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Prediction of Key Parameters Affecting Cost and Duration of Sustainable Smart City Construction Projects Using the Fuzzy DEMATEL Model

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ABSTRACT

This study develops prediction models for smart management system of construction projects by identifying the parameters that influence project cost and duration. Among sixteen parameters, the Fuzzy DEMATEL model is applied to a sample of ten construction projects to estimate the net influence weights (D-R) of these parameters on cost and duration of these projects. The outcomes indicated that the model demonstrated high accuracy in predicting the key parameters affecting cost and duration. In particular, both the "application of sustainability standards" and "effective coordination between contractors" significantly impact project cost and duration. On the other hand, "the availability of raw materials" was found to be a parameter with lower influence. Based on these outcomes, the model offers a visualization of causal relationships, which supports in prioritizing smart project efficiency. This study highlights the importance of fuzzy-based methodologies in construction project analysis and offers a practical framework for decision-making to enhance planning and implementation in smart construction projects.

Keywords: Smart city projects, Fuzzy DEMATEL model, Construction project analysis, Project cost and duration, Sustainable development strategies.

1. INTRODUCTION

Smart management systems and renewable energy solutions are a key component of smart construction projects. The smart processes used during the whole project life cycle make better use of resources and improve the quality of life in cities **(Balasubramanian, 2020; Ding, 2008)**. Cost and duration are the most critical for success in the construction of smart city projects **(Yang et al., 2021)**. The project design and the availability of raw materials are the most important parameters that influence the final project cost and delivery timeline **(Hwang et al., 2014; Wu, 2011; Ali and Burhan, 2024)**.
The complexity in the interdependence of these parameters, along with the uncertainty in human judgment, leads to challenges for decision-makers in the smart construction project **(Zingraff-Hamed et al., 2021; Mohammed and Altaie, 2025)**. Therefore, there is an

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increasing demand for advanced analytical models capable of uncovering causal relationships among these factors and systematically prioritizing them. From another context, the previous studies attempt to overcome these challenges by applying a decision-making (FMCDM) system **(Tzeng et al., 2011; Chen-Yi et al., 2007)**.

Therefore, in this study the fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) method is proposed which has demonstrated strong effectiveness in construction project management, particularly in disentangling the multifaceted interactions of parameters **(Wu and Lee, 2007)**. The conventional DEMATEL systems produce crisp numerical values which limits their ability to accurately replicate the nuances of human decision-making. Based on that the integrating fuzzy theory with the DEMATEL method may addressing fuzzy multi-criteria decision-making (FMCDM) problems **(Hussain and Hussain, 2023)**. The fuzzy DEMATEL model is a developed tool for analysing complex systems under uncertainty **(Gabus and Fontela, 1972; Kaufmann, 1988)**. By combining fuzzy set theory with the DEMATEL framework developed, it translates linguistic expert judgements into fuzzy numerical values. Based on that model, raises enable a systematic evaluation of cause-effect relationships among criteria **(Zadeh, 1965; Rajab and Breesam, 2025)**.

This study applies the Fuzzy DEMATEL model to analyze 16 critical parameters. Experts identified the parameters through consensus, Delphi rounds, and the Fuzzy Analytical Hierarchy Process (FAHP) to provide a clear understanding of their impact on the cost and duration of the projects. By mapping the relationships among these parameters, decision-makers can make informed choices that enhance smart project management.

2. FUZZY DEMATEL MODEL

The Fuzzy DEMATEL model is a robust tool for evaluating relationships among variables across multiple fields **(Bavafa et al., 2018; Mahdiyar et al., 2018)**. The conventional DEMATEL technique identifies the relationship criteria based on the multi-criteria decision-making (MCDM) approach **(Lin et al., 2018)**. Nevertheless, Battelle Memorial Institute **(Gabus and Fontela, 1973)** developed the DEMATEL to identify integrated solutions by integrating fuzzy set theory with decision analysis methods. Based on that, Fuzzy DEMATEL is able to map the structure of causal relationships among parameters. The outcome of the DEMATEL is the classification of parameters into two groups, cause and effect **(Nilashi et al., 2019)**, which supports the decision-making process. The technique operates on directional graphs, which display directional relationships between subsystems. According to the literature **(Lafta et al., 2025; Abidali and Ali, 2018)**, the most common approach to handle uncertainty in DEMATEL is by using ordinary fuzzy sets.

The fuzzy approach uses linguistic terms along with predefined membership functions, usually represented as triangular fuzzy numbers. This approach enables handling of ambiguous expert expressions and judgements. **Fig. 1** illustrates the theoretical structure (general framework) adopted for constructing the Fuzzy DEMATEL model **(Nilashi et al., 2019; Dikmen and Taş, 2018)**.

3. RESEARCH METHODOLOGY

3.1 Fuzzy Sets

Fuzzy sets are an approach that uses linguistic terms with membership functions to set the degree in a range between 0 and 1. Based on that partial membership to represent uncertainty, unlike classical sets where elements are either 0 or 1 in a decision-making system **(Başhan and Demirel, 2019)**. The triplet $\tilde{A} = (l, m, u)$ can be used to represent a triangular fuzzy number, where l, m, and u stand for the lower, middle, and upper numbers of the fuzzy, which are real values (x ≤ y ≤ z). A triangular fuzzy function can be explained as follows **(Kumar et al., 2017; Jiang et al., 2016).**

$$\mu_{\tilde{A}} = \begin{cases} 0, & x < 1 \\ (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & x \ge u \end{cases} \tag{1}$$

In **Fig. 2** the triangular fuzzy funiction is illustrated, showing the relationship between linguistic terms and their corresponding triangular fuzzy numbers. Based on that, **Fig. 3** provides fuzzy ratings for each membership function.

