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Original Research

Developing a Hybrid SWOT-MCDM Framework for Formulating Smart Technology Adoption Strategies in Urban Construction Under Conditions of Uncertainty: A Case Study of Qom Municipality

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Abstract:

Smart technology adoption in urban construction is a key driver toward the development of smarter cities. However, the complexities and uncertainties associated with technology acceptance necessitate strategic planning based on structured decision-making frameworks. A hybrid SWOT–MCDM framework was developed under uncertainty for formulating effective strategies for smart technology adoption. In the first phase of the study, a modified six-dimensional SWOT model, including the traditional dimensions (Strengths Opportunitie (SO), Weaknesses Opportunities (WO), Strengths Threats (ST), Weaknesses Threats (WT)) along with two additional dimensions (Weaknesses Strengths (WS), Opportunitie Threats (OT)) was employed to identify and categorize the key facto+rs influencing technology adoption. In the second phase, the Multi-Criteria Decision-Making (MCDM) approach under Uncertainty was utilized to prioritize the resulting strategic alternatives. The proposed framework was implemented in Qom Municipality - Iran. The findings revealed that among the identified factors, "holding training workshops and seminars" with a weight of 0.1152 was the most influential sub-factor in the strengths category. Furthermore, the evaluation of proposed strategies based on the SWOT framework indicated that the SO strategy (leveraging strengths to exploit opportunities) ranked first with a score of 4.826, followed by the SW (4.660), ST (3.809), WO (3.845), WT (3.338), and OT (3.259) strategies, respectively. This prioritization demonstrates that focusing on maximizing strengths and opportunities can facilitate the successful development and implementation of smart technologies. Sensitivity analysis confirmed the robustness and validity of the prioritization results. Hence, the framework can serve as a tool for policy-makers and urban planners in formulating targeted strategies and making informed investment decisions in innovative construction infrastructures.

Keywords: Developing; Strategy; Smart technology adoption; Urban construction industry; Multi-criteria decision-making (MCDM); Four-dimensional SWOT matrix; Six-dimensional SWOT matrix

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1. Introduction

Urban centers or cities are complex ecosystems that are established by humans with diverse interests and tendencies and include a set of interpersonal and intergroup interactions to achieve a desirable and sustainable environment for growth and an appropriate and standard quality of life. Nowadays, there is an increasing focus on the development of smart city projects, technologies, and systems related to this phenomenon in the world, including Iran, and governments are trying to provide the necessary infrastructure to create cities with features that can be described as a smart city [1]. On the other hand, a city can be considered a smart city if its economic, social, and environmental development is balanced, and this development is achieved through democratic processes and participatory governance of the government and citizens. As a tool for enhancing the citizens' life quality, the concept of smart city has gained increasing importance on the agenda of policymakers. The concept of smart cities has attracted increasing attention in the past few years as a model for addressing issues such as global population growth, environmental challenges, and the significant role of information technology in society. Of the world's population, 54% currently lives in urban areas, which is anticipated to reach 60% by 2030. In Iran, more than 63.5 million people, about 75% of the population, live in cities, which has caused a major environmental and demographic crisis [2]. On the other hand, economic developments after the Industrial Revolution have led to drastic changes in the size of cities and population. Meanwhile, the development of smart cities with the help of technology is on the rise. Information and communication technology have been increasingly considered a tool for creating sustainable smart cities. Since around 90% of the global digitized data has been recorded in the last two years, many municipalities around the world have begun to use big data for developing and sustaining smart cities [3]. They have also considered key smart city characteristics, standards, values, and specifications of innovative city programs that lead to sustainability, enhanced quality of life, governance, long service cycles, and smart use of urban and natural resources. Today, the development of information technology in Iran has been considered by the government and the private sector to identify, transfer, absorb, localize, and accompany global knowledge of smartization. Smartization is a process used to apply information and communication technology and infrastructures to respond to urban challenges [4]. Tehran, Mashhad, Tabriz, Arak, Qom, Isfahan, Shiraz, Kish Island, Urmia, and other cities have joined this process. Studies have shown that smart cities are on the rise because transforming the cities digitally can enhance people's quality of life and well-being [5]. The activation of smart cities is done with the help of the urban construction industry, which is the foundation for the creation, development, and reuse of the environment. Despite the important role of smart cities in each country's economy, the urban construction industry has had an important effect on the environment via air pollution, noise, waste production, and undesirable use of energy in the urban construction phase [6]. The smart building concept uses smart technology to decrease energy use and enhance users' comfort and satisfaction. Smart buildings are generally called buildings with an integrated service platform for managing energy facilities intelligently, controlling consumption, and adopting security systems. Balta Balta-Ozkan et al. [7] describe smart buildings as places equipped with a communication network, home appliances, sensors, and devices with remote monitoring, evaluation, or control and with services meeting the residents' requirements. Smart buildings can also be described as structures that are connected flexibly, interact with the ecosystem, and are capable of producing, storing, and consuming energy more efficiently. A smart city should be aligned with the components of sustainable development (society, environment, and economy) [8]. Industry and academic experts agree that smart cities offer an ideal solution to address the challenges of urbanization, population growth, environmental pollution, and energy efficiency [9]. Smart cities help improve urban living standards economically, socially, and environmentally. Smart cities are designed to boost the competitive advantage of cities, increase sustainability, enable smart citizens to live in the real world, and are used as a means to manage urban and environmental challenges [10]. If smart cities use their resources efficiently, the results will lead to the use of tangible (transportation infrastructure, natural resources, and energy distribution networks) and intangible (intellectual capital of companies, human capital, and organizational capital in governmental departments) assets [11, 12]. On the other hand, an important and notable issue is that the urban construction industry has low productivity and high reliance on labor. This industry deals with multiple stakeholders and is generally resistant to new changes [13], which has led to the lack of smart technology adoption in the urban construction industry. Thus, the urban construction industry lags behind other industries in adopting new technologies. Despite the fact that the urban construction sector is widely recognized as a late adopter of innovative technological advancements, few studies have considered the following two important points:

1) Presenting strategic plans to stakeholders and partners for adopting smart technologies in the urban construction industry.

2) Developing strategic plans for adopting smart technologies in the urban construction industry, the results of which will lead to the start of digital transformation in the construction industry [14].

Given the importance of the presented material, the researchers aim to fill the knowledge gap that identifies strengths, weaknesses, opportunities, and threats in smart technology adoption in the urban construction industry. Accordingly, they present a flexible strategy for the development and strategic recognition of smart technology adoption in the urban construction industry due to the fact that strategic management encompasses both the theoretical and practical aspects of devising, executing, and assessing multifaceted decisions that enable the organization to achieve its objectives. Based on this definition, strategic management focuses on integrating project management, cost, time, quality, and development. According to many researchers, the strategy formulation phase is the most fundamental step in the strategic management process. In the strategy

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formulation phase, first, a vision is prepared for implementing and using smart technology in the urban construction industry, the surrounding environment is analyzed, and the existing opportunities and threats are identified. Next, internal potentials, shortcomings, and weaknesses are extracted. Then, objectives are defined according to the analyses of internal and environmental conditions by considering the missions of implementing and using smart technology in the urban construction industry. Afterward, strategies are extracted based on internal factors (strengths-weaknesses) and environmental factors (opportunities-threats). These strategies are often extracted from a matrix called Strength, Weakness, Opportunity, and Threat (SWOT), the results of which lead to the proposal of strategies to stimulate the growth of implementation and implementation of smart technology in the urban construction industry. While the results of the traditional four-dimensional SWOT matrix lead to strategies for the adoption of smart technologies in the construction industry, they exhibit a range of deep knowledge gaps that are addressed and refined in the present study from two analytical perspectives. In the first perspective, strategies for smart technology adoption are analyzed using both the original four-dimensional SWOT matrix and its modified six-dimensional version. In fact, the use of the six-dimensional framework offers superior analytical capacity and greater flexibility in strategy formulation-advantages that are particularly critical in complex and turbulent environments such as the construction industry. This enhanced model not only provides a stronger deductive basis for analyzing organizational factors but also creates a broader analytical space for developing integrated and innovative strategies. In the extended six-dimensional framework, two new dimensions have been added to the traditional SWOT matrix [15]:

1) **Fifth dimension: Opportunity-Threat (OT) strategies:** These strategies leverage environmental opportunities to mitigate or neutralize external threats. For instance, the use of digital payment tools such as cryptocurrencies to counteract the threat of international financial sanctions on Iranian companies, or the utilization of regional cooperation mechanisms to offset global trade pressures, are examples of such strategies. Analytically, this dimension enables the identification and exploitation of synergies between two opposing environmental forces.

2) **Sixth dimension: Weakness-Strength (WS) strategies:** In this dimension, the organization aims to compensate for or correct its internal weaknesses by capitalizing on its internal strengths. Examples include employing experienced and skilled human resources to train new or less qualified staff, or allocating robust technical and knowledge-based resources to underperforming units. This dimension proves to be particularly critical and practical under specific conditions such as sanctions, resource limitations, or internal organizational crises.

Importantly, these two new dimensions are derived from empirical observations and the practical needs of organizations in real-world operational environments. They can be regarded as a form of strategic reverse engineering-in other words, those strategic approaches that are already being informally adopted by many organizations are now systematically and analytically represented within this new framework. From a theoretical standpoint, this development aligns with contemporary environmental analysis approaches (such as the works of Fahey and Narayanan [16]; Courtney et al. [17]), which emphasize that more precise categorization and integrative analysis of environmental components lead to more accurate decision-making. Empirically, domestic studies—such as those by Motallebi et al. [15], Ataei-Qaracha and Davoudi [18], and Bararinia [19] have demonstrated that the use of the extended SWOT framework results in the extraction of strategies that cannot be adequately conceptualized or positioned within the traditional SWOT matrix. Therefore, the revised six-dimensional SWOT framework is not only a conceptually defensible extension but also, from a practical standpoint, more compatible with the complex and dynamic realities of technology-driven projects in the construction sector. It serves as a more powerful tool for developing realistic, integrated strategies.

