, and intuitionistic fuzzy value. have been utilized in this concept under research on Intuitionistic Fuzzy Sets (IFSs). The term 'intuitionistic fuzzy pair' was proposed to unify the terminology within this field, aiming for consistency in communication among researchers [4].

When individuals find themselves indecisive about a decision based on a question's answer, they often resort to asking the question in reverse to gain clarity on the current situation. Thus, the aim is to clarify the situation by posing both functional and dysfunctional questions that address the same scenario. For instance, imagine a scheduled meeting where attendance is expected from all participants. When someone responds unexpectedly to the question 'Are you attending the meeting?' it may prompt the follow-up question, 'So, you are not attending the meeting?' This sequence combines both functional and non-functional questions, seeking to resolve the prevailing uncertainty. None of the existing fuzzy set extensions consider answers to functional and dysfunctional questions simultaneously. Therefore, the Intuitionistic Fuzzy Sets with Ordered Pairs (IFSOP) method was developed to address inconsistencies in expert decisions by considering both functional and dysfunctional aspects [5–7]. It evaluates the consistency of decision-makers' judgments regarding a subject, taking into account both functional (O) and dysfunctional (P) viewpoints. Decision-makers' responses to functional and dysfunctional questions are used to measure uncertainty in the decision-making process. Ideally, the sum of these assessments should be 1.0, indicating confident decision-making. However, due to decision-making uncertainty, the sum may not always be exactly 1.0 ($O + P \neq 1.0$). In such cases, decision-maker inconsistency is represented by $I = 1 - |O - P|$. This section provides the preliminaries of IFSOP [5-7].

IFSOP operates with two sets of data concerning a decision point: functional and non-functional, each represented by an IFS. In the illustration below, we consider a glass of water. The decision maker is prompted with a question within the IFS framework, asking about the level of fullness of the glass. The response from the decision maker determines the membership or non-membership of the glass's fullness within the set representing 'fullness.' This type of inquiry is termed a functional question within IFSOP. Conversely, its opposite is termed a dysfunctional question. In essence, while IFSOP inquires about the level of fullness, it also poses the question of emptiness to gauge the decision maker's confidence in their decision. Practically, the answers to functional and dysfunctional questions complement each other. Traditional IFS-based Multiple Criteria Decision Making (MCDM) approaches only consider the functional question, whereas IFSOP-based MCDM approaches incorporate both functional and dysfunctional questions, each represented by their respective IFS. In Figure 1, the fullness of the glass is depicted by both IFS and IFSOP [5-7].

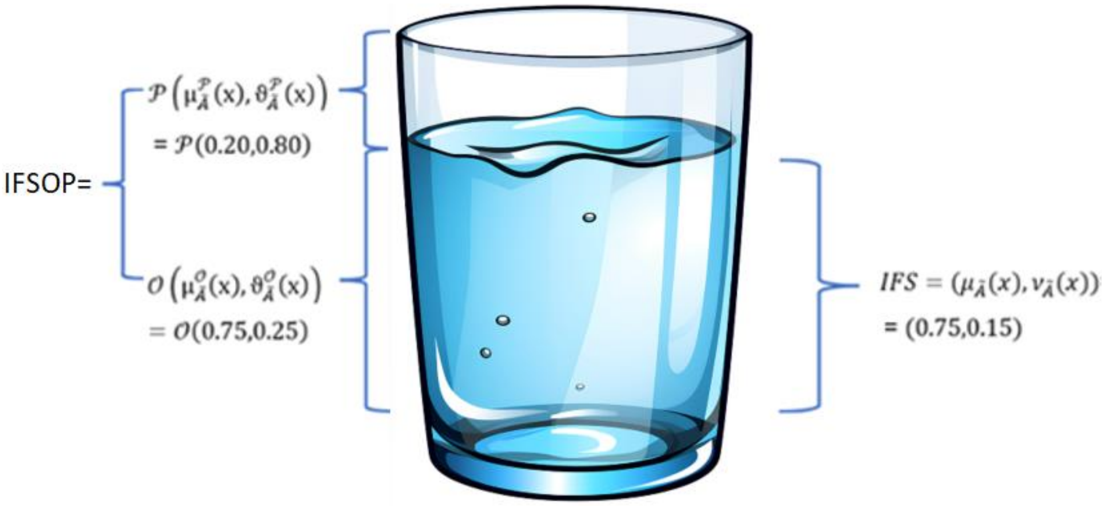

Figure 1. Fullness of the glass is depicted by both IFS and IFSOP

2.1 Intuitionistic fuzzy sets with ordered pairs

Definition 1. Consider a universe of discourse X. An IFSOP $\tilde{A}$ is represented as follows,