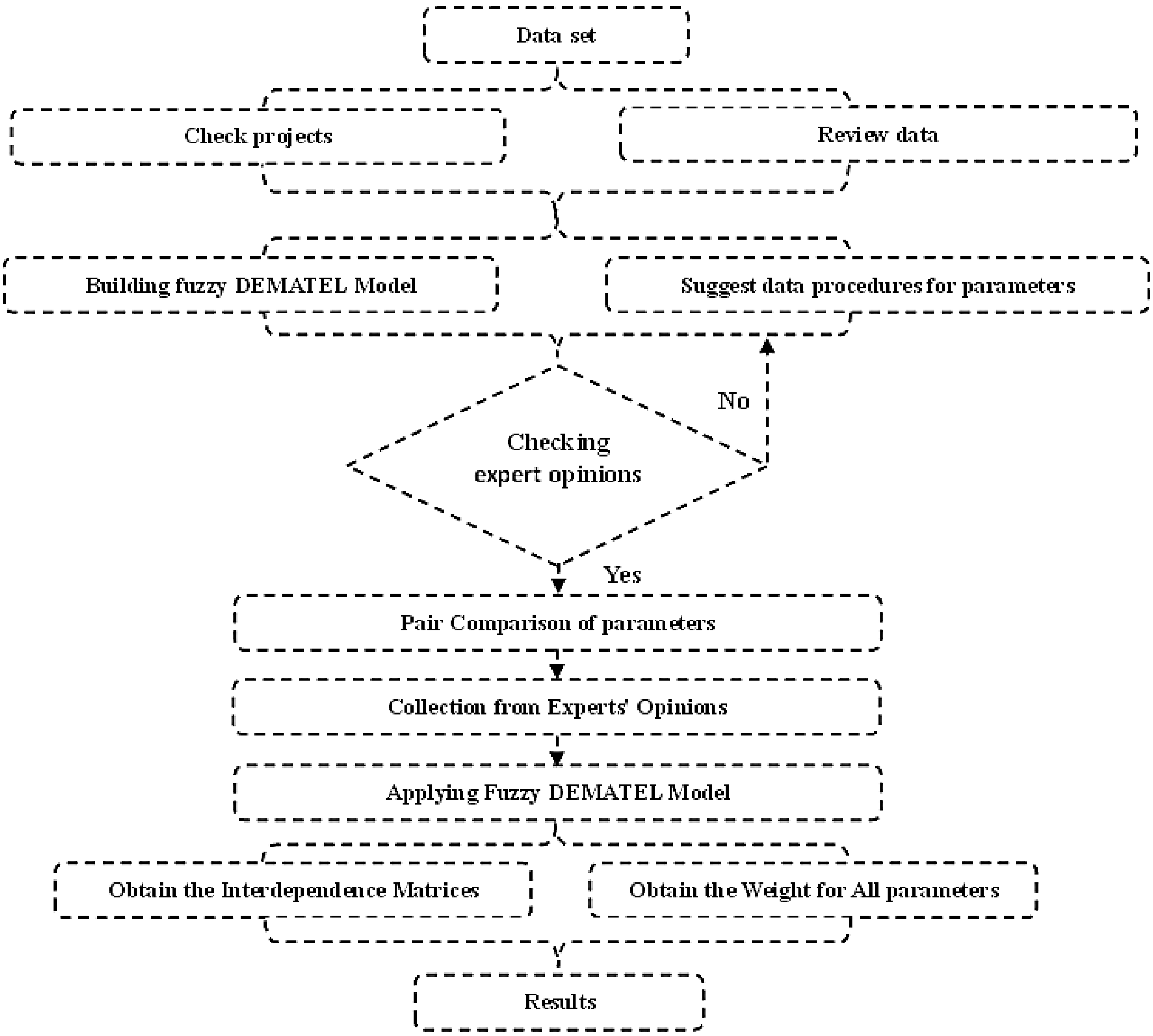

Figure 1. General framework for the Fuzzy DEMATEL Model **(Nilashi et al., 2019; Dikmen and Taş, 2018)**

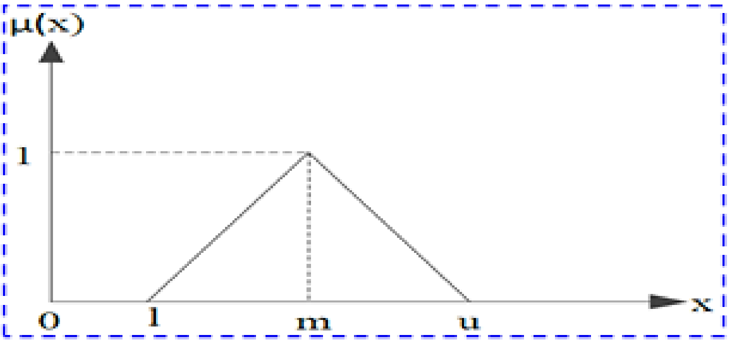

Figure 2. Triangular Fuzzy number **(Jeng, 2015).**

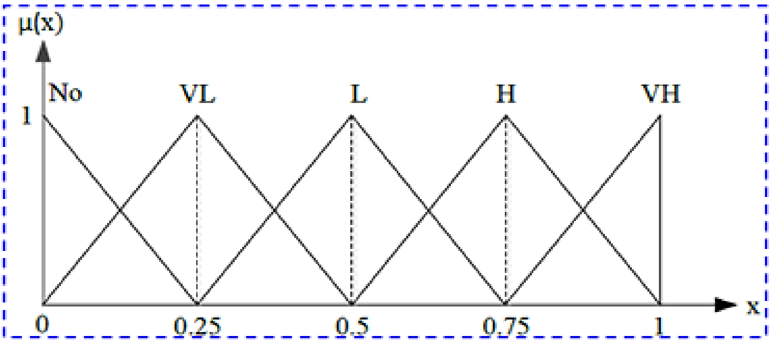

Figure 3. The membership function of fuzzy ratings **(Başhan and Demirel, 2019)**

Table 1. Pairwise comparison of evaluation criteria using a fuzzy scale.

