Journal of Data Science and Modeling, Vol. 2, No. 1, 39-59, December 2023

Research Manuscript

Intelligent Modeling of Persian Vernacular Architecture Based on the Fuzzy Delphi Method (FDM)

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Received: 01/02/2024 Accepted: 03/03/2024

Abstract: The current research focuses on the fuzzy Delphi technique (FDM) with the aim of introducing a novel approach to modeling Persian vernacular architecture. The main objective of utilizing the Delphi method is to attain the most reliable consensus among a group of expert opinions. This advantage aids in addressing the primary research question: determining the efficacy of the fuzzy Delphi technique in intelligently modeling Persian vernacular architecture. To identify the main factors of the research model, systematic literature reviews were conducted alongside semi-structured interviews with experts. Subsequently, Qualitative Content Analysis (QCA) was employed to extract various themes, which served as the primary factors of the research model. Finally, by applying the fuzzy Delphi technique, the present study examined the degree of certainty and accuracy of these factors in two stages, ultimately identifying 28 factors relevant to the modeling of Persian vernacular architecture.

Keywords: Intelligent modeling; Fuzzy Delphi; Vernacular architectural heritage; Sustainability awareness; Architectural education.

Mathematics Subject Classification (2010): 62A86.

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1. Introduction

The present study aims to highlight the cultural, historical, and environmental significance inherent in vernacular architecture and to impart the narrative of sustainability to students. This objective will be accomplished by employing fuzzy modeling to delineate the innovative and sustainable attributes of Persian vernacular architecture—a unique approach setting this research apart from others. By doing so, this study serves as a conduit between traditional and modern technologies, showcasing the most iconic cultural and historical practices in renewable energy management, focusing on water resources management, energy conservation, and sustainable construction. Employing a research methodology integrating quantitative and qualitative analyses, a fuzzy approach is adopted to tackle the measurement uncertainty associated with qualitative data from focus group discussions. Within this framework, fuzzy logic proves efficacious in addressing complex and ill-defined problems characterized by environmental uncertainty and information fuzziness, thereby offering a robust framework for reasoning (Ramanathan and Sharma (2017)).

2. Statement of Purpose

Persian vernacular architecture stands as an emblematic symbol of our nation's civilization, boasting a rich history of embodying the core tenets of sustainable development. This aspect of Persian heritage encompasses various vernacular architectural marvels such as Kariz, Qanat, Abanbar, Yakhchal, Windcatchers, and Asbaad, which have excelled in renewable resource management. The 'Cultural Heritage, Handcrafts, and Tourism Organization of Iran,' as the sole official entity of the government, bears the responsibility of preserving, safeguarding, and acknowledging Iran's tangible and intangible cultural heritage (Zarghami et al., 2016). Nonetheless, despite the concerted efforts of public organizations to conserve and protect national heritage, many vernacular structures teeter on the brink of destruction. Consequently, the deteriorating maintenance conditions of the few remaining Persian vernacular buildings, such as the Windcatchers of Yazd, the Asbaads of Nashtifan, and other traditional structures in the heart of the country's desert regions, underscore the urgent need for preservation and maintenance of these invaluable architectural legacies (Yousefi Moghadam, 2014). Moreover, the absence of an interactive and dynamic sustainability education program and the imperative to promote Education for Sustainable Development (ESD) within the national educational system necessitates the current research's endeavor to elucidate the historical wisdom embedded in Persian vernacular architecture and model its sustainable features using the fuzzy Delphi Method. This underscores the importance of educating students on the significance of vernacular architectural heritage, with a particular emphasis on conserving and promoting its socio-cultural and sustainable values—an educational initiative falling under the umbrella term of learning for sustainability.

3. Literature Review

3.1 Vernacular Architecture and Sustainability Education

Throughout much of human history, the advantages of vernacular architecture have been acknowledged, though this recognition experienced some decline during the modern era. However, in recent decades, there has been a rapid increase in studies on vernacular architecture, indicating a growing interest among researchers—a trend likely to continue (Nguyen et al. (2019)). Vernacular architecture is often linked to sustainable architecture in the literature, making its study crucial for understanding its self-sustaining principles and climate-conscious approach (Ozorhon and Ozorhon (2020); Biradar and Mama (2017)).