$$\tilde{A} = \left\{\left\langle \mathrm{x}, \left(\mathcal{O}\left(\mu_{\tilde{A}}^{\mathcal{O}}(\mathrm{x}), \vartheta_{\tilde{A}}^{\mathcal{O}}(\mathrm{x})\right), \mathcal{P}\left(\mu_{\tilde{A}}^{\mathcal{P}}(\mathrm{x}), \vartheta_{\tilde{A}}^{\mathcal{P}}(\mathrm{x})\right)\right) \right| \mathrm{x} \in \mathrm{X}\right\} \tag{1}$$

Here, the functions $\mu_{\tilde{A}}: \mathrm{X} \rightarrow [0,1], \nu_{\tilde{A}}: \mathrm{X} \rightarrow [0,1]$ indicate the degrees of membership and non-membership of x to sets O and P, respectively. Sets O and P represent functional and dysfunctional sets, satisfying the conditions $0 < \mu_{\tilde{A}}^{\mathcal{O}}(\mathrm{x}) + \vartheta_{\tilde{A}}^{\mathcal{O}}(\mathrm{x}) \leq 1$ and $0 < \mu_{\tilde{A}}^{\mathcal{P}}(\mathrm{x}) + \vartheta_{\tilde{A}}^{\mathcal{P}}(\mathrm{x}) \leq 1$. The inconsistency in judgment is represented by

$$\mathcal{J}^{A} = \left(\frac{\left(\mu_{\tilde{I}}^{\mathcal{O}}(\mathrm{x}) - \vartheta_{\tilde{I}}^{\mathcal{P}}(\mathrm{x})\right)^2 + \left(\vartheta_{\tilde{I}}^{\mathcal{O}}(\mathrm{x}) - \mu_{\tilde{I}}^{\mathcal{P}}(\mathrm{x})\right)^2 + \left(1 - \mu_{\tilde{I}}^{\mathcal{O}}(\mathrm{x}) - \vartheta_{\tilde{I}}^{\mathcal{O}}(\mathrm{x})\right)^2 + \left(1 - \mu_{\tilde{I}}^{\mathcal{P}}(\mathrm{x}) - \vartheta_{\tilde{I}}^{\mathcal{P}}(\mathrm{x})\right)^2}{2}\right)^{\frac{1}{2}} \tag{2}$$

where $0 \leq \mathcal{J}^{A} \leq 1$ and $0 \leq \mu_{\tilde{A}}^{\mathcal{O}}(\mathrm{x}) + \vartheta_{\tilde{A}}^{\mathcal{O}}(\mathrm{x}) + \mu_{\tilde{A}}^{\mathcal{P}}(\mathrm{x}) + \vartheta_{\tilde{A}}^{\mathcal{P}}(\mathrm{x}) \leq 2$. An IFSOP $\tilde{A}$ exhibits maximum inconsistency if $\mathcal{J}^{A} = 1$, and maximum consistency if $\mathcal{J}^{A} = 0$ (see [5–7]).

Definition 2. Consider $\tilde{\alpha} = \{\mathcal{O}(a,b), \mathcal{P}(c,d)\}$, $\tilde{\alpha}_1 = \{\mathcal{O}(a_1,b_1), \mathcal{P}(c_1,d_1)\}$, and $\tilde{\alpha}_2 = \{\mathcal{O}(a_2,b_2), \mathcal{P}(c_2,d_2)\}$ as IFSOP numbers. If none of them exhibits maximum consistency or maximum inconsistency, the basic operators are defined as follows [5–7]:

- Addition:

$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 = \begin{cases} \left\{\mathcal{O}\left(\frac{a_1 + a_2 - 2a_1a_2}{1 - a_1a_2}, \frac{b_1b_2}{b_1 + b_2 - b_1b_2}\right), \mathcal{P}(c_1 + c_2 - c_1c_2, d_1d_2)\right\}, a_{\mathrm{i}}, b_i \in (0,1) \\ \{\mathcal{O}(1,0), \mathcal{P}(c_1 + c_2 - c_1c_2, d_1d_2)\}, \quad a_1 = a_2 = 1 \; and \; b_1 = b_2 = 0 \end{cases} \tag{3}$$

- Multiplication:

$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 = \begin{cases} \left\{\mathcal{O}(a_1a_2, \quad b_1 + b_2 - b_1b_2), \mathcal{P}\left(\frac{c_1c_2}{c_1 + c_2 - c_1c_2}, \frac{d_1 + d_2 - 2d_1d_2}{1 - d_1d_2}\right)\right\}, c_{\mathrm{i}}, d_i \in (0,1) \\ \{\mathcal{O}(a_1a_2, \quad b_1 + b_2 - b_1b_2), \mathcal{P}(0,1)\}, c_1 = c_2 = 0 \; and \; d_1 = d_2 = 1 \end{cases} \tag{4}$$

- Multiplication by a scalar:

$$\lambda \cdot \tilde{\alpha} = \left\{\mathcal{O}\left(\frac{\lambda a}{(\lambda-1)a+1}, \frac{b}{\lambda-(\lambda-1)b}\right), \mathcal{P}\left(\left(1 - (1-c)^{\lambda}\right), d^{\lambda}\right)\right\} \text{ for } \lambda > 0 \tag{5}$$

- λ^{th} power of $\tilde{\alpha}$: $\lambda > 0$

$$\tilde{\alpha}^{\lambda} = \left\{\mathcal{O}\left(a^{\lambda}, \left(1 - (1-b)^{\lambda}\right)\right), \mathcal{P}\left(\frac{c}{\lambda-(\lambda-1)c}, \frac{\lambda d}{(\lambda-1)d+1}\right)\right\} \; for \; \lambda > 0 \tag{6}$$

Definition 3. Let $\lambda, \lambda_1, \lambda_2 \geq 0$, then (see [5–7])

$$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 = \tilde{\alpha}_2 \oplus \tilde{\alpha}_1 \tag{7}$$

$$\tilde{\alpha}_1 \otimes \tilde{\alpha}_2 = \tilde{\alpha}_2 \otimes \tilde{\alpha}_1 \tag{8}$$

$$\lambda(\tilde{\alpha}_1 \oplus \tilde{\alpha}_2) = \lambda \cdot \tilde{\alpha}_1 \oplus \lambda \cdot \tilde{\alpha}_2 \tag{9}$$

$$(\tilde{\alpha}_1 \otimes \tilde{\alpha}_2)^{\lambda} = \tilde{\alpha}_1^{\lambda} \otimes \tilde{\alpha}_2^{\lambda} \tag{10}$$

$$\lambda_1 \cdot \tilde{\alpha} \oplus \lambda_2 \cdot \tilde{\alpha} = (\lambda_1 + \lambda_2) \cdot \tilde{\alpha} \tag{11}$$

$$\tilde{\alpha}^{\lambda_1} \otimes \tilde{\alpha}^{\lambda_2} = \tilde{\alpha}^{\lambda_1 + \lambda_2} \tag{12}$$

Definition 4. Let $\tilde{\alpha}_i = \{\mathcal{O}(a_i, b_i), \mathcal{P}(c_i, d_i)\}$ be a collection of IF Weighted Geometric Mean with ordered pairs ($IFWGM^{OP}$) with respect to, $\lambda_i = (\lambda_1, \lambda_2 \dots, \lambda_n); \lambda_i \in [0,1]$ and $\sum_{i=1}^{n} \lambda_i = 1$, $IFWGM^{OP}$ is defined as [5–7]:

$$\begin{aligned} IFWGM^{OP}(\tilde{\alpha}_1, \tilde{\alpha}_2 \dots \dots, \tilde{\alpha}_n) &= \tilde{\alpha}_1^{\lambda_1} \otimes \tilde{\alpha}_2^{\lambda_2} \otimes \dots \dots \otimes \tilde{\alpha}_n^{\lambda_n} \\ &= \left\{\mathcal{O}\left(\prod_{i=1}^{n} a_i^{\lambda_i}, \left(1 - \prod_{i=1}^{n} (1 - b_i)^{\lambda_i}\right)\right), \right. \\ &\left. \mathcal{P}\left(\frac{\prod_{i=1}^{n} c_i}{\sum_{i=1}^{n} c_i^{n-1} \lambda_i (1 - c_i) + \prod_{i=1}^{n} c_i}, \frac{\sum_{i=1}^{n} \lambda_i d_i}{1 + \sum_{i=1}^{n} \left(\lambda_i d_i - \frac{d_i}{n}\right)}\right)\right\} \end{aligned} \tag{13}$$

In this manuscript, we propose a new formula for the geometric mean given in Eq. (14).

$$IFWGM^{OP}(\tilde{\alpha}_1, \tilde{\alpha}_2 \dots, \tilde{\alpha}_n) = \tilde{\alpha}_1^{\lambda_1} \otimes \tilde{\alpha}_2^{\lambda_2} \otimes \dots \otimes \tilde{\alpha}_n^{\lambda_n} = \left\{ \mathcal{O}\left(\prod_{i=1}^{n} a_i^{\lambda_i}, \left(1 - \prod_{i=1}^{n}(1-b_i)^{\lambda_i}\right)\right), \mathcal{P}\left(1 - \prod_{i=1}^{n}(1-c_i)^{\lambda_i}, \prod_{i=1}^{n} d_i^{\lambda_i}\right) \right\} \quad (14)$$

Definition 5. The consistency index (CI) of IF number with ordered pairs ($\tilde{\alpha} = \{\mathcal{O}(a,b), \mathcal{P}(c,d)\}$) is defined as [5–7]:

$$CI(\tilde{\alpha}) = 1 - \mathcal{J}^{\alpha} = 1 - \left(\sqrt{\frac{(a-d)^2 + (b-c)^2 + (1-a-b)^2 + (1-c-d)^2}{2}}\right), \ 0 \leq CI(\tilde{\alpha}) \leq 1 \quad (15)$$

As the $CI(\tilde{\alpha})$ approaches 1, the decision maker's consistency increases.

Definition 6. The score index $SI(\tilde{\alpha})$ of an IF number with ordered pairs ($\tilde{\alpha} = \{\mathcal{O}(a,b), \mathcal{P}(c,d)\}$) is proposed as follows [5–7]:

$$SI(\tilde{\alpha}) = \begin{cases} \dfrac{(a+b-c+d).CI(\tilde{\alpha})}{2.k}, & SI(\tilde{\alpha}) > 0 \\ 0, & SI(\tilde{\alpha}) \leq 0 \end{cases} \quad (16)$$

where k is the linguistic scale multiplier. When using a standard linguistic scale drawn from a standard table, the value of k, is obtained as follows [5–7]:

$$k = \frac{(a_{max} + b_{min} - c_{min} + d_{max})\left(1 - \left(\sqrt{\frac{(a_{max} - d_{max})^2 + (b_{min} - c_{min})^2 + (1 - a_{max} - b_{min})^2 + (1 - c_{min} - d_{max})^2}{2}}\right)\right)}{2} \quad (17)$$

where a_{max} and b_{min}; c_{min} and d_{max} are the maximum membership value and the minimum non-membership value of the linguistic evaluation scale used for the functional question and dysfunctional question, respectively.

2.2 Intuitionistic fuzzy analytic hierarchy process with ordered pairs

In this section, the main steps of Intuitionistic Fuzzy Analytic Hierarchy Process with Ordered Pairs ($IFAHP^{OP}$) are as follows [7].

Step 1. Problem formulation:

- **Step 1.1.** The first step of the method involves defining the decision problem and establishing the criteria and sub-criteria to be considered. This step often includes identifying the objectives or goals of the decision, determining the relevant factors that contribute to these objectives, and specifying the available decision alternatives or options.
- **Step 1.2.** The expert team to be consulted on the criteria and alternatives is identified and data collection questionnaires are prepared. Then, data is collected on the subject to be analyzed by using the linguistic scale given in Table 1. Hence, fuzzy pairwise decision matrices for both main criteria and sub-criteria are constructed.