No.	Degree of impact (Influence)	Linguistic Terms	Fuzzy Value (TFNs)		
			L	M	U
1	"Very low influence"	Noi	0	0	0.25
2	"Low influence"	VLi	0	0.25	0.5
3	"Moderate influence"	Mi	0.25	0.5	0.75
4	"High influence"	Hi	0.5	0.75	1
5	"Very high influence"	VHi	0.75	1	1

3.2 Data Collection

The study relied on the parameters identified as the most influential in implementing sustainable smart city projects. These criteria were determined through the Delphi method, and then a fuzzy hierarchical analysis was applied, which led to 16 criteria with the most significant impact on smart city projects. A questionnaire has been used to collect judgments from six experts in planning, consulting, and construction management. The evaluation form is set to collect the opinions, comments, and recommendations on pairwise comparisons of choice parameters. **Table 2** lists the parameters that need to be evaluated by the experts.

Table 2. The respondents' answers are summarized.

No.	Parameters	NOi	VLi	Li	Hi	VHi
1	Preparing all drawings and documents for the project and ensuring the absence of ambiguity in them.					
2	Accurately defining the scope of the specification for the SSCP.					
3	The suitability of the Feasibility Study for the planning stage.					
4	The extent of applying the Sustainability Criteria in implementing sustainable smart projects.					
5	The influence range of designers' experience in the design of SSCP.					
6	The extent of complex design in the implementation of the SSCP.					
7	The suitability of designs for safety procedures such as fire, earthquake, flood, radiation, and eco-environmental accidents					
8	The availability of sustainable raw materials used in project implementation.					
9	The extent of Quality control, monitoring and recording the results of quality activities for SSCP.					
10	The extent of effective coordination between the contractors and subcontractors for project activities.					
11	The extent of application of the optimal use of material resources (minimising resource usage, primary material input and output, waste recovery and disposal operations) in the SSCP.					
12	The extent of application ICT approach in SSCP.					
13	possibility of Eco-efficiency implementation (Green business orientation in terms of products and services) in SSCP.					
14	The possibility of implementing alternative sources of energy in the implementation of the SSCP.					
15	The extent of application safety management system and urban health.					
16	Ensure project implementation within the specified cost and schedule time.					

3.3 Fuzzy DEMATEL Model Steps

Fig. 4 below illustrates the detailed research methodology to implement the proposed fuzzy DEMATEL model. This flowchart includes five main steps detailed in three key phases adopted in this study, from extracting expert knowledge using linguistic variables **(phase 1)** through the computational processing to construct relationship matrices **(phase 2)**, and ending with calculating the net weight influence **(D-R)** for the sixteen parameters on the research sample **(ten projects)** in **(phase 3)**.

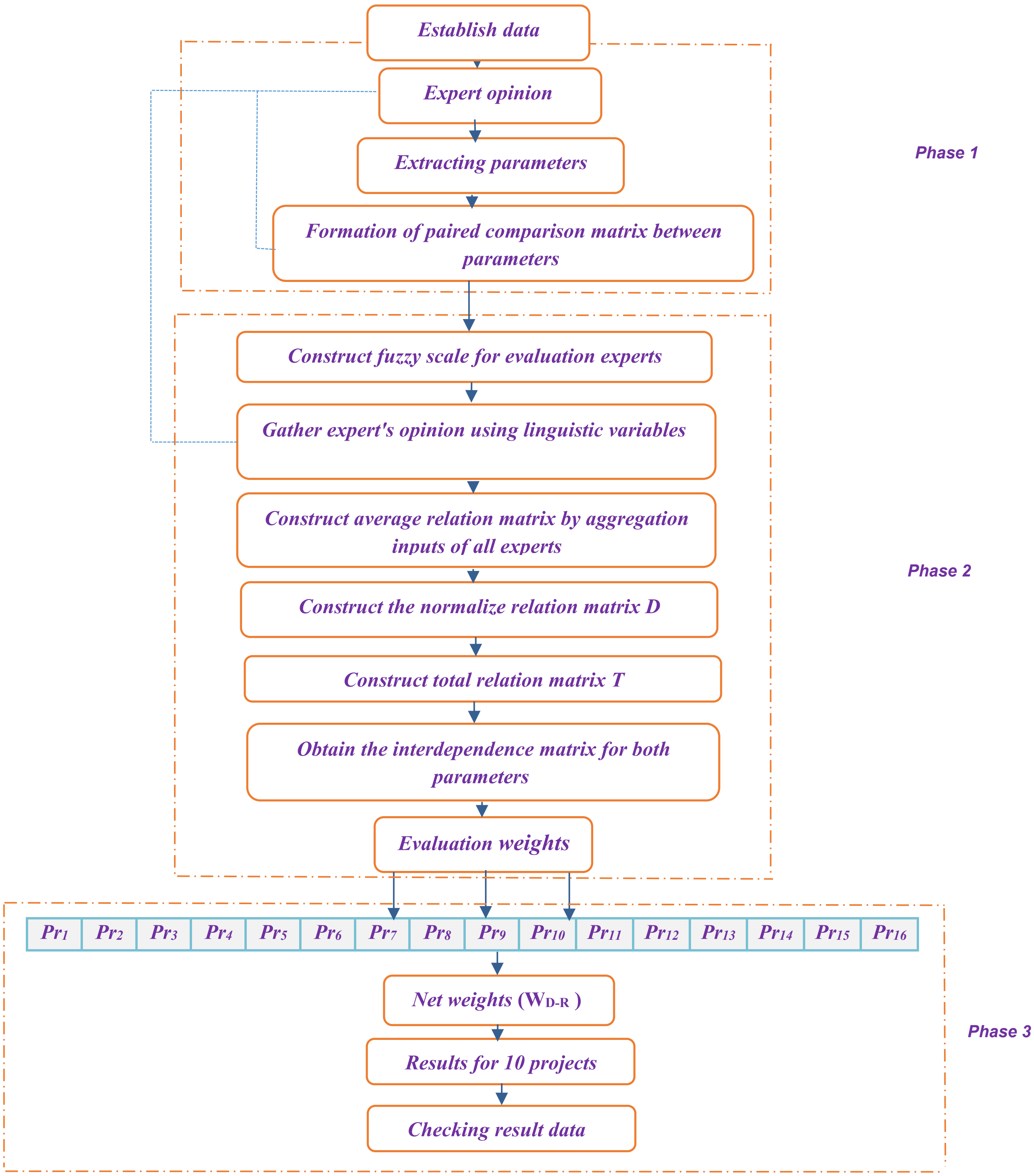

Figure 4. Research methodology for the implementation of Fuzzy Dematel Model

The five main steps are **(Seker and Zavadskas, 2017)**:

1. The first step is creating an orthogonal fuzzy direct-relation matrix sized N×N to determine the relationships among the parameters. In this matrix, the impact of each

row's element on each column's element can be stated as a fuzzy number. The arithmetic mean of all of the experts' judgments is used to build the direct relation matrix z **(Seker and Zavadskas, 2017)**. The fuzzy scale utilized in the model is shown in **Table 1**.

$$Z_{n*n} = [\tilde{z}_{ij}]_{n*n} = \begin{bmatrix} 0 & \cdots\cdots & \tilde{z}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \cdots\cdots & 0 \end{bmatrix} \quad (2)$$

Where: $0 \leq \tilde{z}_{ij} \leq 1$, and i,j=1,2,3,…,n

2. The next step is normalized the matrix; this step is done to transform the “fuzzy criteria scale” to “comparable scales” by using the following formulas **(Wu and Lee, 2007; Başhan and Demirel, 2019)**:

$$\tilde{a}_{ij} = \sum_{j=1}^{n} \tilde{z}_{ij} = \left[\sum_{j=1}^{n} l \; , \sum_{j=1}^{n} m \; , \sum_{j=1}^{n} u\right], \quad \text{Where: } r = \max_{1\leq i\leq n} \sum_{j=1}^{n} u_{ij} \quad (3)$$

$$\tilde{X}_{n*n} = [\tilde{x}_{ij}]_{n*n} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \cdots & \tilde{x}_{nn} \end{bmatrix}, \quad \text{Where:} \tilde{x}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (4)$$

So the fuzzy matrix of the normalized initial direction relation is **(Dikmen and Taş, 2018; Opricovic and Tzeng, 2003)**:

$$l_{ij}^{n} = \frac{\left(l_{ij}^{t} - \min l_{ij}^{t}\right)}{\triangle_{min}^{max}} \quad (5)$$

$$m_{ij}^{n} = \frac{\left(m_{ij}^{t} - \min l_{ij}^{t}\right)}{\triangle_{min}^{max}} \quad (6)$$

$$u_{ij}^{n} = \frac{\left(u_{ij}^{t} - \min l_{ij}^{t}\right)}{\triangle_{min}^{max}} \quad (7)$$

So that… $\triangle_{min}^{max} = \max u_{ij}^{t} - \min l_{ij}^{t}$ (8)

3. Calculate the total-relation matrix with fuzziness. By considering $\widetilde{X} = (\tilde{x}_{ij})_{ij} = (\tilde{l}_{ij}, \tilde{m}_{ij}, \tilde{u}_{ij})_{ij}$
where: $X_l = (\tilde{l}_{ij})_{n*n}$, $X_m\,(\tilde{m}_{ij})_{n*n}$, $X_u = (\tilde{u}_{ij})_{n*n}$
So the elements of these matrices are extracted from $\widetilde{X}$ as follows **(Siet al., 2018):**

$$X_l = \begin{bmatrix} 0 & \cdots & \tilde{l}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{l}_{n1} & \cdots & 0 \end{bmatrix}, \quad X_m = \begin{bmatrix} 0 & \cdots & \tilde{m}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{m}_{n1} & \cdots & 0 \end{bmatrix}, \quad X_u = \begin{bmatrix} 0 & \cdots & \tilde{u}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{u}_{n1} & \cdots & 0 \end{bmatrix} \quad (9)$$

Then the fuzzy total- relation matrix $\tilde{T}$ is obtained as follows **(Mohammed, 2021)**:

$$\tilde{T} = \lim_{K\to+\infty} (\tilde{x}^1 + \tilde{x}^2 + \cdots + \tilde{x}^k) = \begin{bmatrix} \tilde{t}_{11} & \cdots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \cdots & \tilde{t}_{nn} \end{bmatrix} \quad (10)$$

If each element of the fuzzy total-relation matrix is expressed as the $\tilde{t}_{ij} = (l"_{ij}, m"_{ij}, u"_{ij})$It can be calculated by a normalized matrix (X_l, X_m, X_u) is subtracted from matrix I, and multiplied by the normalized matrix as follows **(Ibtisam, 2017; Mohammed, 2021)** :

$$[l"_{ij}] = X_l \times (I - X_l)^{-1} \tag{11}$$
$$[m"_{ij}] = X_m \times (I - X_m)^{-1} \tag{12}$$
$$[u"_{ij}] = X_u \times (I - X_u)^{-1} \tag{13}$$

4. Then, produce a crisp value of the matrix through defuzzification. By calculating the normalized value upper and lower bounds **(Ibtisam, 2017)**:

$$l_{ij}^{s} = m"_{ij} \,/\, \left(1 + m"_{ij} - l"_{ij}\right) \tag{14}$$
$$u_{ij}^{s} = u"_{ij} \,/\, \left(1 + u"_{ij} - l"_{ij}\right) \tag{15}$$

Crisp values are the result of the algorithm. Total normalized crisp values calculation **(Ibtisam, 2017; Lin, 2013):**

$$x_{ij} = \frac{\left(l_{ij}^{s}\left(1-l_{ij}^{s}\right) + u_{ij}^{s} \times u_{ij}^{s}\right)}{\left(1-l_{ij}^{s}+u_{ij}^{s}\right)} \tag{16}$$

5. A causal relationship diagram calculated by summation of rows (D) and columns (R) **(Ibtisam,2017; Talib and Rezouqi,2023)**:

$$D = \sum_{j=1}^{n} T_{ij} \tag{17}$$

$$R = \sum_{i=1}^{n} T_{ij} \tag{18}$$

Then calculate the values of D+R and D-R. D+R signifies the degree of importance of factor i in the overall system, and D-R denotes the net influence of factor i on the entire system.