Defined as unpretentious, native, and traditional structures using regional materials (Curl (2006)), vernacular architecture has been a source of inspiration for advancements in sustainable design and planning. Advocating for the efficient use of natural resources, conscious choices of materials, and environmentally low-impact construction methods, vernacular architecture promotes living in harmony with nature, lessening the strain on energy supplies and preventing environmental degradation (Kırbaş and Hızlı (2016); Kazimee (2018)). As such, the increased interest in the sustainable aspects of vernacular architecture is driven by the world's finite energy resources (Fischer et al. (2022)). Additionally, studying vernacular architecture from an energy standpoint can yield significant benefits, particularly in addressing the global energy crisis (Jahanara et al. (2023)).

Despite technological advancements, there is much to learn from the cultural practices embedded in traditional structures (Nguyen et al. (2019)). Therefore, it is crucial to educate students about the role of vernacular architecture in the history of sustainability, especially in architectural education (Ozorhon and Ozorhon (2020)). For example, Abu-Ghazzeh (1997) emphasized the importance of educating university students about their society's built heritage and demonstrating how vernacular architecture principles can solve contemporary issues. Ozorhon and Ozorhon (2020) highlighted the value of learning about vernacular architecture in architectural education programs, proposing a course called 'Learning from Vernacular Architecture' (LF-VA), which significantly raised student awareness of the subject. Moreover, the book "Vernacular Architecture in the Twenty-First Century: Theory, Education, and Practice" (Asquith and Vellinga (2006)) addresses key topics related to vernacular architecture, including theories, approaches to understanding, and its role in architectural education (Ozorhon and Ozorhon (2020)).

Despite the extensive literature on vernacular architecture, limited empirical research exists on modeling Persian vernacular architecture using fuzzy studies. To address this research gap, the current study emphasizes the importance of learning from the history of Persian architectural heritage, achieved through fuzzy modeling of its most sustainable features.

3.2 Fuzzy Logic

The theoretical basis of fuzzy logic was established in early 1965 by Professor Zadeh at the University of California, Berkeley (Zadeh (1965)). Fuzzy logic has been used to handle uncertainty in human-centered systems analysis, serving as a way to deal with complex, imprecise, uncertain, and vague data (Nunes and Simões-Marques (2012)). It is a simple, direct, and natural approach for transforming linguistic descriptions into mathematical models (Manoharan et al. (2011)). Fuzzy logic attempts to solve problems with an open, imprecise spectrum of data and heuristics, making it possible to obtain an array of accurate conclusions. This mathematical technique is based on the observation that people make decisions based on imprecise and non-numerical information. In this context, fuzzy models or fuzzy sets are mathematical means of representing vagueness and imprecise information (Babuška (1998)).

Regarding the main goal of the current research in intelligent modeling of Persian vernacular architecture using qualitative data, the method of fuzzy logic can be considered as one of the best analytical methods and tools for analyzing research findings in the form of quantitative models and patterns and for assessing the measurement uncertainty of qualitative data related to focus group discussions; an advantage which helps the researchers to answer the main question of the research.

4. Research Methodology

The present study employs a mixed-method research design, combining both quantitative and qualitative methods. Considering this, the qualitative part of the current research includes the systematic literature review as well as focus group discussions. For this purpose and according to the aim of the current research in modeling Persian vernacular architecture, the researchers collect and analyze qualitative data using a sequential procedure in three stages.

Firstly, the main indicators of the vernacular architecture model will be identified by Qualitative Content Analysis (QCA). QCA is a research method in which features of textual, visual, or aural material are systematically categorized and recorded for analysis. In this context, the current study benefits from various types of academic sources, such as digital libraries, review book chapters, peer-reviewed journal articles, conference papers, and archival studies. At this stage, interviews with experts and professors who have expertise, experience, and proficiency with high scientific and research background in the field of research are used to complete the theoretical foundations of the research. It should be noted that the experts were selected based on judgmental sampling and snowball sampling methods. Judgmental sampling, also called purposive sampling or authoritative sampling, is a non-probability sampling technique in which the sample members are chosen only based on the researcher's knowledge and judgment. Therefore, at this stage, the adequacy index of the number of interviews is the Theoretical Saturation. The term theoretical saturation refers to the point at which no additional issues or insights emerge from the data, and all relevant conceptual categories have been identified, explored, and exhausted.