Table 1. Optimistic and pessimistic linguistic scale [7]

Optimistic Linguistic Terms	μ	ϑ	Saaty Scale	Pessimistic Linguistic Terms	μ	ϑ
Exactly Equally Important (EEI)	0.50	0.50	1	Exactly Equally Unimportant (EEU)	0.50	0.50
Slightly More Important (SMI)	0.55	0.45	2	Slightly More Unimportant (SMU)	0.45	0.55
Weakly More Important (WMI)	0.60	0.40	3	Weakly More Unimportant (WMU)	0.40	0.60
More Important (MI)	0.65	0.35	4	More Unimportant (MU)	0.35	0.65
Strongly More Important (StMI)	0.70	0.30	5	Strongly More Unimportant (StMU)	0.30	0.70
Very Strongly More Important (VSI)	0.75	0.25	6	Very Strongly More Unimportant (VSU)	0.25	0.75
Absolutely More Important (AMI)	0.80	0.20	7	Absolutely More Unimportant (AMU)	0.20	0.80
Perfectly More Important (PMI)	0.85	0.15	8	Perfectly More Unimportant (PMU)	0.15	0.85
Exactly More Important (EMI)	0.90	0.10	9	Exactly More Unimportant (EMU)	0.10	0.90

Step 2. Consistency analysis:

- **Step 2.1.** Convert linguistic terms into corresponding membership and non-membership values according to Table 1, where $\tilde{A} = (\tilde{a}^k{}_{ii})_{n\times n} = \left(\left(\mathcal{O}\left(\mu_{ii}^k, \vartheta_{ii}^k\right), \mathcal{P}\left(\mu_{ii}^k, \vartheta_{ii}^k\right)\right)\right)_{n\times n}$, with O and P representing functional and dysfunctional sets, respectively.
- **Step 2.2.** Determine the corresponding Saaty's 1-9 scale (L_s) for the IFSOP fuzzy numbers by establishing a regression model given by Eq. (18).

$$L_s = 11\mu - 9\vartheta \tag{18}$$

- **Step 2.3.** Then, perform consistency analysis for each comparison matrix to calculate the consistency ratio (CR) using Eq. (19).

$$CR = \frac{\frac{\lambda_{max}-n}{n-1}}{RI} \tag{19}$$

  where λ_{max} and *RI* denote the eigenvalue and random index, respectively.

Step 3. $IFAHP^{OP}$ analysis

- **Step 3.1.** Aggregate the intuitionistic fuzzy pairwise comparison matrices using the $IFWGM^{OP}$ as described in Eq. (14) to obtain intuitionistic fuzzy weights for both criteria and sub-criteria.
- **Step 3.2.** Integrate the individual intuitionistic fuzzy weights of criteria and sub-criteria obtained from Step 3.1 using $IFWGM^{OP}$.
- **Step 3.3.** Multiply the intuitionistic fuzzy weights of criteria and sub-criteria according to Eq. (3) to obtain the final intuitionistic fuzzy weights.
- **Step 3.4.** Defuzzify the intuitionistic fuzzy weights of criteria to obtain crisp values by using Equations (15)–(17).
- **Step 3.5.** Normalize the score values to obtain criteria weights.

3 Application

Several factors affecting the pricing of construction projects, which are discussed in numerous research papers [8–11], have been analyzed and some of these factors are considered in this study. Then, the determined factors were evaluated by expert interviews regarding the Turkish market conditions. The obtained factors and their explanations are given below.

- Environmental uncertainties (F1): Uncertainties related to environmental conditions, such as regulatory changes, natural disasters, or market volatility, influence the project environment by introducing risks and unpredictability.
- Uncertainty in material prices and labor costs (F2): Fluctuations or uncertainties in material and labor costs influence project budgets, procurement strategies, and overall project economics.
- Supply and Demand (F3): Construction pricing is greatly influenced by the dynamics of supply and demand. Lowering prices carries inherent risks and may result in considerable work for minimal or no profit. Therefore, during periods of high demand, construction prices tend to rise to mitigate such risks. Conversely, during reduced-demand periods, contractors are willing to undertake projects with higher risk levels at lower prices to sustain their business operations.
- Competition (F4): Intense competition within the industry or market can affect the project environment, leading to pressure on pricing, innovation, and efficiency.
- Project Size (F5): A project's scope, volume of work, or size significantly affects its pricing. Larger projects often require more resources, labor, and time, which increases the cost.
- Project Duration (F6): The amount of time required to complete a project affects its pricing. Longer-duration projects are usually associated with more costs, while shorter-duration projects are usually less costly.
- Experience from past projects (F7): The experience gained from previous projects influences the project environment by providing insights, lessons learned, and best practices.