4. FUZZY DEMATEL ANALYSIS

The Fuzzy DEMATEL Online Software is used to analyze the relationships and determine the weights among the criteria. First, the parameters relevant to the research problem were defined. Then, six experts evaluated the effects among parameters using pairwise comparisons, and rated the impact relationships between parameters as very low influence, low influence, moderate influence, high influence, and very strong influence.
After that, pairwise comparisons were converted into a numerical scale and based on the fuzzy scale described in Table 1, the first direct relationship matrix was generated. **Table 3** displays the direct relation matrix derived from the average of the six experts' evaluations.
Then, initialize a direct connection matrix to normalize the fuzzy direct-relation matrix. The normalized matrix was calculated using equations in step 2, because of the $(\max u_{ij}^{t} = 1 \,\&\, \min l_{ij}^{t} = 0 \; in\; Table\; 3\; so\; the\; \triangle \frac{max}{min} = 1)$ therefore, the $(l_{ij}^{n}, m_{ij}^{n}, u_{ij}^{n})$ remain the same in the normalized fuzzy direct-relation matrix in **Table 4**.

Table 3. The direct relation matrix (average of the six respondents' opinions).

Main	Ex_1	Ex_2	Ex_3	Ex_4	Ex_5	Ex_6
Ex_1	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"
Ex_2	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"
Ex_3	"0.522,0.811,1"	"0.5,0.750,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"
Ex_4	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"
Ex_5	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"
Ex_6	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"

Table 4. The normalized fuzzy direct-relation matrix

Main	Ex_1	Ex_2	Ex_3	Ex_4	Ex_5	Ex_6
Ex_1	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.81,1"	"0.5,0.75,1"
Ex_2	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"
Ex_3	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"
Ex_4	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"
Ex_5	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"	"0.25,0.5,0.75"	"0,0,0"	"0.522,0.811,1"
Ex_6	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"	"0.522,0.811,1"	"0.5,0.75,1"	"0,0,0"

Then, the total-relation fuzzy matrix is computed using the equations in step 3, and shown in **Table 5** below.

Table 5. The fuzzy total-relation matrix.

Main	Ex_1	Ex_2	Ex_3	Ex_4	Ex_5	Ex_6
Ex_1	"0.122,0.512,5"	"0.4,1.170,8"	"0.427,1.152,8"	"0.122,0.512,5"	"0.4,1.170,8"	"0.427,1.152,8"
Ex_2	"0.267,0.889,6.667"	"0.122,0.512,5"	"0.411,1.072,7.333"	"0.267,0.889,6.667"	"0.122,0.512,5"	"0.411,1.072,7.333"
Ex_3	"0.411,1.072,7.333"	"0.427,1.152,8"	"0.122,0.512,5"	"0.411,1.072,7.333"	"0.427,1.152,8"	"0.122,0.512,5.667"
Ex_4	"0.122,0.512,5"	"0.4,1.170,8"	"0.427,1.152,8"	"0.122,0.512,5"	"0.451,1.170,8"	"0.427,1.152,8"
Ex_5	"0.267,0.889,6.667"	"0.122,0.512,5"	"0.411,1.072,7.333"	"0.267,0.889,6.667"	"0.122,0.512,5"	"0.411,1.072,7.333"
Ex_6	"0.411,1.072,7.333"	"0.427,1.152,8"	"0.227,0.882,7.667"	"0.411,1.072,7.333"	"0.427,1.152,8"	"0.122,0.512,5"

Then, the crisp value is calculated using the equations in step 4, where **Table A1** represents the crisp total-relation matrix for the 16 parameters in Appendix A.
Finally, the totals for each column(D) and row(R) of the sixteen-parameter matrix were computed using the equation in step 5 for each of the ten projects, and these values were then used to determine (D + R) and (D – R) for the ten projects. The value of (D + R) indicates the overall degree of relationship among the criteria, whereas (D – R) represents the net influence of each parameter on the (Y cost and Y duration) of the projects.

5. RESULTS AND DISCUSSION

The fuzzy DEMATEL matrices were developed based on an expert opinion poll to evaluate the sixteen parameters, and this analysis led to the final crisp total-relation matrix, which was used to calculate the influential weights and their impact of these parameters on the Key performance indicators of the projects (cost, duration). The positive values of (D + R) and (D – R) presented in **Table 6** indicate that selected parameters show in **Table 2** exhibit strong interrelationships and have a significant impact on the cost and duration of the ten smart construction projects. In the decision-making process, the Fuzzy DEMATEL model is considered an appropriate method for identifying the effect of these parameters involved in implementing sustainable smart city projects. Accordingly, decision-makers rely on Absolute Accuracy (AA%), Mean Percentage Error (MPE%), and Root Mean Square Error (RMSE%). Based on that, the Fuzzy DEMATEL technique provides a more accurate and practical means of predicting the net influence(D-R) of these sixteen parameters on cost and duration of the projects under uncertainty. Furthermore, the Fuzzy DEMATEL approach serves as an effective tool for prioritizing selection criteria and, through its methodological structure, offers a clearer visual and graphical representation of the complex interrelationships among system parameters. The final results for the ten projects are shown in **Table 6.**