In the second perspective, a SWOT model is used to evaluate and prioritize the strategies for adopting smart technologies flexibly, which is done using the hybrid Multi-Criteria Decision Making (MCDM) method under uncertainty for appropriate budgeting and determining a roadmap for developing smart technology in the urban construction industry. Since the SWOT method (in its four-dimensional and six-dimensional forms) cannot give an analytical method to measure the efficacy and rank these strategies based on their importance, a hybrid MCDM method under uncertainty was produced to prioritize the previous sequence of strategies. By merging the MCDM and SWOT techniques, stakeholders/decision makers can make the right decisions by prioritizing these strategies that significantly impact the development, implementation, and adoption of smart technology in the urban construction industry. In the present study, an innovative integrated hybrid MCDM framework under uncertainty was developed to prioritize strategies for adopting smart technologies in the urban construction industry. This three-stage hybrid framework comprises: (1) the use of the fuzzy Delphi method for screening SWOT factors, (2) the fuzzy FUCOM (Full Consistency Method) for determining the weights of criteria, and (3) the fuzzy COCOSO (Combined Compromise Solution) method for ranking strategic alternatives. In the first stage, the fuzzy Delphi method was employed to extract a valid and consensus-based set of key Strengths, Weaknesses, Opportunities, and Threats (SWOT factors). This approach enabled the aggregation and refinement of expert linguistic opinions under conditions of uncertainty, significantly contributing to the validation and finalization of the primary components. In the second stage,

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the fuzzy FUCOM method was utilized for weighting the selected criteria. This method reduces the number of required pairwise comparisons to a minimum ($n - 1$) while maintaining full consistency in decision-makers' preferences. Additionally, it enables direct processing of fuzzy data without the need for defuzzification. Its mathematically structured yet simple design makes it especially suitable for complex decision-making environments, particularly those involving qualitative data. In the third stage, the fuzzy COCOSO method was applied to rank the strategic alternatives. By combining the strengths of techniques such as SAW (Simple Additive Weighting) and WPM (Weighted Product Model), and integrating multiple priority functions, COCOSO is capable of delivering robust and precise ranking outcomes. Furthermore, its ability to manage fuzzy and linguistic data renders it highly effective in decision-making scenarios characterized by uncertainty. The integration of FUCOM and COCOSO within a fuzzy environment yields several significant advantages for MCDM applications, including:

- High accuracy in weighting criteria through FUCOM's consistency-based structure;
- Effective uncertainty management via the incorporation of fuzzy set theory throughout all analytical phases;
- Stable and reliable ranking results facilitated by COCOSO's comprehensive aggregation mechanism;
- High flexibility in handling linguistic and subjective expert inputs.

Furthermore, the notable innovations and unique contributions of this study in employing a hybrid approach for evaluating smart technology adoption strategies in the urban construction industry are as follows:

1) Development of an innovative three-stage decision-making framework, incorporating the fuzzy Delphi method for screening SWOT factors, the fuzzy FUCOM for determining the weights of criteria, and the fuzzy COCOSO method for ranking strategies-applied for the first time in the domain of urban smart technologies.
2) Systematic integration of fuzzy logic theory throughout all phases of the MCDM process, aimed at effectively managing uncertainty and enhancing the analytical accuracy in complex, linguistically-driven environments.
3) Introduction of an analytical model to overcome the limitations of the conventional SWOT method, which on its own lacks the capability for quantitative evaluation and priority-based ranking of strategic alternatives.
4) Application of novel and relatively underutilized methods, such as FUCOM and COCOSO, within the construction industry, thereby expanding methodological diversity and improving the generalizability of the model to similar challenges in urban planning and technology domains.
5) Proposal of a practical roadmap for urban decision-makers, achieved through the precise multi-criteria prioritization of smart technology strategies, which can serve as a strategic tool for policymakers and project managers in guiding smart urban development.

2. Related works

2.1 Review of related works on the adoption of smart technology in the urban construction industry

Smart technology adoption in the urban construction industry is changing how cities are designed, built, and managed. This integration of advanced technologies increases efficiency and sustainability and addresses the growing demand for environmentally friendly infrastructure. A literature review on the adoption of smart technology in the urban construction industry shows that most studies have concentrated on the obstacles and strategies surrounding the adoption of smart technology in the construction industry. For example, in a study titled "Emerging Technologies in the Construction Industry: Challenges and Strategies in Ghana," Kissi et al. [20] stated that the application of innovative technologies significantly affects several sectors universally. However, the construction industry is certainly moving slowly in technology adoption. Therefore, the present research utilized a pragmatic quantitative approach to determine technologies appearing in the construction industry while considering the stakeholders' obstacles and strategies. A structured questionnaire was used to collect data from 80 construction stakeholders. Data were analyzed using descriptive statistics, one-sample t-test, and mean score ranking. The results quantified the challenges of stakeholders regarding technologies emerging in the construction industry and suggested strategies to enhance their application in a developing country. On the other hand, in a study titled "Benefits of Using Smart Building Technologies in Building Construction in Developing Countries", Ejidike and Mewomo [21] reported that smart building has a large market due to digitalization and advantages for the construction industry. Given the universal interest, smart building construction has been turned into a development trend. Research shows smart buildings are more popular than traditional buildings. Yet, construction experts have shown little interest in adopting smart building technology in developing countries. Therefore, this paper aims to identify the benefits of adopting Smart Building Technologies (SBTs) in the construction industry. This study was conducted based on a systematic review of articles published in reputable journals and conferences. A total of 55 articles, including conference and journal articles, retrieved from the Scopus database were used in the study. The findings of this study revealed efficient energy consumption,

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cost-effective building maintenance and operation, job creation, healthcare management, real-time monitoring, safety, and security as the benefits of SBTs. For the advancement of SBTs in emerging economies, it is essential to understand their benefits. This not only enhances the knowledge of construction professionals but also promotes its successful adoption in these areas. Therefore, this research gains insights into the benefits of SBTs in developing countries and at the same time suggests the development of a synergistic framework between the research community and construction experts. In a study titled "Challenges and Strategies for Adopting Smart Technologies in the Construction Industry", Zhu et al. [22] showed that although smart technologies on the Fourth Industrial Revolution can potentially promote industry performance by enhancing work processes and environment, their application in the construction industry is still in its early stages. Therefore, this research aimed to (1) explore barriers to smart technology adoption, (2) suggest efficient strategies to enhance their adoption, and (3) determine organizations' vital differences in the perception of strategies and challenges. To this end, a complete literature review and pilot interviews were performed with industry professionals, following which a survey and post-survey interviews were carried out. The results showed major issues were sharing information, compliance with regulations, and ownership of data, and the most efficient strategies were training expert construction manpower, communication and change management, and providing governmental motivation. Moreover, the significance of regulatory challenges was interpreted differently among organizations of varying sizes. Dixon and Umeokafor [23] explored the determinants of adopting smart technology in the construction projects. They reported that the slow pace of smart technology adoption, challenged the industrial development. In the United Kingdom, the determinants of innovation in the construction phase of a project are hardly understood, which impacts the industry's performance. The study of the current scope fills this gap by determining and evaluating the factors determining innovation in the construction stage. Unstructured exploratory interviews and a structured survey were conducted with construction professionals in the UK. The results indicated that customer demand strongly determines the innovation rate and application of technology in a project. Yet, the industry comprises about 99% Small and Medium-sized Enterprises (SMEs), many of which operate small-scale operations for customers who do not have the budget and incentive to drive innovation in a project. Therefore, SMEs are not exposed to smart technology developments and consequently do not have the skills to affect customers' decisions on innovation. However, big construction companies, including those bidding for government projects, are making extensive progress in researching and developing smart construction technology and implementing it in projects. The implications of the results, although restricted by the sample size, involve inequality as a principal obstacle to innovation in the construction sector, indicating the industry's lack of skills. As a result, the UK government should, together with major construction companies, facilitate monetary incentives and educational programs via organizations such as the Construction Industry Training Board (CITB) to bolster the enhancement of workforce competencies, encompassing individuals engaged in small and medium-sized enterprises (SMEs). Ngo et al. [24], in a study titled "The Impact of Smart Technologies on Construction Projects: Improvement in Project Performance", stated that a lack of knowledge of the advantages of using smart technologies leads to low acceptance in the construction industry. Hence, the present study aims to investigate the most beneficial smart technologies, project performance improvement by implementing smart technologies, and the correlation between smart technologies and project performance improvement. For this purpose, a literature review, interviews, and a survey were first conducted, which showed that the smart technologies that are driving progress include autonomous and robotic vehicles, additive manufacturing, cyber-physical systems, and the Internet of Things (IoT), with projects benefiting the most in terms of productivity, quality, and collaboration. Several correlations were also found between the rankings of perceived benefits and technologies. These findings allow for a better understanding of smart technologies in projects and improved project performance, providing a ground for facilitating the digital construction development. Moreover, in a study entitled "Barriers to the Adoption of Smart Building Technologies in Construction Project Management Processes," Ghansah et al. [25] showed that the most reported barriers in this field include long approval processes for SBTs, the construction industry structure, the high costs of smart building methods and resources, lack of familiarity with SBTs, and technical difficulties during the construction process. A literature review shows that most of the research has emphasized the problems and strategies for adopting smart technology in the urban construction industry and has not provided a comprehensive and accurate review of the current situation and appropriate strategic plans for urban construction projects. For this purpose, considering the study gap and its importance, SWOT analysis was used to analyze the smart technology adoption strategy in the urban construction industry. SWOT analysis is a powerful instrument for current organizations. This matrix helps analysts discover and manage opportunities by recognizing threats, focusing on strengths, and reducing weaknesses to place them in the most appropriate position. Although there is no doubt that the SWOT tool is powerful and useful, studies over the past few decades have shown that, like any technique, it has limitations, which are discussed below in the initial model and its innovation, respectively.