The assessment of the importance level of the criteria was conducted by three contractors with over 15 years of project experience and a track record of delivering various projects. In order to increase the reliability of the collected data, data was collected through face-to-face interviews with each contractor. The evaluations are provided in Table 2.

The linguistic terms given in Table 2 are converted into membership and non-membership values using Table 1. Then, consistency analysis for each comparison matrix is performed by using Equation (19). According to the analysis, the consistency ratios of the matrices are obtained lower than 0.1.

Table 2. Contractors' preferences

Contractor 1							
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
F1	EEI	SMI	WMI	StMI	VSI	AMI	AMI
F2	SMU	EEI	SMI	WMI	StMI	StMI	StMI
F3	MU	SMU	EEI	WMI	WMI	StMI	AMI
F4	StMU	SMU	WMU	EEI	StMI	StMI	AMI
F5	StMU	WMU	StMU	WMU	EEI	WMI	MI
F6	VSU	StMU	StMU	MU	WMU	EEI	EEI
F7	VSU	VSU	AMU	StMU	MU	EEI	EEI

Contractor 2							
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
F1	EEI	WMI	WMI	StMI	StMI	AMI	AMI
F2	SMU	EEI	SMI	WMI	WMI	StMI	StMI
F3	MU	SMU	EEI	WMI	StMI	StMI	AMI
F4	MU	WMU	WMU	EEI	StMI	AMI	AMI
F5	VSU	StMU	WMU	WMU	EEI	WMI	MI
F6	AMU	StMU	StMU	MU	WMU	EEI	EEI
F7	VSU	VSU	AMU	StMU	MU	EEI	EEI

Contractor 3							
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**
F1	EEI	EEI	StMI	StMI	StMI	VSI	AMI
F2	EEU	EEI	EEI	MI	WMI	StMI	StMI
F3	MU	SMU	EEI	WMI	StMI	StMI	VSI
F4	StMU	SMU	WMU	EEI	StMI	StMI	AMI
F5	StMU	MU	StMU	WMU	EEI	WMI	MI
F6	VSU	StMU	StMU	StMU	WMU	EEI	SMI
F7	VSU	VSU	VSU	MU	MU	SMU	EEI

Table 3. Aggregated decision matrix

	F1	**F2**	**F3**	**F4**
F1	(0.5,0.5),(0.5,0.5)	(0.55,0.45),(0.47,0.53)	(0.63,0.37),(0.35,0.65)	(0.7,0.3),(0.32,0.68)
F2	(0.47,0.53),(0.55,0.45)	(0.5,0.5),(0.5,0.5)	(0.53,0.47),(0.45,0.55)	(0.62,0.38),(0.43,0.57)
F3	(0.35,0.65),(0.64,0.36)	(0.45,0.55),(0.53,0.47)	(0.5,0.5),(0.5,0.5)	(0.6,0.4),(0.4,0.6)
F4	(0.32,0.68),(0.7,0.3)	(0.43,0.57),(0.62,0.38)	(0.4,0.6),(0.6,0.4)	(0.5,0.5),(0.5,0.5)
F5	(0.28,0.72),(0.72,0.28)	(0.35,0.65),(0.64,0.36)	(0.33,0.67),(0.67,0.33)	(0.4,0.6),(0.7,0.3)
F6	(0.23,0.77),(0.78,0.22)	(0.3,0.7),(0.7,0.3)	(0.3,0.7),(0.7,0.3)	(0.33,0.67),(0.74,0.26)
F7	(0.25,0.75),(0.8,0.2)	(0.25,0.75),(0.7,0.3)	(0.22,0.78),(0.78,0.22)	(0.32,0.68),(0.8,0.2)