Table 6. Final Output for Fuzzy Dematel model for ten projects

Projects	Code	Y_c	Y_d	D	R	D+R	D-R $_{weight}$ (Y)
$Proj_1$	(Ex_1…….Ex_6)	0.1	0.08	3.68	3.26	6.94	0.42
$Proj_2$	(Ex_1…….Ex_6)	0.15	0.06	3.41	3.26	6.67	0.15
$Proj_3$	(Ex_1…….Ex_6)	0.1	0.1	3.65	3.44	7.09	0.21
$Proj_4$	(Ex_1…….Ex_6)	0.15	0.04	4.52	4.42	8.94	0.1
$Proj_5$	(Ex_1…….Ex_6)	0.16	0.05	3.96	3.82	7.78	0.14
$Proj_6$	(Ex_1…….Ex_6)	0.15	0.05	4.56	4.27	8.83	0.29
$Proj_7$	(Ex_1…….Ex_6)	0.15	0.06	4.13	3.57	7.7	0.56
$Proj_8$	(Ex_1…….Ex_6)	0.2	0.15	3.93	2.94	6.87	0.99
$Proj_9$	(Ex_1…….Ex_6)	0.1	0.18	3.25	3.172	6.422	0.078
$Proj_{10}$	(Ex_1…….Ex_6)	0.15	0.17	4.67	4.08	8.75	0.59
Checking result							
FDM			**MPE**		**MAPE**	**AA%**	**RMSE**
FDM $_{Duration}$			56.68		56.68	96.6	3.36
FDM $_{Cost}$			51.9		51.9	75.45	3.08

6. CONCLUSIONS

The results of this study demonstrate that the DEMATEL fuzzy model is an effective analytical tool for examining the parameters that influence the cost and duration of sustainable smart city construction projects. The application of the 16-critical parameter model clearly identified the causal relationships between these factors. The application of sustainability standards and effective coordination among contractors are the most influential parameters on project costs and duration. Furthermore, the results suggest that the availability of raw materials has a relatively minor effect. Furthermore, the DEMATEL fuzzy model provides causal relationships among the parameters to allocate resources efficiently, optimize project performance, reduce costs, besides achieve sustainability goals. Based on the results of the statistical analysis, it is recommended that the DEMATEL fuzzy model be adopted as the primary decision support tool during the planning and execution phases of sustainable smart city construction projects.

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Credit Authorship Contribution Statement

Yerevan A. Ali: Writing - original draft, review and editing, research and data collection. Abbas M. Burhan: Supervision, review and editing, validation, project management.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Abidali, R., and Ali, Y., 2018. Factors affecting on the performance of contractors in constriction project: Bagdad, Iraq. *Journal of University of Babylon for Engineering Sciences*, 26(6), pp. 257-265.

Ali, Y.A., and Burhan, A.M., 2024. Review of smart cities and identifying. *Current Trends in Civil Engineering and Engineering Sciences*,2, P. 479.

Balasubramanian, S., 2020. Stakeholders' role in delivering sustainable supply chains in the construction sector. *International Journal of Society Systems Science*, 12(2), pp. 165-184. https://doi.org/10.1504/IJSSS.2020.108415.

Başhan, V., and Demirel, H., 2019. Application of fuzzy dematel technique to assess most common critical operational faults of marine boilers. *Politeknik Dergisi*, 22(3), pp. 545-555. https://doi.org/10.2339/politeknik.426644.

Bavafa, A., Mahdiyar, A., and Marsono, A.K., 2018. Identifying and assessing the critical factors for effective implementation of safety programs in construction projects. *Safety Science*, 106, pp. 47-56. https://doi.org/10.1016/j.ssci.2018.02.025 .

Chen-Yi, H., Ke-Ting, C., and Gwo-Hshiung, T., 2007. FMCDM with fuzzy DEMATEL approach for customers' choice behavior model. *International Journal of Fuzzy Systems*, 9.(4)

Dikmen, F.C., and Taş, Y., 2018. Applying DEMATEL approach to determine factors affecting hospital service quality in a university hospital: A case study. *Journal of Administrative Sciences*, 16(32), pp. 11-28.

Ding, G.K., 2008. Sustainable construction—The role of environmental assessment tools. *Journal of environmental management*, 86(3), pp. 451-464., https://doi.org/10.1016/j.jenvman.2006.12.025.

Gabus, A., and Fontela, E., 1973. Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility.

Gabus, A., and Fontela, E.J.B.G.R.C., 1972. World problems, an invitation to further thought within the framework of DEMATEL. *Battelle Geneva Research Center, Geneva, Switzerland*, 1(8), pp. 12-14.

Hussain, A., and Hussain, I., 2023. Sustainability assessment for construction projects: A cost-sustainability tradeoff approach. *Journal of Cleaner Production*, 423, P. 138727. https://doi.org/10.1016/j.jclepro.2023.13872 .

Hwang, B.G., Zhao, X., and Goh, K.J., 2014. Investigating the client-related rework in building projects: The case of Singapore. *International Journal of Project Management*, 32(4), pp. 698-708. https://doi.org/10.1016/j.ijproman.2013.08.009 .

Ibtisam A.A., 2017. Developing A framework for integrating sustainability with building regulations for affordable housing projects in Iraq. A Dissertation for Degree of the Doctor, Submitted to the College of Engineering - University of Baghdad– Iraq.

Jeng, D.J.F., 2015. Generating a causal model of supply chain collaboration using the fuzzy DEMATEL technique. *Computers & Industrial Engineering*, 87, pp. 283-295, https://doi.org/10.1016/j.cie.2015.05.007.

Jiang, X.L., Wu, Z.B., and Yang, Y., 2016. A fuzzy DEMATEL method to analyze the criteria for sustainable supplier selection. In Green Building, Environment, Energy and Civil Engineering, pp. 101-108. CRC Press.

Kaufmann, A., 1988. Theory of expertons and fuzzy logic. *Fuzzy Sets and Systems*, 28(3), pp. 295-304. https://doi.org/10.1016/0165-0114(88)90036-X

Kumar, A., Kaviani, M.A., Hafezalkotob, A., and Zavadskas, E.K., 2017. Evaluating innovation capabilities of real estate firms: A combined fuzzy Delphi and DEMATEL approach. *International Journal of Strategic Property Management*, 21(4), pp. 401-416. https://doi.org/10.3846/1648715X.2017.1409291 .

Lafta, S.A., Raheem, H.M., Hassooni, A.N., and Ali, Y.A., 2025. Development of trip production models using household surveys for urban travel demand forecasting. *Engineering, Technology & Applied Science Research*, 15(5), pp. 26952-26958. https://doi.org/10.48084/etasr.11671 .