2.2 The initial SWOT model and research innovation

SWOT analysis is an established method to aid strategy development and is often used to investigate the internal and external environments of an organization [27]. It categorizes the main strengths and shortcomings attributed to the system and compares them with the present and future ones [28]. It is extensively employed in strategic planning, where each factor influencing the system environment is examined in detail. Evaluating the internal environment of the system determines the strengths and weaknesses, while evaluating the external environment of the system reveals the opportunities and threats [29]. SWOT analysis summarizes the most important and influential factors related to the internal and external environments that may influence the organization's future, which are usually called strategic factors [30]. The SWOT matrix is determined by identifying the above parameters, identifying four types of strategies: Strengths-Opportunities (SO) strategy, Weakness-Opportunities (WO) strategy, Strengths-Threats (ST) strategy, and Weakness-Threats (WT) strategy. As indicated in Table 1, correct application of SWOT is a good basis for designing a strategy. In the following, each of the four strategies is described:

1) **SO Strategy:** This strategy represents internal strengths and the use of external opportunities. All organizations strive to reach this point by using ST, WO, or WT strategies to reach a point where they use SO strategy to turn weaknesses into strengths and threats into opportunities for the organization.

2) **WO Strategy:** With this strategy, the organization tries to improve internal weaknesses by taking advantage of opportunities in the external environment. Sometimes there are opportunities outside the organization, but the organization cannot take advantage of these opportunities due to internal weaknesses.

3) **ST Strategy:** This strategy encourages the organization to use its strengths to resist external threats or reduce or eliminate them.

4) **WT Strategy:** Organizations that use this strategy take a defensive stance to decrease internal weaknesses and prevent threats from the external environment. A company with these conditions, which has many internal weaknesses, will face many external threats and will fight for its survival, so it tries to reduce its activities (downsizing or divestiture strategies), merge with other companies, declare bankruptcy, or finally dissolve.

Several examples of successful use of SWOT analysis can be seen in areas such as regional energy planning [31], sustainable energy development [32], and power supply [33], bioenergy and wind energy [34], solar energy [35], environmental policy and management [36], shale gas development [37], and municipal solid waste management [38]. Several European nations have used SWOT analysis to prioritize strategies and assure the stability of horizontal policies in the country. However, a major drawback of the conventional SWOT analysis is that the importance of each element in the decision-making process cannot be measured and it is difficult to assess which element had more effect on a strategic decision. In other words, the SWOT method does not provide an analytical means to figure out the relative importance of individual factors or the potential to assess the desirability of alternative options based on such elements. Some of the key drawbacks of the traditional SWOT method are as follows:

1) Oversimplification: SWOT analysis may lead to simplification of complex situations and prevent organizations from identifying some key strategic calls.

2) Lack of prioritization: Due to the qualitative nature of the statements in the SWOT matrix, it is not possible to prioritize them quantitatively, which can lead to confusion in decision-making.

3) Lack of transparency: Some factors may be simultaneously considered strengths and weaknesses. For example, the location of a store can be both a strength (high accessibility) and a weakness (high rental costs).

4) Applying personal opinion: SWOT analysis is usually based on subjective perceptions, which may lead to different interpretations and subject the data to personal biases.

5) Focusing on internal factors: Many businesses focus more on internal strengths and weaknesses in SWOT analysis and neglect to identify external opportunities and threats.

6) Lack of quantitative data: Using qualitative perceptions instead of quantitative data may reduce the accuracy of the analysis and produce inaccurate results.

7) Inconsistencies in diagnosis: Sometimes managers may have inconsistencies in diagnosing a factor as a threat or an opportunity, which can confuse decision-making.

8) Lack of flexibility in building strategies in the four-dimensional matrix.

In short, the traditional and four-dimensional SWOT model is one of the simplest and most practical models

Table 1. Traditional four-dimensional SWOT model [26].

Four-Dimensional SWOT matrix	Strength (S)	Weakness (W)
Opportunity (O)	SO (First Dimension)	WO (Second Dimension)
Threat (T)	ST (Third Dimension)	WT (Fourth Dimension)

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in determining strategies for adopting smart technology in urban construction and decision-making strategies in many industries and services. It is currently being used in management, administration, engineering, medicine, agriculture, and other fields due to its ease of understanding and application. While being practical and comprehensive, this matrix also has important shortcomings and ambiguities which were presented on a case-by-case basis. This research addressed the shortcomings of the initial model and expanded it to a more flexible and practical one. In the following, the innovation of this research is presented in five parts, as follows:

1) Identifying strengths, weaknesses, opportunities, and threats to develop a strategic plan for adopting smart technology in the urban construction industry in the current conditions using a six-dimensional model.

2) Assessing the importance of the criteria used to develop a flexible strategic plan for smart technology adoption in the urban construction industry using the Full Consistency Method (FUCOM) in conditions of uncertainty: The FUCOM analysis in uncertain conditions, in weighing and ranking the relevant criteria and sub-criteria in SWOT, creates a more reliable and effective analysis and a more reliable ranking in the model, thereby creating strategies by combining the most important criteria and sub-criteria with the highest weight.

3) Identifying potential strategies for smart technology adoption in the urban construction industry in the current situation using the traditional four-dimensional SWOT matrix and the six-dimensional matrix presented: Expanding and developing the four-dimensional SWOT matrix and creating a six-dimensional matrix provides more flexibility and efficiency for presenting different strategies. Strategies of a nature have been added to the matrix, many of which are currently applicable to decision-making in many organizations but cannot be explained and located in the four-dimensional matrix. Therefore, the design of this matrix and the inclusion of dimensions will make this matrix more flexible and closer to reality. It can be argued that the added dimensions are considered a type of reverse engineering. In other words, several types of strategies currently being implemented in many organizations are transferred from the applied environment to the matrix. The added dimensions are:

A) **The fifth dimension, called OT:** The fifth dimension includes strategies that use existing environmental opportunities to repel or reduce environmental threats.

B) **The sixth dimension, called WS strategy:** It includes strategies that attempt to use internal strengths to eliminate existing weaknesses. An overview of this framework is shown in Table 2.

The reasons and theoretical basis for this choice are briefly and convincingly explained below:

- **Acknowledging the Limitations of Traditional SWOT and Moving Toward More Dynamic Versions:** The strategy literature indicates that the traditional form of SWOT provides a cross-sectional, two-dimensional (internal/external) analysis and has limited ability to represent complex interactions or temporal aspects. Consequently, various researchers have proposed "dynamic" and "extended" versions of SWOT to model trends, uncertainties, and interactions among driving factors. This progression is both observed and recommended in the literature, and our study follows this methodological trajectory.
- **Theoretical Justification for the WS Dimension (Weaknesses–Strengths Interaction):** Resource-Based View (RBV) and Dynamic Capabilities perspectives emphasize that organizational resources and internal structures interact with one another, and their impact on organizational outcomes is not merely the arithmetic sum of strengths and weaknesses. Rather, it is the combination and mode of interaction that determines outcomes. The WS dimension explicitly identifies how existing strengths can mitigate weaknesses (or vice versa) and provides a more operational approach for designing internal strategies (e.g., enhancing internal synergies). This level of analysis is not covered in conventional SWOT, making the addition of WS theoretically and practically justified. (This is also conceptually linked to TOWS and the matching of internal and external factors.)
- **Theoretical Justification for the OT Dimension (Opportunities–Threats Interaction):** The scenario planning and uncertainty management literature shows that opportunities and threats in the external environment are not independent or fixed; rather, they often appear in combinations that generate different future scenarios. Interactive OT analysis enables the identification of "boundary conditions"-situations in which opportunities are

Table 2. The framework of the proposed innovative model (six-dimensional) [26].

~~Six-dimensional SWOT matrix~~	Sixth Dimension (WS)		
	S	W	
Fifth Dimension (OT)	O	SO (First Dimension)	WO (Second Dimension)
	T	ST (Fourth Dimension)	WT (Third Dimension)

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constrained by threats or threats are transformed into change drivers in the presence of certain opportunities. This scenario-oriented perspective transforms the analysis from mere description to forecasting and designing robust strategies. The theoretical basis for this approach is well-documented in scenario planning and uncertainty perception literature.

- **Methodological Reasons and Operational Advantages of Adding WS and OT:**

1) **Reducing ambiguity and preventing information distortion:** The four-dimensional framework can sometimes lead to contradictory summaries or loss of intra-structural information. Adding WS allows the identification of hidden internal conflicts and opportunities.

2) **Reflecting external interactive relationships:** OT enables the design of scenarios and strategies that simultaneously address or leverage combined opportunities and threats.

3) **Enhancing the translation of analysis into strategy:** WS and OT provide clearer inputs for adaptive matrices (e.g., SWOT), facilitating the extraction of more sophisticated strategies, which is particularly effective in technology adoption contexts, where both technical and environmental factors change rapidly. The key point is that WS and OT are not independent additive dimensions; rather, they function as “interactive metrics” that structure and operationalize the information already present in the four traditional dimensions. Therefore, the goal is not to “increase repetition” or “magnify the model” but to enhance analytical discriminability and strategic inference capability.

4) Prioritizing the implementation of the aforementioned company’s strategies using the COCOSO method in conditions of uncertainty to achieve flexible strategies.

5) Reviewing and positioning the aforementioned company’s flexible strategies using a developed hybrid approach in conditions of uncertainty.

6) Assessing the suitability of strategies according to the old framework of the fuzzy SWOT matrix and determining and confirming the suitability of flexible strategies and potential alternatives in the fuzzy SWOT model.