Then, in the second stage and through different quantitative techniques, the effectiveness of the indicators identified in the first stage is examined and confirmed. Finally, in the third stage, the network between them will be investigated for the purpose of fuzzy modeling. The next section provides an overall view of the research three-step methodology.

4.1 The first stage: Qualitative Content Analysis: QCA (qualitative research)

Qualitative Content Analysis involves a process designed to condense raw data into categories or themes based on valid inference and interpretation. This process uses inductive reasoning, whereby themes and categories emerge from the data through the researcher's careful examination and constant comparison (Mirzadeh (2009)). According to Corbin and Strauss, in qualitative research, data are not in the form of numbers and figures but in the form of words and sentences (Corbin andStrauss (2014)). Since the current research aims to present a model that can conceptualize the components of vernacular architecture by collecting qualitative data, this study adopts an inductive approach and exploratory methodology. Considering this, Qualitative Content Analysis has been chosen to analyze the qualitative data of the first stage of the research, in which the key structure is based on Codes, Categories, and Themes. In this research, after gathering and collecting the data and defining the keywords extracted from reviewing papers and interviewing experts, the relevant phrases are classified, and the key concepts are deduced; this stage is called "coding of keywords." In the next step, the resulting codes are analyzed, and the codes that have common themes are grouped. These common topics are known as "categories." Next, the common categories together form a "Theme" that has larger and more abstract concepts. The formation of categories and themes will eventually lead to the emergence of the key findings of the study, which can be finally displayed in the forms of the most contributing factors and the main indicators of the research model.

4.2 The second stage: Structural Equation Modeling (quantitative research)

One of the most appropriate analysis methods in behavioral science and social science research is Multivariate analysis (MVA). MVA involves evaluating multiple variables to identify any possible association among them. In this context, structural equation modeling is a practical tool for solving many problems of social and behavioral research. These methods are a set of statistical methods for modeling relationships between research variables, which consist of factor analysis, regression, and path analysis methods. This method, which is an extension of the general linear model, shows the researcher the possibility of establishing several relationships between variables simultaneously, and hence it is also called the Multiple Linear Regression (MLR) (Habibi et al. (2015)). Considering this, the main purpose of examining these techniques in the current research is to study the effect of the factors identified in the first stage on the fuzzy modeling of Persian vernacular architecture.

4.3 The third stage: Fuzzy modeling

The fuzzy Delphi technique is a powerful technique that utilizes triangulation statistics to determine the distance between the levels of consensus within the expert panel. It is a method of group decision-making and iterative forecasting that involves consulting a panel of experts and implementing systematic feedback rounds (Latifi et al. (2019)). The fuzzy Delphi technique was presented in 1985 by Murray, Pipino, and Gigch to solve the problems, ambiguities, and inconsistencies observed in the classic Delphi method, in which "triangular fuzzy numbers" are used to explain the experts' opinions and focus group discussions (Azar and Taghiani (2014)). Considering this, the current research applies fuzzy numbers to gather the opinions of experts to analyze them through the fuzzy technique. Therefore, according to the research methodology in using the fuzzy logic technique, in the first step, the two endpoints of triangular fuzzy numbers are formed by the maximum and minimum values of experts' opinions. In this case, the maximum and minimum values of experts' opinions will be considered as boundary points of fuzzy triangular numbers, and the geometric mean will be used as the degree of membership of fuzzy triangular numbers to remove the effect of boundary points. It is worth mentioning that, in conducting the analysis using the Fuzzy Delphi technique, all the comments and suggestions put forth by experts should be considered for improvement (Nurul et al. (2019)). The four steps of the Fuzzy Delphi Method (FDM) are as follows:

- **Reviewing papers and interviewing experts** In the first step, and in order to find the initial indicators of the research model, experts are asked to determine the degree of the importance of each identified factor using verbal variables.

- **Converting verbal variables into triangular fuzzy numbers** At this step, first, the opinions of 20 experts about each indicator are collected, and then these values are aggregated. To aggregate the opinions of n respondents, verbal variables will be defined as triangular fuzzy numbers. As seen in Table 3, these numbers can be shown as (l, m, u), which indicate the smallest likely value, the most probable value, and the largest possible value of any fuzzy event.