Lin, K.P., Tseng, M.L., and Pai, P.F., 2018. Sustainable supply chain management using approximate fuzzy DEMATEL method. *Resources, Conservation and Recycling*, 128, pp. 134-142, https://doi.org/10.1016/j.resconrec.2016.11.017 .

Lin, R.J., 2013. Using fuzzy DEMATEL to evaluate the green supply chain management practices. *Journal of cleaner production*, 40, pp. 32-39, https://doi.org/10.1016/j.jclepro.2011.06.010.

Mahdiyar, A., Tabatabaee, S., Abdullah, A., and Marto, A., 2018. Identifying and assessing the critical criteria affecting decision-making for green roof type selection. *Sustainable cities and society*, 39, pp. 772-783. https://doi.org/10.1016/j.scs.2018.03.007.

Mohammed J.A.F., 2021. Fuzzy dematal in construction cost management. International Conference Azadi Online, Iran .

Mohammed, E., and Altaie, M.R., 2025. Review and analysis of smart city evaluation frameworks. *Journal of Engineering*, 31(4), pp. 62-81. https://doi.org/10.31026/j.eng.2025.04.05 .

Nilashi, M., Samad, S., Manaf, A.A., Ahmadi, H., Rashid, T.A., Munshi, A., Almukadi, W., Ibrahim, O., and Ahmed, O.H., 2019. Factors influencing medical tourism adoption in Malaysia: A DEMATEL-Fuzzy TOPSIS approach. *Computers & Industrial Engineering*, 137, P. 106005, https://doi.org/10.1016/j.cie.2019.106005 .

Opricovic, S., and Tzeng, G.H., 2003. Defuzzification within a multicriteria decision model. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 11(05), pp. 635-652. https://doi.org/10.1142/S0218488503002387.

Rajab, N.D., and Breesam, H.K., 2025. Identifying key standards for sustainable school design in Iraq: A survey and statistical analysis. *Journal of Engineering*, 31(4), pp. 27-43. https://doi.org/10.31026/j.eng.2025.04.03 .

Seker, S., and Zavadskas, E.K., 2017. Application of fuzzy DEMATEL method for analyzing occupational risks on construction sites. *Sustainability*, 9(11), P. 2083. https://doi.org/10.3390/su9112083.

Si, S.L., You, X.Y., Liu, H.C., and Zhang, P., 2018. DEMATEL technique: a systematic review of the state-of-the-art literature on methodologies and applications. *Mathematical problems in Engineering*, 2018(1), P. 3696457. https://doi.org/10.1155/2018/3696457.

Talib, M.H., and Rezouqi, S.E., 2023, December. Retraction: Predicted of cost parameters in construction projects using fuzzy logic inference model. *In AIP Conference Proceedings* (Vol. 2977, No. 1, P. 020042). AIP Publishing LLC. https://doi.org/10.1063/5.0182242.

Tzeng, G.H., and Huang, J.J., 2011. Multiple attribute decision making: methods and applications. CRC press.

Wu, W.W., and Lee, Y.T., 2007. Developing global managers' competencies using the fuzzy DEMATEL method. *Expert systems with applications*, 32(2), pp. 499-507, https://doi.org/10.1016/j.eswa.2005.12.005 .

Wu, W.W., 2011. Beyond Travel & Tourism competitiveness ranking using DEA, GST, ANN and Borda count. *Expert Systems with Applications*, 38(10), pp. 12974-12982. https://doi.org/10.1016/j.eswa.2011.04.096 .

Yang, Z., Chen, H., Mi, L., Li, P., and Qi, K., 2021. Green building technologies adoption process in China: how environmental policies are reshaping the decision-making among alliance-based construction enterprises?. *Sustainable Cities and Society*, 73, P. 103122., https://doi.org/10.1016/j.scs.2021.103122 .

Zadeh, L.A., 1965. Fuzzy sets. *Information and control*, 8(3), pp. 338-353, https://doi.org/10.1016/S0019-9958(65)90241-X .

Zingraff-Hamed, A., Bonnefond, M., Bonthoux, S., Legay, N., Greulich, S., Robert, A., Rotgé, V., Serrano, J., Cao, Y., Bala, R., and Vazha, A., 2021. Human–river encounter sites: Looking for harmony between humans and nature in cities. *Sustainability*, 13(5), P. 2864. https://doi.org/10.3390/su13052864.

Appendix A

Table A1 represents the crisp total-relation matrix for the 16 parameters.