3. Methodology

A research method is a systematic effort to achieve the study’s objectives and consists of clearly defined steps. The first step in designing a research methodology is to determine the type of research. The type of research is determined based on the study’s objective, the data collection approach, and the nature of the data. The second step involves specifying the data analysis procedure, which indicates the methods the researcher will use to analyze the collected data. As previously stated, the aim of the present study is to evaluate strategies for the adoption of smart technologies in the urban construction industry using a novel SWOT–MCDM model under conditions of uncertainty. To achieve this goal, the study is classified as applied research in terms of objective, descriptive-survey research in terms of data collection, and a mixed-method (qualitative–quantitative) study in terms of data nature. In the data generation process, the qualitative phase involved identifying strengths, weaknesses, opportunities, and threats through in-depth interviews with experts. The fuzzy Delphi method was subsequently employed to collect and refine expert opinions, ensuring that strategic factors and criteria were identified, screened, and validated with minimal bias and maximum accuracy. This method is particularly suitable under uncertainty, as it integrates diverse viewpoints, and the parameters used are aligned with expert insights and the study’s objectives. Following the identification of SWOT factors, the SWOT matrix and alternative strategies were constructed. Based on this process, the adoption of smart technology in Qom’s urban construction industry resulted in four traditional strategies and two additional strategies:

- **Strength–Opportunity (SO) Strategy:** Also called the aggressive strategy, it leverages opportunities by utilizing existing strengths.
- **Strength–Threat (ST) Strategy:** Also called the competitive strategy, it uses strengths to mitigate the effects of threats.
- **Weakness–Opportunity (WO) Strategy:** Also called the conservative strategy, it addresses weaknesses and leverages opportunities in the external environment.
- **Weakness–Threat (WT) Strategy:** Also called the mitigation strategy, it reduces weaknesses and prevents potential threats.
- **Opportunity–Threat (OT) Strategy:** Examines the interaction between environmental opportunities and threats, helping organizations manage threats by capitalizing on existing opportunities.
- **Weakness– Strength (WS) Strategy:** Analyzes weaknesses and opportunities to help organizations reduce or eliminate weaknesses by exploiting available opportunities.

After forming the SWOT matrix, the identified factors-including strengths, weaknesses, opportunities, and threats-were evaluated using the fuzzy FUCOM method to determine the weight of each factor and its sub-criteria. For this purpose, a researcher-designed pairwise comparison questionnaire was developed for the four SWOT dimensions, along with the sub-criteria identified during the fuzzy Delphi screening process. Experts were asked to express their opinions on each criterion using verbal variables provided in the questionnaire.

Given the relatively large number of factors in this study, the fuzzy FUCOM method reduces the number of pairwise comparisons, which enhances the accuracy of

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the results and facilitates precise completion of the comparisons by experts. After analyzing the FUCOM results, the fuzzy COCOSO method was employed to prioritize strategies according to the derived weighted criteria. This method, which integrates multiple multi-criteria decision-making indices and can handle uncertainty effectively, provides a reliable ranking with high accuracy for strategic options. To ensure the stability of the rankings, sensitivity analyses were conducted based on variations in criterion weights as well as changes in the data analysis method. To validate the methodology, the logic and key parameters of each method are described below [39, 40]:

1) **Fuzzy FUCOM Method and Related Parameters:** FUCOM is a novel weighting method designed to reduce the number of comparisons while achieving full consistency in criteria prioritization. First, criteria are ranked by experts based on relative importance. Then, the Comparative Priority Ratio (CPR) between successive criteria is calculated; these ratios serve as the model's primary parameters. Finally, a linear programming model is solved to obtain the final weights such that the Deviation from Full Consistency (DFC) is minimized. In this study, the obtained DFC value indicates acceptable consistency in expert judgments and high reliability of the derived weights.

2) **Fuzzy CoCoSo Method and Employed Parameters:** CoCoSo is a hybrid multi-criteria decision-making method that combines three common approaches: SAW, WPM, and WASPAS. Its main parameters are as follows:

   ◦ **Normalization method:** Linear fuzzy normalization was used to standardize the scale of criteria, which is a widely applied approach in fuzzy MCDM.

   ◦ **Scoring function:** The final scores of options were calculated using a triangular linear scoring function, converting fuzzy numbers into crisp values.

   ◦ **Weighted coefficients for combining results (λ, ω):** In the final CoCoSo equations, these coefficients were set to 0.5 by default to ensure balanced integration of the model components and prevent ranking bias. Finally, comparative analyses with other methods confirmed the validity of the CoCoSo results for research verification. In the present study, the given stages are shown in figure 1.

It should be noted that the primary objective of this study was not to develop a new fuzzy method, but rather to focus on the comprehensive and systematic application of fuzzy approaches in strategic analysis under conditions of real uncertainty. In this context, the present research integrates the fuzzy FUCOM for criteria weighting with the fuzzy CoCoSo method for strategy ranking, thereby providing a practical and reliable framework for multi-criteria decision-making in a complex and ambiguous environment. This integration enables the incorporation of expert perspectives, the fuzzification of both qualitative and quantitative data, and the reduction of bias in criteria evaluation and weighting. Moreover, considering that the assessments were conducted collectively and subjectively, and that the criteria possess inherently qualitative and ambiguous characteristics, the complete fuzzification of the decision-making process-from the transformation of expert judgments into triangular fuzzy numbers to fuzzy normalization and aggregation in CoCoSo-represents a significant applied innovation. Furthermore, this study, for the first time in the domain of smart construction and urban technology adoption, proposes a fuzzy strategic decision-making process based on an actual (rather than theoretical) SWOT matrix. This framework encompasses the fuzzification of SWOT relationships, fuzzy weighting using FUCOM, fuzzy ranking via CoCoSo, and sensitivity analysis to evaluate the robustness of strategies in response to variations in criteria weights and analytical methods. Therefore, the core innovation of this research lies not in inventing a new fuzzy method, but in providing an integrated and practical fuzzy framework for analyzing strategies for smart technology adoption under real uncertainty—a contribution that is exceptionally rare and unprecedented in the existing literature.

3.1 Research experts in the qualitative and quantitative phases of the study

This study, aimed at developing a hybrid SWOT-MCDM framework for formulating smart technology adoption strategies in urban construction under uncertainty, was conducted in two phases: qualitative and quantitative. The following section introduces the experts involved in both phases:

3.1.1 Experts in the qualitative phase of the study

As previously mentioned, the first part of this study was dedicated to the qualitative phase, during which SWOT were identified through in-depth interviews with subject-matter experts. Subsequently, these factors were screened and validated using the fuzzy Delphi method. This phase required the participation of a group of experts with relevant expertise and experience in the field of smart technologies within the urban construction industry and project management. Given the qualitative and specialized nature of the fuzzy Delphi method, 20 experts with relevant backgrounds in smart technologies were selected from the Municipality of Qom Province. The selection of 20 participants aligns with scientific standards and similar studies; for instance, Okoli and Pawlowski [41] recommended that the number of experts in Delphi studies typically range between 5 and 30. This range is sufficient to capture diverse and specialized perspectives relevant to the research topic while enabling effective management of data collection and analysis with the necessary quality and accuracy [41, 42]. In this phase, experts with diverse experience in technology-driven projects and urban construction projects within the Qom Municipality shared their insights, leading to a comprehensive and credible identification of key SWOT

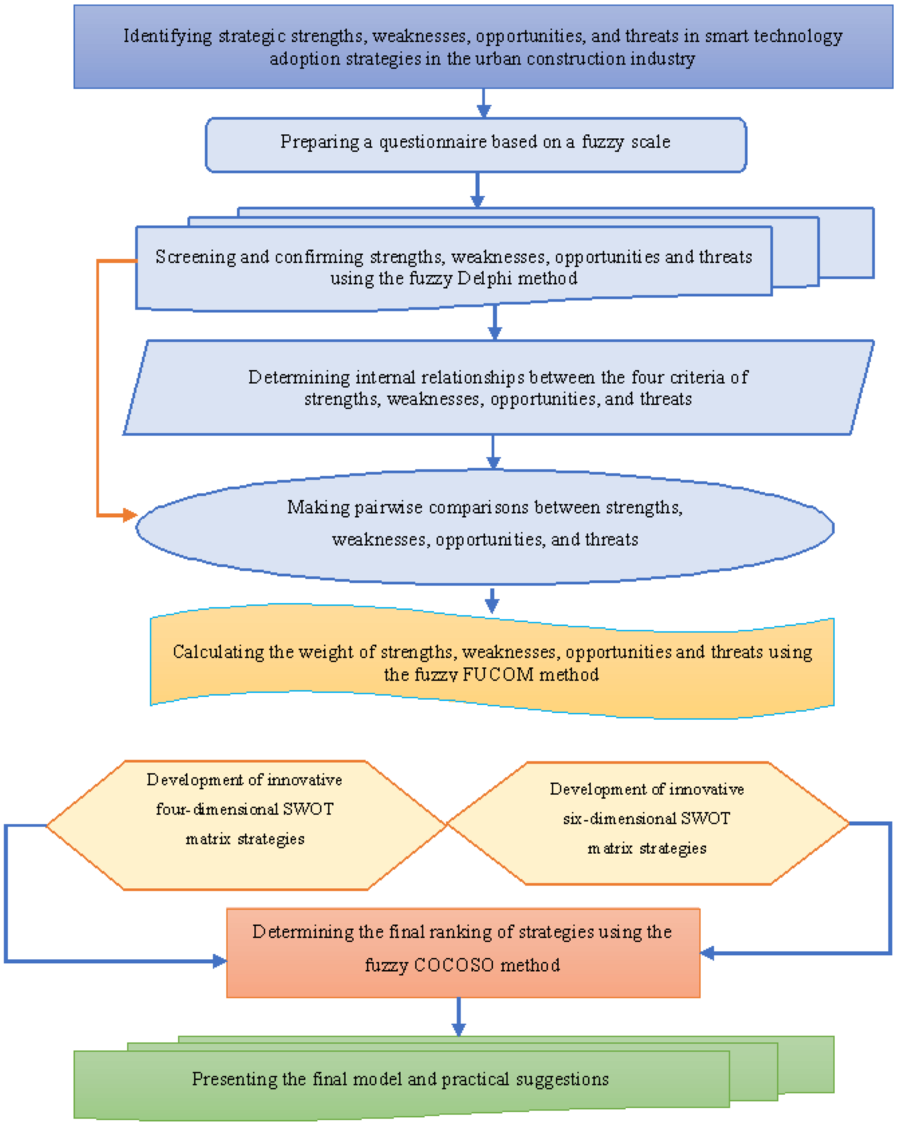

Figure 1. The framework of SWOT method.

factors. The selection of Qom Municipality as the focal area for this research was based on a combination of strategic and practical reasons [42], which are as follows:

1) **Significance of Geographical and Cultural Position of Qom Province:** As one of Iran's key cities with a prominent religious, cultural, and pilgrimage status, Qom plays a vital role in national urban and infrastructure development. This status has driven demand for high-quality construction projects, where smart technologies can address the needs of sustainable development.