- **Defuzzification** In the fuzzy logic method, the researcher will be able to summarize the average sum of triangular fuzzy numbers by a definite value that has the best corresponding average. In other words, the final outputs of a fuzzy system must be converted into precise values. It is called 'defuzzification', which aims to convert fuzzy quantities into precise values. Therefore, if the output numbers related to the indicators are more than 0.7, it is interpreted as the approval of each indicator (Azar and Taghiani (2014)).

- **The distance between the levels of consensus within the expert panel** In the last step, the repetition of the Delphi steps will proceed until the expert's disagreement between the two stages of the survey falls below a minimal threshold (0.2), in which the survey process is stopped (Cheng and Lin (2002)).

5. Collecting and analyzing the research data

5.1 Collecting research literature (library studies)

The first step in intelligent modeling is to identify the main indicators of the research model. Therefore, the main question of this step is defined as follows:

"What are the main effective factors in the modeling of Persian vernacular architecture?" This stage starts by reviewing and studying the literature of the research to create a deeper understanding and recognition of the main features of Persian vernacular architecture. For this purpose, and using the systematic review approach, the related academic resources, such as papers, have been identified and then by studying them carefully, a list of the most important factors contributing to the research model has been completed in the first step.

5.2 The first survey of experts (interview)

In this step, expert opinions were obtained through meetings and in-depth interviews. Therefore, 20 experts, including a combination of experts working in different professions related to the research topics, were selected through Judgmental Sampling and Snowball Sampling methods. During the interview, the key issues raised by the interviewees were noted down and after the end of each part of the interview, while summarizing the interviewee's conversations, the key points taken by the interviewer were given feedback to confirm or reject them.

5.3 Integration of research literature and experts' opinions (Thematic analysis)

In order to analyze the qualitative data of the research, the "Thematic analysis" method was applied. Thematic analysis is a method of analyzing qualitative data. It is usually applied to a set of texts, such as an interview or transcripts. The researcher closely examines the data to identify common themes – topics, ideas, and patterns of meaning that come up repeatedly (Asgharpour (2007)). Therefore, using thematic analysis, the data related to the papers and experts' opinions were reviewed and coded, and in this way, various concepts used in this research were extracted. These concepts are divided according to their main contents in the form of conceptual categories. These categories were classified into 28 different themes as table 1.

Table 1: The most effective factors in intelligent modeling of Persian vernacular architecture (combination of the first survey of expert and papers)

Code	Indicators	Expert Codes	Sources
R1	Harnessing renewable energy using sustainable and cultural practices		Zarghami et al. (2016) Yousefi Moghadam (2014)
R2	Using nature-inspired strategies in sustainable		Nguyen et al. (2019) Kazimee (2018)

	energy management		
R3	Compatibility with heritage, values and local needs (Principle of Humanism)		Zarghami et al. (2016) Salman (2018)
R4	Using the potential of geographical and ecological infrastructure of the region		Jahanara et al. (2023)
R5	Turning environmental challenges and threats into opportunities, by focusing on climate-specific design principles	7-2	Kırbaş and Hızlı (2016) Abu-Ghazzeh (1997)
R6	Considering the role of natural factors (light, wind, rainfall, etc.) in climatically compatible design	16	Jahanara et al. (2023) Curl (2006)
R7	Using eco-friendly and cost-effective local materials, to reduce energy consumption (Principle of self-sufficiency)	1-12	Asquith and Vellinga (2006) Kazimee (2018)
R8	Using green and sustainable building practices methods with low environmental impact	16	Ozorhon and Ozorhon (2020)
R9	Focusing on 'social sustainability' in design and architecture (The three fundamental pillars of sustainable development)	2-3-5-6 8-9-10-11 11-13-18 19-20	Nguyen et al. (2019) Salman (2018)
R10	Focusing on 'environmental sustainability' in design and architecture (The three fundamental pillars of sustainable development)	1-2-3-10	Jahanara et al. (2023) Kırbaş and Hızlı (2016)
R11	Focusing on 'economic sustainability' in design and architecture (The three fundamental		Kırbaş and Hızlı (2016)