Table A1. The crisp total-relation matrix for the sixteen parameters

Parameter	Pr1	Pr2	Pr3	Pr4	Pr5	Pr6	Pr7	Pr8	Pr9	Pr10	Pr11	Pr12	Pr13	Pr14	Pr15	Pr16
Pr1	“ 0.0”	“ 0.24”	“ 0.3”	“ 0.26”	“ 0.23”	“ 0.28”	“ 0.27”	“ 0.3”	“ 0.26”	“ 0.27”	“ 0.15”	“ 0.24”	“ 0.30”	“ 0.26”	“ 0.26”	“ 0.26”
Pr2	“ 0.22”	“ 0.0”	“ 0.29”	“ 0.26”	“ 0.25”	“ 0.25”	“ 0.26”	“ 0.3”	“ 0.28”	“ 0.29”	“ 0.21”	“ 0.15”	“ 0.29”	“ 0.26”	“ 0.25”	“ 0.25”
Pr3	“ 0.16”	“ 0.16”	“ 0.0”	“ 0.19”	“ 0.2”	“ 0.2”	“ 0.22”	“ 0.27”	“ 0.22”	0.24”	“ 0.15”	“ 0.11”	“ 0.16”	“ 0.19”	“ 0.22”	“ 0.21”
Pr4	“ 0.19”	“ 0.18”	“ 0.36”	“ 0.0”	“ 0.24”	“ 0.24”	“ 0.21”	“ 0.27”	“ 0.24”	“ 0.27”	“ 0.19”	“ 0.18”	“ 0.28”	“ 0.16”	“ 0.24”	“ 0.28”
Pr5	“ 0.17”	“ 0.17”	“ 0.27”	“ 0.13”	“ 0.0”	“ 0.18”	“ 0.24”	“ 0.25”	“ 0.22”	“ 0.27”	“ 0.11”	“ 0.18”	“ 0.27”	“ 0.19”	“ 0.14”	“ 0.14”
Pr6	“ 0.17”	“ 0.15”	“ 0.21”	“ 0.19”	“ 0.26”	“ 0.0”	“ 0.13”	“ 0.23”	“ 0.21”	“ 0.23”	“ 0.17”	“ 0.15”	“ 0.21”	“ 0.19”	“ 0.26”	“ 0.18”
Pr7	“ 0.13”	“ 0.14”	“ 0.2”	“ 0.17”	“ 0.22”	“ 0.15”	“ 0.0”	“ 0.15”	“ 0.22”	“ 0.21”	“ 0.12”	“ 0.14”	“ 0.27”	“ 0.17”	“ 0.22”	“ 0.15”
Pr8	“ 0.21”	“ 0.199 ”	“ 0.25”	“ 0.22”	“ 0.21”	“ 0.28”	“ 0.20”	“ 0.0”	“ 0.13”	“ 0.28”	“ 0.21”	“ 0.19”	“ 0.25”	“ 0.22”	“ 0.21”	“ 0.21”
Pr9	“ 0.189 ”	“ 0.167 ”	“ 0.31”	“ 0.21”	“ 0.22”	“ 0.20”	“ 0.19”	“ 0.29”	“ 0.0”	“ 0.25”	“ 0.25”	“ 0.26”	“ 0.30”	“ 0.29”	“ 0.26”	“ 0.25”
Pr10	“ 0.154 ”	“ 0.244 ”	“ 0.21”	“ 0.26”	“ 0.26”	“ 0.28”	“ 0.24”	“ 0.37”	“ 0.23”	“ 0.0”	“ 0.15”	“ 0.24”	“ 0.30”	“ 0.26”	“ 0.28”	“ 0.26”

Pr16	Pr15	Pr14	Pr13	Pr12	Pr11
“ 0.127 ”	“ 0.174 ”	“ 0.171 ”	“ 0.193 ”	“ 0.159 ”	“ 0.219 ”
“ 0.142 ”	“ 0.151 ”	“ 0.168 ”	“ 0.18”	“ 0.155 ”	“ 0.151 ”
“ 0.20”	“ 0.21”	“ 0.27”	“ 0.24”	“ 0.16”	“ 0.32”
“ 0.13”	“ 0.14”	“ 0.23”	“ 0.16”	“ 0.19”	“ 0.14”
“ 0.21”	“ 0.27”	“ 0.14”	“ 0.24”	“ 0.20”	“ 0.25”
“ 0.15”	“ 0.16”	“ 0.18”	“ 0.24”	“ 0.20”	“ 0.28”
“ 0.18”	“ 0.13”	“ 0.22”	“ 0.21”	“ 0.22”	“ 0.26”
“ 0.29”	“ 0.23”	“ 0.25”	“ 0.27”	“ 0.27”	“ 0.30”
“ 0.26”	“ 0.21”	“ 0.22”	“ 0.24”	“ 0.22”	“ 0.28”
“ 0.25”	“ 0.23”	“ 0.27”	“ 0.27”	“ 0.24”	“ 0.29”
“ 0.25”	“ 0.17”	“ 0.17”	“ 0.19”	“ 0.19”	“ 0.0”
“ 0.26”	“ 0.15”	“ 0.16”	“ 0.18”	“ 0.0”	“ 0.15”
“ 0.30”	“ 0.21”	“ 0.27”	“ 0.0”	“ 0.19”	“ 0.29”
“ 0.29”	“ 0.19”	“ 0.0”	“ 0.16”	“ 0.19”	“ 0.24”
“ 0.26”	“ 0.0”	“ 0.14”	“ 0.24”	“ 0.22”	“ 0.28”
“ 0.0”	“ 0.18”	“ 0.14”	“ 0.24”	“ 0.22”	“ 0.25”

التنبؤ بتاثير المعايير الاساسية على كلفة ومدة مشاريع المدن الذكية المستدامة بستخدام نموذج ديميتل الضبابي

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الخلاصة

تطور هذه الدراسة نموذج تنبؤي لمشاريع البناء الذكية من خلال تحديد المعاملات الفعالة التي تؤثر على تكلفة المشروع ومدته التنفيذية. تم اختيار ستة عشر معاملاً تُعتبر الأكثر تأثيراً في تنفيذ المشاريع الذكية. تم تطبيق النموذج المقترح (DEMATEL الضبابي) لتقدير أوزان لهذه المعاملات عبر عشرة مشاريع إنشائية للمدن الذكية. أشارت النتائج إلى أن النموذج أظهر دقة عالية في التنبؤ بالمعاملات الرئيسية المؤثرة على التكلفة والمدة التنفيذ. وعلى وجه الخصوص، فإن كلاً من "تطبيق معايير الاستدامة" و"التنسيق الفعال بين المقاولين" يؤثران بشكل كبير على تكلفة المشروع ومدته التنفيذية. من ناحية أخرى، تبين أن "توافر المواد الخام" يمثل معاملاً ذا تأثير أقل. بناءً على هذه النتائج، يقدم النموذج تصويراً واضحاً للعلاقات السببية، مما يساعد في تحديد أولويات كفاءة المشاريع الذكية. تُبرز هذه الدراسة أهمية المنهجيات القائمة على المنطق الضبابي في تحليل المشاريع الإنشائية، وتوفر إطاراً عملياً لصنع القرار بهدف تحسين التخطيط والتنفيذ في المشاريع الذكية المستدامة.

الكلمات المفتاحية: مشاريع المدن الذكية، نموذج ديمتل الضبابي، تحليل المشاريع الإنشائية، تكلفة المشروع ومدته التنفيذية، استراتيجيات التنمية المستدامة.