2) **High Rate of Urban Growth and Development:** Due to rapid population growth and urban expansion, Qom faces numerous managerial and operational challenges in its construction projects. The adoption of smart technologies can help improve efficiency, reduce costs, and enhance project quality.

3) **Municipality's Commitment to Smartification and Innovation:** As the main authority in urban management, Qom Municipality has directed its policies and programs toward utilizing modern technologies to improve urban services and construction processes. This commitment provides a favorable context for conducting applied research in this field.

4) **Access to Specialized and Local Human Resources:** The presence of a considerable number of experts and specialists in smart technologies and construction within Qom enables the utilization of expert knowledge and experience for comprehensive and operational analysis.

5) **Generalizability of Research Findings:** Given the structural similarities and shared challenges among other Iranian metropolitan and mid-sized cities, the findings of this study can serve as a practical and transferable model for other regions.

The statistical profile of the experts is presented in Table 3:

Table 3. Statistical profile of experts in the qualitative phase.

	Attribute	Frequency (20 experts)	Percentage
Average Work Experience	More than 20 years	15	75%
	10 – 20 years	3	15%
	5 – 10 years	2	10%
Educational Level	Ph.D.	10	50%
	Master's Degree	10	50%
Area of Expertise	Construction Project Management	12	60%
	Emerging Technologies	6	30%
	Urban Planning and Economics	2	10%
Position	Project Manager	10	50%
	Senior Technology Advisor	6	30%
	Technical Expert	4	20%

3.1.2 Experts in the quantitative phase of the study

The selection of experts in the quantitative phase is a critical step before distributing questionnaires. At this stage, the selected experts must represent the broader target population to ensure the validity and reliability of the responses collected. The target population consisted of professionals from the municipality, employers, consultants, and contractors involved in the urban construction industry of Qom Province. Only well-established, reputable, and experienced companies were included. The primary contractors in this study were selected from among eligible contractors and consultants operating in compliance with the rules and regulations of the Iranian Plan and Budget Organization. For data collection, two main methods were considered: a census approach (collecting data from all members of the population) and sampling (selecting a portion of the population as its representative). Due to time and cost constraints, especially when the population size is large, sampling is often a more efficient and economical method. In estimation-based sampling, the researcher personally estimates the sample size based on various factors. In some cases, a minimum sample size is clearly defined, enabling the researcher to ensure that the estimated sample does not fall below the required threshold. For instance, in studies requiring stratified sampling, the minimum sample size per stratum is generally between 15 and 20 individuals [43]. Therefore, given the four groups-municipality professionals, employers, consultants, and contractors-a minimum total sample size of 60 to 80 individuals is required. Statistical methods are then used to determine an appropriate sample size, particularly when the overall population is not fully accessible due to limitations in information. The following equation (1) was used for this purpose:

$$n = \frac{n^2 pq}{d^2} \tag{1}$$

where

- p is the estimated proportion of individuals with the target characteristic in the population,
- $q = 1-p$ (the proportion without the characteristic),
- d is the acceptable margin of error,
- t is the value from the Gaussian (normal) distribution corresponding to the desired confidence level.

Assuming a 90% confidence level, the value of t based on Table 4 derived from the Gaussian curve is 1.64, and the acceptable margin of error d is 0.05. The characteristic of interest in this population is work experience in smart urban construction projects, with a threshold of five years being an appropriate benchmark.

Table 4. Relationship between t-value and confidence level [43].

Row	Confidence level	t-value
1	68.30%	1.00
2	95%	1.96
3	95.50%	2.00
4	99%	2.58
5	99.70%	3.00
6	99.90%	3.29

In other words, individuals with more than five years of experience in smart urban construction projects represent p, while those with less than five years represent q. However, exact values for p and q are not readily available in the target population. Therefore, initial estimation is conducted, followed by refinement based on the actual distribution of characteristics within the obtained sample. In this study, 160 questionnaires were distributed, and 140 completed responses were received. Among the 140 respondents, 130 had more than five years of relevant experience. Therefore, $p = 0.93$, $q = 0.07$. Based on the prior assumptions, the estimated minimum required sample size was 70, which is less than the actual number of qualified respondents (130). Thus, a sample size of

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130 is deemed appropriate for the study.

3.2 Fuzzy Delphi model

Dalkey and Helmer introduced the Delphi method in 1963. This survey method is based on expert opinions with three major characteristics: anonymous response, controlled repetition and feedback, and statistical group response. This technique is a systematic method for collecting and coordinating the informed judgments of a group of experts about a specific question or issue. In many real situations, the judgment of experts cannot be expressed and interpreted in definite quantitative numbers; in other words, definite data and numbers are insufficient to model real-world systems due to ambiguity and uncertainty in the decision-makers' judgment. To overcome ambiguity and uncertainty in the decision-making process, Lotfi Zadeh developed the fuzzy Sets Theory in 1965. Therefore, the present study used the fuzzy Delphi method to confirm and screen the identified strengths, weaknesses, opportunities, and threats. fuzzy Delphi method, introduced by Ishikawa et al., is formed by combining the Delphi method and fuzzy Sets Theory. The phases of this method are [41]:

1) Identifying strengths, weaknesses, opportunities, and threats through in-depth interviews with construction industry experts.

2) Gathering the ideas of decision-making professionals: After determining strengths, weaknesses, opportunities, and threats, a panel of decision-making experts aware of the research topic was created. Then, questionnaires were sent to them to determine whether the identified factors were related to the research topic and to screen the items. The importance of each index was determined by linguistic variables (Table 5). In the present study, triangular fuzzy numbers were utilized.

Table 5. Verbal expressions and fuzzy Delphi numbers [41].

Verbal expressions	Triangular fuzzy numbers
Very little	(0,0,0.25)
Little	(0,0.25,0.5)
Moderate	(0.25,0.5,0.75)
Much	(0.5,0.75,1)
Very much	(0.75,1,1)

3) Verifying and screening the factors: It is done by comparing the acquired value of each index with the threshold value $\tilde{S}$. The threshold value is measured by the decision maker's subjective inference, which directly influences the number of screened factors. There is no easy and valid method to measure the threshold value. In this study, the threshold value was considered to be 0.7. The triangular fuzzy values of the experts' opinions should be measured, followed by calculating their fuzzy average to measure the mean opinion of n respondents. The fuzzy number τ for each index is computed using the following equations [44]:

$$\tilde{\tau}_{ij} = (a_{ij}, b_{ij}, c_{ij}), i = 1, 2, \dots, n, \quad j = 1, 2, \dots, m \tag{2}$$

$$a_j = \sum \frac{a_{ij}}{n} \tag{3}$$

$$b_j = \sum \frac{b_{ij}}{n} \tag{4}$$

$$c_j = \sum \frac{c_{ij}}{n} \tag{5}$$

where index i represents the expert and index j shows the decision-making index. Further, the defuzzied value of the mean fuzzy number is gained through equation (6).

$$Crisp = \frac{a + b + c}{3} \tag{6}$$

3.3 Fuzzy FUCOM

The FUCOM method was introduced by Pamučar et al. [45]. The main advantages of the FUCOM method are: 1) It enables pairwise comparison of evaluation criteria not only through the use of integer values but also by employing decimal values; 2) It utilizes a simple algorithm to derive the weights of the criteria; and 3) It requires fewer pairwise comparisons for determining the weights of the criteria. Mental models for determining weights based on pairwise comparisons require decision-makers to assess the degree of influence that criterion i exerts on criterion j. The degree of influence of criterion i on criterion j is presented as the comparison value a_{ij}. Since the obtained values from the comparisons a_{ij} are not based on precise measurements but rather on subjective estimations, the inherent uncertainties can be expressed using fuzzy numbers. Linguistic scales are more frequently used for comparing two factors. Based on the original structure of the FUCOM method, an extension of the traditional model in a fuzzy environment was introduced by Pamučar et al. [46]. The FUCOM method is known as the complete compatibility method, which is always consistent. The optimization variable in z is actually determined to determine the degree of consistency or low compatibility that is obtained by solving the optimization model and an defuzzied number that is always close to zero. Unlike classical FUCOM model proposed in 2018 and the optimization model is used in deterministic environment, the fuzzy model is used which, as it contains uncertainties, the accuracy of the results is higher.The fuzzy FUCOM algorithm can be implemented in the following steps [46]:

Step 1: The evaluation criteria are determined as a set $C = \{C_1, C_2, \dots, C_n\}$.

Step 2: In this step, the evaluation criteria must be ranked. Decision-makers initially identify the rank of the criteria based on their opinions and preferences regarding the relative importance of each criterion. The first rank is assigned to the factor that is expected to have the highest weight coefficient, and the ranking proceeds accordingly down to the last position, which is allocated to the criterion anticipated to have the lowest weight coefficient. In this way, the ranking of the criteria is compiled $C_{j(1)} > C_{j(2)} > \ldots > C_{j(k)}$, where k denotes the rank of the criterion. If two or more criteria share the same rank, the equality sign (=) is used between them instead of the greater-than symbol (>).

Step 3: The criteria are compared using a triangular fuzzy number. Verbal expressions and corresponding fuzzy numbers are used according to Table 6.