	pillars of sustainable development)		
R12	Focusing on sustainable principles of green architecture	1-3-4-6 8-9-10-18	Nguyen et al. (2019) Salman (2018)
R13	Realization of the Iranian-Islamic Lifestyle		
R14	Focusing on the proportions of human, nature, and architecture (Principle of Holism)		Kazimee (2018) Yousefi Moghadam (2014)
R15	Considering the impact of environmental psychology on architectural design in order to maintain the comfort and well-being of the users	2-3-5-6 8-9-10-11-18-19	Yousefi Moghadam (2014)
R16	Commitment to harmony geometric order in the design of vernacular architecture		
R17	Considering the role physical components in the design of vernacular architecture	2	Abu-Ghazzeh (1997)
R18	Using local knowledge, skills and technology within traditional sustainable practices	2-3-8-11	Zarghami et al. (2016)
R19	Design and development of natural air conditioning systems using local climate conditions	2-6-8-13	
R20	Avoiding futility by using optimal site potential and creating multi-functional spaces	3-4-10	
R21	Focusing on improving and developing greenspaces	3-16	
R22	Development and promotion of sustainable lifestyle by creating harmony with	5-14	Salman (2018) Biradar and Mama (2017)

	nature		
R23	Designing sustainable structures that reduce the cost of repairs and maintenance	5	
R24	Creating a sense of belonging to the place for the indigenous peoples and local communities	6-14-19	Biradar and Mama (2017)
R25	Utilizing Minimalist design with focus on practicality of the spaces	7-14	Zarghami et al. (2016) Ozorhon and Ozorhon (2020)
R26	Creating symbols and cultural icons of indigenous people with placed-based architecture	8	
R27	Avoiding imitation throughh innovative design with problem-solving approach	8	
R28	Having the potential to solve major current environmental problems, such as energy crisis and climate change		Jahanara et al. (2023)

5.4 The second survey of experts (questionnaire)

Considering the important role of focus group discussions in the current research, 20 experts, including a combination of university professors and experts working in academia, have been selected and were asked to evaluate the degree of importance of the most contributing factors in modeling the sustainable features of Persian vernacular architecture. To do so, the researchers used a questionnaire with five-point Likert scale by which experts expressed their opinions regarding the importance of the factors identified by the scales such as, "Not at all important," "Low importance," "Moderately important," "Very important," and "Extremely important."

As can be seen from Table 2, among the 28 predetermined indicators, all indicators were identified as acceptable. Therefore, in the next step and in order to determine the validity of the questionnaire, content analysis was used. Content analysis is a research tool used to determine the presence of certain words, themes,

Table 2: The most effective factors in intelligent modeling of Persian vernacular architecture (The second survey of experts)

Code	Mean	Standard deviation	t-statistic	Sig.	Result
R1	4.40	0.50	12.46	0.0001	accepted
R2	4.55	0.51	13.58	0.0001	accepted
R3	4.25	0.55	10.16	0.0001	accepted
R4	3.55	1.15	2.15	0.0450	accepted
R5	4.25	0.72	7.80	0.0001	accepted
R6	4.45	0.51	12.70	0.0001	accepted
R7	4.20	0.95	5.64	0.0001	accepted
R8	3.80	0.89	4.00	0.0010	accepted
R9	3.85	0.93	4.07	0.0010	accepted
R10	3.70	0.86	3.62	0.0020	accepted
R11	3.55	0.89	2.77	0.0120	accepted
R12	3.35	1.27	2.23	0.0320	accepted
R13	3.45	0.94	2.13	0.0250	accepted
R14	3.80	0.95	3.76	0.0010	accepted
R15	3.75	0.97	3.47	0.0030	accepted
R16	4.10	1.07	4.59	0.0001	accepted
R17	4.05	0.76	6.19	0.0001	accepted
R18	4.00	0.79	5.63	0.0001	accepted
R19	3.90	0.64	6.28	0.0001	accepted
R20	3.50	0.95	2.36	0.0290	accepted
R21	4.30	0.80	7.26	0.0001	accepted
R22	4.15	0.93	5.51	0.0001	accepted
R23	3.85	0.93	4.07	0.0010	accepted
R24	4.20	0.62	8.72	0.0001	accepted
R25	4.00	0.86	5.21	0.0001	accepted
R26	4.25	0.79	7.11	0.0001	accepted
R27	3.75	0.72	4.68	0.0001	accepted
R28	4.05	0.69	6.84	0.0001	accepted

or concepts within given qualitative data (i.e., text). Using content analysis, researchers can quantify and analyze the presence, meanings, and relationships of such certain words, themes, or concepts. In this context, the "Not at all important" to "Moderately important" scales were coded as zero, and "Very important" to "Extremely important" scales were coded as one.