	F5	**F6**	**F7**
F1	(0.72,0.28),(0.28,0.72)	(0.78,0.22),(0.23,0.77)	(0.8,0.2),(0.25,0.75)
F2	(0.63,0.37),(0.35,0.65)	(0.7,0.3),(0.3,0.7)	(0.7,0.3),(0.25,0.75)
F3	(0.66,0.34),(0.34,0.66)	(0.7,0.3),(0.3,0.7)	(0.78,0.22),(0.22,0.78)
F4	(0.7,0.3),(0.4,0.6)	(0.73,0.27),(0.33,0.67)	(0.8,0.2),(0.32,0.68)
F5	(0.5,0.5),(0.5,0.5)	(0.6,0.4),(0.4,0.6)	(0.65,0.35),(0.35,0.65)
F6	(0.4,0.6),(0.6,0.4)	(0.5,0.5),(0.5,0.5)	(0.52,0.48),(0.48,0.52)
F7	(0.35,0.65),(0.65,0.35)	(0.48,0.52),(0.52,0.48)	(0.5,0.5),(0.5,0.5)

The intuitionistic fuzzy pairwise comparison matrices are aggregated using the $IFWGM^{OP}$ as described in Equation (14). The aggregated matrix is given in Table 3. Then the Intuitionistic fuzzy weighted geometric mean operator is used to integrate the individual intuitionistic fuzzy weights of criteria and sub-criteria. The final intuitionistic fuzzy weights and the normalized weights given in Table 4 are obtained by using Equations (15–17).

Table 4. Importance degrees of the factors

	Individual Fuzzy Weights	**CI**	**SI**	**Normalization**
F1	(0.66,0.34),(0.35,0.65)	0.99	0.71	0.20
F2	(0.59,0.41),(0.41,0.59)	1.00	0.65	0.18
F3	(0.56,0.44),(0.43,0.57)	0.99	0.63	0.17
F4	(0.53,0.47),(0.52,0.48)	0.96	0.52	0.14
F5	(0.43,0.57),(0.59,0.41)	0.99	0.45	0.12
F6	(0.36,0.64),(0.66,0.34)	0.98	0.37	0.10
F7	(0.32,0.68),(0.70,0.30)	0.98	0.33	0.09

The analysis of factors influencing construction pricing reveals several key insights. Environmental uncertainties emerge as the most significant factor, with a score of 0.20, underscoring the profound impact of regulatory changes and market volatility on pricing dynamics. Following closely behind is the uncertainty in material prices and labor costs, with a score of 0.18, highlighting the crucial role of cost fluctuations in shaping construction prices. Supply and demand dynamics also play a substantial role, as evidenced by a score of 0.17, indicating the influence of market forces on pricing strategies. Competition within the industry is another important consideration, albeit slightly less so, with a score of 0.14. Moreover, the scale of the project, as indicated by its size and duration, contributes moderately to pricing decisions, with scores of 0.12 and 0.10, respectively. Lastly, while past project experience provides valuable insights, its influence on pricing decisions appears relatively lower, with a score of 0.09. Overall, these findings shed light on the multifaceted nature of construction pricing, shaped by a complex interplay of environmental, economic, and market factors.

4 Conclusion

In conclusion, this study aimed to define the significance levels of parameters affecting price bids in construction tender processes using a newly proposed method based on the intuitionistic fuzzy analytic hierarchy process with ordered pairs. The analysis revealed several key factors influencing construction pricing, including environmental uncertainties, uncertainty in material prices and labor costs, supply and demand dynamics, competition within the industry, and the scale and duration of the project. Environmental uncertainties emerged as the most significant factor, underscoring the profound impact of regulatory changes and market volatility on pricing dynamics. The findings highlight the complexity of pricing in construction projects and the importance of considering various factors in developing competitive and sustainable pricing strategies. By shedding light on the multifaceted nature of construction pricing, this study contributes to the understanding and management of uncertainties, unbalanced pricing, and risk factors in construction bidding. Moving forward, further research could explore additional factors and methodologies to enhance pricing accuracy and competitiveness in construction projects. Additionally, practical implications of the findings could inform decision-making processes for construction stakeholders, policymakers, and researchers seeking to optimize bid pricing strategies and mitigate risks in tender processes.

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