Table 6. Fuzzy linguistic scale [46].

Code	Verbal variable	Fuzzy number		
		Low (L)	Medium (M)	Up (U)
1	Equal importance	1	1	3
2	Low importance	1.5	1	0.67
3	Quite important	2.5	2	1.5
4	Very important	3.5	3	2.5
5	Quite important	4.5	4	3.5

The comparison is performed based on the first-rank criterion; therefore, the importance of the fuzzy criterion $\omega_{c_{j(k)}}$ is obtained for all criteria. Since the most important criterion is being compared with itself, a total of $n-1$ comparison must be made with the remaining criteria. Based on the defined significance of the criteria, the fuzzy comparative importance $\tilde{\varphi}_{k/(k+1)}$ is determined using equation (7).

$$\tilde{\varphi}_{k/(k+1)} = \frac{\omega_{c_{j(k+1)}}}{\omega_{c_{j(k)}}} = \frac{(\omega^l_{c_j(k+1)}, \omega^m_{c_j(k+1)}, \omega^u_{c_j(k+1)})}{(\omega^l_{c_j(k)}, \omega^m_{c_j(k)}, \omega^u_{c_j(k)})} \tag{7}$$

Therefore, a fuzzy vector of the relative importance of decision criteria is obtained through equation (8).

$$\phi = (\tilde{\varphi}_{1/2}, \tilde{\varphi}_{2/3}, \ldots, \tilde{\varphi}_{k/(k+1)}) \tag{8}$$

In this equation, $\tilde{\varphi}_{k/(k+1)}$ represents the importance that the ranking criterion $C_{j(k)}$ has based on the ranking coefficient $C_{j(k+1)}$.

Step 4: The fuzzy weights of the criteria $(\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n)^T$ are calculated. The final weight values have the following conditions:

Condition 1: The weight ratio of the observed criteria $C_{j(k)}$ and $C_{j(k+1)}$ must be equal to their comparative importance $\tilde{\varphi}_{k/(k+1)}$ which is defined in **Step 2**, in equation (9) it is done as follows:

$$\frac{\tilde{w}_k}{\tilde{w}_{k+1}} = \tilde{\varphi}_{k/(k+1)}. \tag{9}$$

Condition 2: In addition to the conditions defined previously, the final weighted values must also satisfy the transferability; that is:

$$\frac{\tilde{w}_k}{\tilde{w}_{k+1}} \times \frac{\tilde{w}_{k+1}}{\tilde{w}_{k+2}} = \frac{\tilde{w}_k}{\tilde{w}_{k+2}}, \qquad \tilde{\varphi}_{k/(k+1)} \times \tilde{\varphi}_{(k+1)/(k+2)} = \tilde{\varphi}_{k/(k+2)}. \tag{10}$$

Therefore, another condition that must be satisfied by the final weighted values is obtained as equation (11).

$$\frac{\tilde{w}_k}{\tilde{w}_{k+2}} = \tilde{\varphi}_{k/(k+1)} \times \tilde{\varphi}_{(k+1)/(k+2)} \tag{11}$$

Equations (9-11) can be explained by making the constraint of model 12. In model 12, the equations are included between (9) and (11), and certainly when the model is solved, the result is calculated based on the constraint. For example, equation (11) is expressed that $\frac{\tilde{w}_k}{\tilde{w}_{k+2}}$ is obtained from the multiplication of the equation $\tilde{\varphi}_{k/(k+1)} \times \tilde{\varphi}_{(k+1)/(k+2)}$ as $\frac{\tilde{w}_k}{\tilde{w}_{k+2}}$ is shown in equation (12). Perfect compatibility, i.e. $z = 0$, is only achieved if the transferability between weight coefficients is fully satisfied. So it can be said that when $\frac{\tilde{w}_k}{\tilde{w}_{k+2}} - \tilde{\varphi}_{k/(k+1)} = 0$ and $\frac{\tilde{w}_k}{\tilde{w}_{k+2}} - \tilde{\varphi}_{k/(k+1)} \times \tilde{\varphi}_{(k+1)/(k+2)} = 0$ perfect compatibility is achieved. To satisfy this condition, it is necessary to determine the weight value of the criteria $(\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n)^T$ in such a way that the conditions $|\frac{\tilde{w}_k}{\tilde{w}_{k+2}} - \tilde{\varphi}_{k/(k+1)}| \leq z$ and $|\tilde{W}^{\tilde{w}_k}_{\tilde{w}_{k+2}} - \tilde{\varphi}_{k/(k+1)} \times \tilde{\varphi}_{(k+1)/(k+2)}| \leq z$ are achieved by minimizing z. Based on the defined conditions, the final linear model for determining the optimal fuzzy values of the factor weight coefficients can be set as equation (12).

$$\begin{aligned} &\text{Min} Z \\ &s.t. \\ &|\tilde{w}_k - \tilde{w}_{k+1} \otimes \tilde{\varphi}_{k/(k+1)}| \leq Z, \forall j \\ &|\tilde{w}_k - \tilde{w}_{k+2} \otimes \tilde{\varphi}_{k/(k+1)} \otimes \tilde{\varphi}_{(k+1)/(k+2)}| \leq Z, \forall j, \\ &\sum_{j=1}^{n} \tilde{w}_j = 1, \quad \text{for all j}, \\ &w^l_j \leq w^m_j \leq w^u_j, w^l_j \geq 0, \forall j \quad j = 1, 2, \ldots, n \end{aligned} \tag{12}$$

In equation (12), the following constraints:

$$\begin{aligned} &|\tilde{w}_k - \tilde{w}_{k+1} \otimes \tilde{\varphi}_{k/(k+1)}| \leq Z, \forall j \\ &|\tilde{w}_k - \tilde{w}_{k+2} \otimes \tilde{\varphi}_{k/(k+1)} \otimes \tilde{\varphi}_{(k+1)/(k+2)}| \leq Z, \forall j, \end{aligned}$$

values $\tilde{\varphi}_{k/(k+1)}$ and $\tilde{\varphi}_{(k+1)/(k+2)}$ are integers that are paired comparisons of the k-criteria. So, the constraint on equation (12) is the multiplication of an integer in a variable, so the model is linear. Also, the constraints in model in equation (12) are fuzzy as the symbol (~) is a fuzzy symbol, i.e., in the model solved by software solved for both low, intermediate, and high (l, m, u) constraints.

After finding the fuzzy weights, the defuzzified weights of the criteria are obtained using equation (13).

$$w_j = \frac{w^l_j + 4w^m_j + w^u_j}{6} \tag{13}$$

Equations (6) and (13) are among the defuzzification relationships. Equation (6) is related to fuzzy Delphi method and equation (13) is related to fuzzy FUCOM method. These two relationships are used both for the same purpose, which is the same as defuzzification, but since they have been taken from different base papers, it has been tried to draw on the basis of the base paper [46].

3.4 Fuzzy COCOSO method

This method is used to rank research options. Its steps are based on the research of Demir et al. [40].

Step 1: Developing a decision-making matrix: Suppose the decision-making matrix of people's opinions is:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix} \quad (14)$$

$$i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n$$

$\tilde{D}$ of each column indicates a item and each row shows a criterion. X_{ij} represents the quantity of the ith option in the j^{th} criterion. In the present research, verbal expressions and fuzzy numbers (Table 7) were utilized to assess the criteria from the perspective of each expert.

Table 7. Verbal expressions and fuzzy numbers [40].

Code	Priority	Fuzzy equivalent of priorities		
		Low (L)	Medium (M)	Up (U)
1	Very little	1	1	3
2	Little	1	3	5
3	Medium	3	5	7
4	Much	5	7	9
5	Very much	7	9	11

Step 2: Normalization of the decision-making matrix: Normalization is carried out in almost all multi-criteria decision-making methods. The normalization of the decision matrix is done by equation (15).

$$\tilde{r}_{ij} = (r^l_{ij}, r^m_{ij}, r^u_{ij}) = \frac{\tilde{z}_{ij} - \min(\tilde{z}_{ij})}{\max(\tilde{z}_{ij}) - \min(\tilde{z}_{ij})} \quad (15)$$

Step 3: Calculation of the weighted sum and weighted product values: In this step, based on equations (16) and (17), the weighted sum (S) and weighted power (P) values are calculated for each option. In these equations, W_j is the expert weight fed into the fuzzy COCOSO method as input.

$$\tilde{S}_{ij} = (S^l_{ij}, S^m_{ij}, S^u_{ij}) = \sum_{j=1}^{n} \tilde{W}_{jc} \tilde{r}_{ij} \quad (16)$$

$$\tilde{P}_{ij} = (P^l_{ij}, P^m_{ij}, P^u_{ij}) = \sum_{j=1}^{n} (\tilde{r}_{ij})^{\tilde{W}_{jc}} \quad (17)$$

Step 4: Determining the criteria evaluation score using three strategies: In this section, the scores of the criteria are obtained from equations (18-20) based on three strategies. Equation (18) indicates the arithmetic mean of WSM and WPM scores, while equation (19) expresses the relative scores of WSM and WPM compared to the best scores. Equation (20) shows a compromise between the WSM and WPM models. In this relation, λ is determined by the decision-maker but has great flexibility in the case of 0.5.

$$k_{ia} = \frac{\tilde{P}_i + \tilde{S}_i}{\sum_{i=1}^{m} (\tilde{P}_i + \tilde{S}_i)} \quad (18)$$

$$k_{ib} = \frac{\tilde{S}_i}{\min(\tilde{S}_i)} + \frac{\tilde{P}_i}{\min(\tilde{P}_i)} \quad (19)$$

$$k_{ic} = \frac{\lambda \tilde{S}_i + (1-\lambda)\tilde{P}_i}{\lambda \max(\tilde{S}_i) + (1-\lambda)\max(\tilde{P}_i)}; 0 \le \lambda \le 1 \quad (20)$$

Step 5: Defuzzification of k_{ia}, k_{ib}, and k_{ic}: The fuzzy values calculated in the fourth step are defuzzified using equations (21-23).

$$k_{ia} = \frac{k^l_{ia} + k^m_{ia} + k^u_{ia}}{3} \quad (21)$$

$$k_{ib} = \frac{k^l_{ib} + k^m_{ib} + k^u_{ib}}{3} \quad (22)$$

$$k_{ic} = \frac{k^l_{ic} + k^m_{ic} + k^u_{ic}}{3} \quad (23)$$

Step 6: Determining the final score and ranking: The final score is calculated through equation (24). This relation represents the sum of the geometric mean and arithmetic mean of the three strategies in the previous step. The higher the score (k) of any option, the better that option is.