The first step in determining the validity of the test is to examine the content validity. Content validity depends on the logical analysis of the content of a test, which is determined based on the experts' judgment. In this method, the main questionnaire is given to experts, and they are asked to determine whether the questions accurately measure the intended attribute and align with the research's main goals or not. If there is a high level of consensus among the expert panel, that test has content validity. In the next step and based on the number of experts who evaluated the validity of the questionnaire, the minimum value of CVR is considered acceptable. Therefore, the questions for which the calculated CVR is less than the given value should be excluded from the test. Considering this, the minimum acceptable CVR value based on the number of 20 experts is 0.6. Since the coefficients of all the extracted themes are higher than 0.6, it can be concluded that all the themes of the main model have been recognized as important from the point of view of all the experts. It should be mentioned that in order to evaluate the levels of consensus within the expert panel, Holsti's coefficient of reliability was used with the following formula:

$$PAo = \frac{2A}{N1 + N2} = \frac{2 \times 311}{336 + 327} = 0.938 \tag{5.1}$$

In this formula, PAo is the percentage agreement between the two coders, A is the number of coders' decisions in two stages of coding, $N1$ is the total number of decisions taken by the coders in the first stage, and $N2$ is the total number of decisions and coded units in the second stage. This number ranges from zero (no agreement) to one (complete agreement). It should be noted that in order to achieve an acceptable reliability in qualitative studies, the levels of consensus within the expert panel must be at least 80%, and in this study, Holsti's coefficient of reliability is 0.938, which indicates an acceptable level of reliability. After designing the questionnaire, the 20 experts are asked to express their opinions about the degree of validity of the questionnaire. Krippendorff's alpha (α) was also used as another reliability coefficient to re-measure the level of consensus among experts. It should be noted that the acceptable coefficient for agreement between experts should be at least more than 0.67, which according to the results, this value is equal to 0.83 in the present study. Therefore, it is concluded that the levels of consensus within the expert panel are high, and the questionnaire has acceptable validity to collect the data of the research.

After a relatively comprehensive review of the research literature and experts' opinions and identification of the contributing factors to the final model, in order to establish a relationship between the main indicators of the vernacular architecture model and achieve a conceptual model, the fuzzy Delphi analysis method was used for the final modeling. The fuzzy studies of the current research are carried out in three steps as follows.

5.4.1 Analysis of indicators

In the first step, the verbal variables related to the experts' opinions are defined as triangular fuzzy numbers (l, m, u), which respectively indicate the smallest likely value, the most probable value, and the largest possible value of any fuzzy event. According to the results listed in Table 3, all the indicators had a Crisp number greater than 0.7, indicating the confirmation of the indicators derived from the opinions of experts.

5.4.2 Fuzzy Delphi analysis of indicators

In this stage, the confirmed indicators were once again exposed to the judgment of experts, and then the amount of disagreement between the experts was calculated in two stages of the fuzzy Delphi method. The Delphi steps are repeated until the point at which the experts' disagreement between the two stages of the survey falls below a very low threshold (0.2), at which point the survey process concludes. Therefore, the following steps, separated by variables, show the results of this step of the research: According to the Crisp values of the above tables, no indicator was eliminated in the second round, indicating the end of the process of identifying the most contributing factors to the research model. The identification of factors concludes when the average results of the first and second survey steps are compared, and if the difference between them is less than the very low threshold (0.2), the survey process is terminated. Therefore, 28 verified indicators in two steps were determined as the final indicators of the research model. In the end, and according to the obtained information, the entropy level of each indicator (E_j) is calculated as follows, with k as a constant value keeping the value of E_j between 0 and 1. In this regard, the value of m indicates the number of options:

$$E_j = -k \sum^{m} i = 1pijln(p_{ij}), \quad k = \frac{1}{ln(m)} \tag{5.2}$$

Subsequently, the degree of deviation (d_j) is calculated, which explains to what extent the relevant indicator provides useful information for modeling. In the next step, according to the formula $d_j = 1 - E_j$, the value of weight (W_j) is calculated. Finally, by using the relation $W_j = \frac{d_j}{\sum d_j}$, calculations related to the entropy