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \quad (24)$$

4. Case study: Application of the proposed a hybrid SWOT-MCDM framework to Qom Municipality

In this section, a case study is presented to demonstrate the application of a hybrid SWOT-MCDM framework proposed in the previous sections. The case was implemented in the Qom Municipality. Qom Province, as one of the cultural and religious centres of Iran, has moved toward smart construction in recent years. This trend has become more important, especially given the growing urban needs and population growth. Smart construction in Qom not only increases the comfort and convenience of residents but can also help manage resources and reduce energy consumption. Given the dry climate and water shortage of this province, it is highly important to use modern technologies. Despite the progress made,

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there are still challenges. The need for education and culture-making among citizens is essential to accept these technologies. Also, cooperation between various agencies and institutions is essential for the success of these projects because the adoption of smart technology in the urban construction industry of Qom province can be considered an important step toward sustainable urban development. Given the efforts of the municipality and companies active in this field, it is expected that Qom become a smart city that not only meets the needs of its residents but also serves as a suitable model for other cities. On the other hand, an important and noteworthy issue is that the urban construction industry of Qom province deals with multiple stakeholders and has a general resistance to changes, leading to the lack of acceptance of smart technology in the urban construction industry. Accordingly, the present research evaluated and prioritized smart technology adoption strategies in the urban construction industry of Qom province using the SWOT-MCDM model under conditions of uncertainty. This evaluation and prioritization can help identify SWOT in the adoption of technologies and also address multi-criteria decision-making in this field. Using the SWOT-MCDM model can help to more accurately identify the obstacles and opportunities in adopting smart technologies in the urban construction industry of Qom province. A step-by-step analysis and review of the findings is presented below:

4.1 Identifying strategic strengths, weaknesses, opportunities, and threats in smart technology adoption strategies in the urban construction industry and screening and confirming them using the fuzzy Delphi method

To achieve the research objectives and identify the strengths, weaknesses, threats, and opportunities for adopting smart technologies in urban construction and develop a matrix of strategies resulting from the SWOT matrix, eight experts working in the Qom province municipality were recruited in this study. Through interviews, the participants were asked to answer the research questions to develop a SWOT analysis matrix considering the explanations mentioned about the features and benefits of the SWOT analysis. The interviews with experts were conducted at the municipality. After conducting the interviews, the researchers studied the text of each interview immediately, and the information of each interview was written down. Next, based on the review of the interviews conducted and the recorded findings, the components of the SWOT matrix were identified. Then, the factors identified in four dimensions of strengths, weaknesses, opportunities, and threats were provided to the expert group members, and they were asked to express their opinions about each criterion through verbal expressions included in the questionnaire. Afterward, after integrating the decision-making matrix, the fuzzy mean of the scores was obtained and converted into a definite number through equation (6). After that, the threshold value of 0.7 was considered for the screening and final confirmation of the identified strengths, weaknesses, opportunities, and threats. The final results led to the confirmation of 47 final factors (Table 8).

4.2 Developing potential strategies based on traditional SWOT (four-dimensional) and innovative SWOT (six-dimensional) matrices

After identifying and assessing the importance of the criteria approved in Table 9, an attempt was made to formulate the most creative potential strategies for the four internal and external factors for the four-dimensional and six-dimensional SWOT matrices as follows:

Based on the results obtained from the SWOT analysis, 37 strategies were developed for adopting smart technology in urban construction in Qom province. Determining these strategies greatly helps improve the performance of organizations or governments. However, selecting and prioritizing these strategies, considering financial, human, and time constraints, has always been one of the important challenges for decision-makers and managers in organizations and governments. Therefore, to make an efficient, effective, and optimal decision and to prevent confusion among managers and policymakers, the developed strategies must be prioritized and the optimal ones must be selected and put on the agenda. In this regard, multi-criteria decision-making methods can be used to prioritize strategies.

4.3 Calculating the weight of strengths, weaknesses, opportunities and threats using the fuzzy FUCOM method

As previously mentioned, fuzzy FUCOM is a decision-making technique aimed at determining the weight of evaluation criteria within the SWOT matrix—namely, the strengths, weaknesses, threats, and opportunities related to the adoption of smart technology in urban construction. This technique is based on the principles of pairwise comparisons among SWOT criteria (**Step 3**) and the validation of results along with deviation from maximum consistency (**Step 4**). The method compares the significance of all components at a specific hierarchical level and satisfies the consistency conditions explained in **Step 4**. The FUCOM technique, which significantly addresses the shortcomings of the Best-Worst Method (BWM) and the Analytic Hierarchy Process (AHP), eliminates the issue of redundancy in the pairwise comparison of criteria. In this section of the study, the evaluation criteria of the SWOT matrix—including strengths, weaknesses, threats, and opportunities regarding the adoption of smart technology in urban construction—were weighted using the fuzzy FUCOM technique. To determine the weights of the criteria, five models must be solved:

1) Identification of the local weights of the strength criteria

2) Identification of the local weights of the weakness criteria

3) Identification of the local weights of the opportunity criteria

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Table 8. Final strengths, weaknesses, opportunities, and threats.

Criterion	Sub-criterion	Code
Strength	Using engineering software in design and construction control	S1
	The existence of a dynamic engineering system and the efforts of engineers from Qom in this field	S2
	Localization of available software and technologies worldwide	S3
	The power of knowledge-based companies and their use in line with the goals of the provincial science and technology park	S4
	Activities of the Smart City Research Center in Qom	S5
	The presence of universities to create and develop new technologies	S6
	Designing a native model of Qom’s smart city by the Smart City Research Center	S7
	Implementing the initial infrastructure for connecting IoT network hardware (Gateway and antennas) based on the Lora WAN protocol to create a LoRa umbrella in five locations in Qom	S8
	University graduates of artificial intelligence	S9
	Holding training courses and seminars in engineering organizations and Qom municipality	S10
	The willingness of urban managers and planners (albeit limited) to adopt smart construction	S11
	Private sector participation at the provincial level	S12
Weakness	Lack of reputable company representatives for spare parts warranty and repair of smart systems	W1
	Lack of a single authority for controlling and monitoring smart systems	W2
	High costs of smart equipment and technologies	W3
	Lack of development of society’s culture in using smart technology	W4
	Lack of technical knowledge of infrastructure problems	W5
	Lack of coordination between managerial organizations and related institutions	W6
	Lack of a comprehensive, integrated, and strategic approach to smart city construction	W7
	Lack of awareness and training of many contractors and engineers about new technologies	W8
	Uncertainty about return on investment in smart projects by investors	W9
	Lack of appropriate digital infrastructure, information technology, and the internet	W10
	Lack of support from city officials, including the municipality, city council, and road and urban development engineering system	W11
	Poor advertising and culture building to raise awareness and encourage stakeholders’ participation in smart construction	W12

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Continued of table 8

Opportunity	Increasing demand for sustainable buildings	O1
	Population growth and housing needs	O2
	Improving the quality of life	O3
	Increasing the use of Building Information Modeling (BIM) in Iran's construction industry	O4
	Developing the use of big data in various industries	O5
	Providing governmental facilities to companies developing knowledge-based and new technologies in recent years in the country	O6
	Changes in attitude and appropriate acceptance of managers of organizations interested in smartization	O7
	Improving some approved laws or guidelines	O8
	Facilitating the issuance of customs permits for the import of branded equipment and technology at the level of high-tech projects	O9
	Attention of officials, policymakers, and the public to the achievement of sustainable development	O10
	Growth in the production of sustainable and quality materials in Iran	O11
	Manufacturing and developing emerging technologies such as intelligence, robotics, augmented reality and virtual reality, and 3-D printing in construction worldwide	O12

Threat	Inflation	T1
	Sanctions	T2
	Failure to issue licenses for foreign companies to operate and cooperate with domestic companies by the government and regulatory bodies	T3
	Lack of vision and smartization science among senior and middle managers of beneficiary organizations	T4
	Fluctuations in import and export costs	T5
	Iranian families' failure to prioritize smart technology	T6
	Construction market fluctuations	T7
	Restrictions on imports of reputable brands	T8
	Fluctuations in financial and currency markets	T9
	Government budget restrictions	T10
	Limited human resources with expertise to use and implement emerging technologies	T11

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Table 9. Matrix of smart technology adoption strategies in the urban construction industry of Qom province.