Table 3: The results of the first step of fuzzy studies

Code	L	M	U	Crisp	Results
R1	0.640	0.835	0.950	0.808	accepted
R2	0.643	0.838	0.945	0.808	accepted
R3	0.590	0.805	0.930	0.775	accepted
R4	0.633	0.825	0.938	0.798	accepted
R5	0.620	0.823	0.945	0.796	accepted
R6	0.610	0.818	0.935	0.788	accepted
R7	0.928	0.828	0.945	0.800	accepted
R8	0.600	0.810	0.940	0.783	accepted
R9	0.605	0.808	0.933	0.782	accepted
R10	0.655	0.845	0.950	0.817	accepted
R11	0.640	0.830	0.938	0.803	accepted
R12	0.603	0.813	0.935	0.783	accepted
R13	0.600	0.810	0.940	0.783	accepted
R14	0.585	0.795	0.928	0.769	accepted
R15	0.665	0.845	0.948	0.819	accepted
R16	0.615	0.820	0.940	0.792	accepted
R17	0.655	0.845	0.950	0.817	accepted
R18	0.600	0.810	0.940	0.783	accepted
R19	0.598	0.810	0.930	0.779	accepted
R20	0.675	0.858	0.955	0.829	accepted
R21	0.695	0.870	0.960	0.842	accepted
R22	0.608	0.815	0.940	0.788	accepted
R23	0.660	0.848	0.955	0.821	accepted
R24	0.615	0.820	0.940	0.792	accepted
R25	0.545	0.778	0.915	0.746	accepted
R26	0.625	0.825	0.950	0.800	accepted
R27	0.570	0.793	0.925	0.763	accepted
R28	0.645	0.838	0.955	0.813	accepted

Table 4: The results of the second step of fuzzy studies

Code	L	M	U	Crisp	Results
R1	0.648	0.840	0.950	0.813	accepted
R2	0.663	0.850	0.950	0.821	accepted
R3	0.683	0.863	0.955	0.833	accepted
R4	0.678	0.860	0.950	0.829	accepted
R5	0.695	0.870	0.960	0.842	accepted
R6	0.643	0.838	0.945	0.808	accepted
R7	0.665	0.845	0.948	0.819	accepted
R8	0.758	0.910	0.970	0.879	accepted
R9	0.703	0.875	0.960	0.846	accepted
R10	0.718	0.885	0.960	0.854	accepted
R11	0.668	0.853	0.955	0.825	accepted
R12	0.698	0.873	0.955	0.842	accepted
R13	0.715	0.883	0.965	0.854	accepted
R14	0.728	0.890	0.970	0.863	accepted
R15	0.723	0.888	0.965	0.858	accepted
R16	0.695	0.870	0.960	0.842	accepted
R17	0.720	0.885	0.970	0.858	accepted
R18	0.675	0.858	0.955	0.829	accepted
R19	0.623	0.820	0.928	0.790	accepted
R20	0.693	0.868	0.965	0.842	accepted
R21	0.718	0.885	0.960	0.854	accepted
R22	0.713	0.880	0.970	0.854	accepted
R23	0.673	0.850	0.948	0.823	accepted
R24	0.648	0.840	0.950	0.813	accepted
R25	0.650	0.843	0.945	0.813	accepted
R26	0.653	0.838	0.943	0.811	accepted
R27	0.735	0.895	0.970	0.867	accepted
R28	0.660	0.848	0.955	0.821	accepted

Table 5: The distance between the value of the first and second steps of fuzzy analysis

Code	1^{st} Value	2^{nd} Value	deviant	Results
R1	0.813	0.808	0.004	Agreement
R2	0.821	0.808	0.013	Agreement
R3	0.833	0.775	0.058	Agreement
R4	0.829	0.798	0.031	Agreement
R5	0.842	0.796	0.046	Agreement
R6	0.808	0.788	0.021	Agreement
R7	0.819	0.800	0.019	Agreement
R8	0.879	0.783	0.096	Agreement
R9	0.846	0.782	0.064	Agreement
R10	0.854	0.817	0.037	Agreement
R11	0.825	0.803	0.023	Agreement
R12	0.842	0.783	0.058	Agreement
R13	0.854	0.783	0.071	Agreement
R14	0.863	0.769	0.093	Agreement
R15	0.858	0.819	0.039	Agreement
R16	0.842	0.792	0.050	Agreement
R17	0.858	0.817	0.042	Agreement
R18	0.829	0.783	0.046	Agreement
R19	0.790	0.779	0.011	Agreement
R20	0.842	0.829	0.013	Agreement
R21	0.854	0.842	0.013	Agreement
R22	0.854	0.788	0.067	Agreement
R23	0.823	0.821	0.002	Agreement
R24	0.813	0.792	0.021	Agreement
R25	0.813	0.746	0.067	Agreement
R26	0.811	0.800	0.011	Agreement
R27	0.867	0.763	0.104	Agreement
R28	0.821	0.813	0.008	Agreement

indicators will be analyzed. It should be noted that the lower weight suggests that the indicator's effect is consistent across all options, and its significance in the final decision-making process is minimal and insignificant. In the final analysis phase of the research, the effectiveness of the fuzzy Delphi technique in intelligent modeling of Persian vernacular architecture is determined. For this purpose, the variable representing the impact of using fuzzy modeling on increasing the certainty and accuracy of the research results ranges from 1 to 28. Values less than or equal to 3 are considered to have no effect, while values greater than 3 are deemed impactful. As shown in the table above, the average effect of using intelligent fuzzy modeling to improve the accuracy of research results is 3.83, with a standard deviation of 0.85, a t-statistic of 6.65, and a significance level of 0.0001. Consequently, at the 0.05 significance level, the null hypothesis is rejected, while the alternative hypothesis is accepted. This indicates the effective use of intelligent fuzzy modeling in enhancing the accuracy and certainty of research results.

6. Summary and conclusions

Limited empirical research exists in the realm of modeling vernacular architecture, particularly with a focus on intelligent modeling using fuzzy logic techniques. Addressing this research gap, the current project emphasized the importance of employing the fuzzy Delphi method (FDM) and Qualitative Content Analysis (QCA) to determine the main factors of the research model and address the measurement uncertainty of qualitative data.

The research aimed to utilize the fuzzy Delphi method for intelligently modeling the sustainable features of Persian vernacular architecture and evaluate its efficacy in analyzing qualitative data. The findings identified 28 effective factors crucial for fuzzy modeling of Persian vernacular architecture. The fuzzy Delphi technique served as a robust analytical method to accurately analyze data from existing literature and research interviews, capable of recognizing, representing, manipulating, interpreting, and utilizing vague and uncertain data. This approach highlights the rationale behind employing fuzzy logic in the study and its advantage in enhancing the accuracy of qualitative results, modeling ambiguous and imprecise data, and quantifying the most sustainable features of Persian vernacular architecture.

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Table 6: Indicators rank calculation using Shannon entropy

Code	entropy	d_j	W_j
R1	0.980	0.020	0.014
R2	0.982	0.018	0.013
R3	0.845	0.155	0.109
R4	0.914	0.086	0.060
R5	0.857	0.143	0.100
R6	0.972	0.028	0.020
R7	0.992	0.008	0.005
R8	0.970	0.030	0.021
R9	0.989	0.011	0.008
R10	0.963	0.037	0.026
R11	0.999	0.001	0.001
R12	0.996	0.004	0.003
R13	0.937	0.063	0.044
R14	0.941	0.059	0.041
R15	0.982	0.018	0.012
R16	0.937	0.063	0.044
R17	0.967	0.033	0.023
R18	0.974	0.026	0.019
R19	0.987	0.013	0.009
R20	0.954	0.046	0.033
R21	0.949	0.051	0.036
R22	0.998	0.002	0.002
R23	0.988	0.012	0.008
R24	0.971	0.029	0.020
R25	0.989	0.011	0.008
R26	0.942	0.058	0.041
R27	0.095	0.051	0.036
R28	0.928	0.072	0.051

Table 7: A one sample t-test result, the effect of using intelligent fuzzy modeling on improving the accuracy of research results

Mean	Standard deviation	t-statistic	df	Sig.
3.83	0.85	6.65	19	0.0001

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