Strategies SO	Strategies ST
1. Collaborating with universities and research centers to develop new specialties such as artificial intelligence, robotics, and sustainable energy	1. Using local expertise and knowledge (universities and knowledge-based companies in the province) to reduce dependence on imports of expensive equipment and minimize the effects of sanctions
2. Strengthening digital infrastructure and the Internet of Things (IoT) to advance sustainable and smart projects	2. Strengthening private and public sector cooperation to provide financial resources to reduce dependence on market fluctuations
3. Developing a smart and sustainable construction market in response to the growing demand for housing and improving the quality of life	3. Promoting the culture of using smart technologies and developing public awareness through advertising
4. Developing and implementing educational and public information programs in cooperation with engineering and municipality organizations	4. Establishing a comprehensive framework for managing the risk of smart projects in the face of economic fluctuations
5. Using governmental facilities to attract capital in the field of smart and sustainable technologies	5. Developing and promoting local standards in cooperation with research centers and universities in Qom
Strategies WO	**Strategies WT**
1. Creating and developing educational and skill-building platforms to enhance the awareness and skills of contractors and engineers in new technologies in cooperation with universities, engineering organizations, and research centers	1. Establishing an integrated management and monitoring system to improve coordination between institutions concerned with developing joint guidelines
2. Using legal opportunities and customs facilities for importing and accessing advanced equipment and technologies	2. Setting up provincial repair and support centers for smart equipment to reduce dependence on foreign companies
3. Importing the necessary technologies from other countries to address the shortcomings of emerging digital and advanced technologies	3. Creating incentives and supportive financial and monetary policies to reduce investors' concerns, facilitate capital inflows, and minimize financial risks
4. Using big data and building information modeling in the construction process	4. Holding consultative meetings and public engagements to attract support for smart projects and improve engagement with the public
5. Promoting advertising and culture-building on the necessity of smartization through the active participation and planning of managers of beneficiary organizations	
WS strategy	**OT strategy**
1. In-house design and production of smart tools and technologies with a focus on reducing dependence on foreign products and costs	1. Creating industrial clusters to develop local technologies and reduce costs and dependence on foreign brands
	2. Creating data analysis systems to predict market changes and effectively manage financial resources
2. Establishing an independent entity to manage and coordinate different departments related to smart city projects with the help of the Smart City Research Center	3. Providing governmental facilities to companies developing knowledge-based technologies in exchange for the production and development of sanctioned technologies
3. Using university graduates and knowledge-based companies to reduce the lack of technical knowledge and infrastructure problems	4. Using emerging technologies such as intelligence, robotics, augmented reality and virtual reality, and 3-D printing in construction worldwide by eliminating limitations in expert human resources
4. Cooperation among research centers and universities, the engineering system, municipalities, etc. to develop comprehensive smart construction strategies	5. Holding internal and external meetings and conferences between leading and pioneering managers of beneficiary organizations and senior and middle managers resistant to change
5. Using engineering software in construction design and control to solve the problem of the lack of a single reference for the control and monitoring of intelligent systems	6. Establishing NGOs advocating sustainable development to educate and develop a culture of intelligence at the city level
6. The existence of a dynamic engineering system and the efforts of engineers of Qom to improve the knowledge of many contractors and engineers about novel technologies	7. Calling for financial participation of environmental advocates in smart construction to reduce governmental budget constraints and provide capital
7. Designing a native model of the smart city of Qom by the Smart City Research Center by developing a comprehensive and strategic integrated approach to smart city construction	8. Using domestically produced sustainable, quality materials to improve and reduce construction production costs and deal with sanctions
8. Implementing the initial infrastructure for connecting IoT network hardware (Gateway and antennas) based on the Lora WAN protocol to create a LoRa umbrella in five locations in Qom to solve the problem of digital infrastructure, information technology, and proper internet	9. Using new (changed) rules or guidelines for the entry of branded goods 10. Providing targeted policies and programs by managers of leading stakeholders through meetings and workshops to develop the culture and change the attitudes of Iranian families

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4) Identification of the local weights of the threat criteria

5) Identification of the local weights of the combined strength, weakness, opportunity, and threat criteria

Subsequently, each model was solved in order. This section presents the model for identifying the local weights of the strength criteria. Due to the extensive computational workload, the adopted steps are outlined below:

Step 1: Ranking the strength sub-criteria based on importance: The first step in this method involves prioritizing the strength sub-criteria based on their level of importance, which was calculated through the fuzzy Delphi method. The first rank is assigned to the factor expected to have the highest weight coefficient, and ranking continues accordingly down to the factor anticipated to have the lowest weight coefficient. The results of this step are presented in Table 10. Based on Table 10, the criteria S10, S8, . . ., S5 are ranked in order of importance.

Step 2: Constructing the pairwise comparison matrix: In this step, the most important criterion is S10. Therefore, the average value of criterion S10 is considered as (1,1,1), and it is divided by the fuzzy averages of all other criteria to determine the relative importance of each criterion compared to the first criterion. The results are presented in Table 11. For instance, the calculations for criterion S11 are performed as follows:

$$S11 = \frac{(1,1,1)}{(0.6,0.85,0.925)} = (1.08, 1.176, 1.667)$$

Subsequently, based on the fuzzy FUCOM model, an optimization model is formulated. The constraints are divided into two sections: the first section includes the comparison of each criterion with its immediate successor, and the second section involves the comparison of each criterion with two criteria within its group. For the first three criteria, the constraints are exemplified as follows:

□ First part:

$$\varphi\frac{S10}{S8} = \frac{(1.039, 1.176, 1.667)}{(1,1,1)} = (1.039, 1.176, 1.667)$$

$$\varphi\frac{S8}{S11} = \frac{(1.081, 1.176, 1.667)}{(1.039, 1.176, 1.667)} = (0.649, 1, 1.604)$$

□ Second part: Then, based on the multiplication rule, it is as follows:

$$\varphi\frac{S10}{S11} = \varphi\frac{S10}{S8} = \varphi\frac{S8}{S11} = (1.039, 1.176, 1.667) \times (0.649, 1, 1.604) = (0.674, 1.176, 2.674)$$

Calculations are also performed for other criteria and the optimization model is formed. The fuzzy weights of the criteria are then calculated.

Step 3: Solving the optimization model and determining the weight of strengths: Next, in order to determine the weights of the criteria, the optimization model is formulated based on equation (12) and solved using LINGO software, version 18. The output of this process, which includes the final weights of the criteria, is presented in Table 12. Furthermore, the FUCOM method is inherently a consistently structured technique, and consistency assessment is embedded internally and structurally within the model—unlike methods such as AHP, which rely on a separate consistency index. Also, using equation (13), the fuzzy weight becomes non-fuzzy. Accordingly, holding training courses and seminars in the engineering system organization and Qom municipality was ranked first, weighing 0.1152.

Similarly, an optimization model was developed for the main criteria. Then, it was solved by Lingo software, the final weights of which are given in Table 13. Accordingly, strengths with a weight of 0.3169 obtained the first rank.

And then the final weights of the sub-criteria are measured by multiplying the weight of the main criteria by the relative weight of the sub-criteria obtained from the fuzzy FUCOM method, which is given in Table 14.

As observed, "organizing and conducting training courses and seminars within the Engineering Organization and Municipality of Qom" has been identified as the most significant sub-criterion within the strengths group. The relative weight of this sub-criterion is 0.1152, and its final weight—after multiplication by the weight of the strength criterion is 0.0365. The high importance of this sub-criterion can be explained for several reasons:

1. **Dependence of technology adoption on human capacity:** The adoption of smart technologies in construction projects is highly dependent on the skills, knowledge, and awareness of engineers, managers, and contractors. A lack of training and technical knowledge is considered one of the main barriers to the successful implementation of these technologies.

2. **Data-driven weighting:** The high weight of this sub-criterion results from the combination of the strength criterion weight and the relative weight of the sub-criterion, based on expert evaluations. This indicates that targeted training and human capacity development play a more decisive role in the success of smart projects than some hardware or software infrastructures.

3. **Consistency with field realities:** The obtained findings align with practical experience and field evidence regarding the adoption of innovative technologies, making them logically justifiable.

4. **Superiority of human factors over technical infrastructure:** In the context of smart technology adoption, the presence of technical infrastructure alone is insufficient; human skills and capabilities

Table 10. Initial prioritization of strength sub-criteria.

Code	Criterion	Fuzzy Mean	Non-Fuzzy Mean	Significance
S10	Holding training courses and seminars in the engineering organization and the municipality of Qom	(0.65,0.9,0.963)	0.869	1
S8	Implementing the initial infrastructure for connecting IoT network hardware (Gateway and antennas) based on the LoRaWAN protocol to create a LoRa umbrella in five locations in Qom	(0.6,0.85,0.963)	0.827	2
S11	The willingness of urban managers and planners (albeit limited) to adopt smart construction	(0.6,0.85,0.925)	0.821	3
S3	Localization of software and technologies available worldwide	(0.575,0.825,0.938)	0.802	4
S4	The power of knowledge-based companies and their use in line with the goals of the provincial science and technology park	(0.575,0.825,0.925)	0.800	5
S9	University graduates of artificial intelligence	(0.563,0.813,0.963)	0.796	6
S2	The existence of a dynamic engineering system and the efforts of engineers of Qom in this field	(0.563,0.813,0.9)	0.785	7
S12	Private sector participation at the provincial level	(0.55,0.8,0.95)	0.783	8
S1	Use of engineering software in design and construction control	(0.55,0.8,0.938)	0.781	9
S6	The presence of universities to create and develop new technologies	(0.5,0.75,0.888)	0.731	10
S7	Designing a native model of Qom's smart city by the Smart City Research Center	(0.5,0.75,0.888)	0.731	11
S5	Activities of the Smart City Research Center in Qom	(0.513,0.75,0.863)	0.729	12

Table 11. Comparison of criteria with the most important criterion.

	S10	S8	S11	S3	S4	S9	S2	S12	S1	S6	S7	S5
$\tilde{\varphi}_{k/(k+1)}$	(1,1,1)	(1.039, 1.176, 1.667)	(1.081, 1.176, 1.667)	(1.067, 1.212, 1.739)	(1.081, 1.212, 1.739)	(1.039, 1.231, 1.778)	(1.111, 1.231, 1.778)	(1.053, 1.25, 1.818)	(1.067, 1.25, 1.818)	(1.127, 1.333, 2)	(1.127, 1.333,2)	(1.176, 1.404, 2.105)

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Table 12. Weight of strength sub-criteria.

Criterion code	Fuzzy weight	Non-fuzzy weight	Ranking
S1	(0.0374, 0.0821, 0.0821)	0.0747	10
S2	(0.0399, 0.0849, 0.0849)	0.0774	9
S3	(0.0482, 0.0947, 0.0947)	0.0870	4
S4	(0.0454, 0.0915, 0.0915)	0.0838	5
S5	(0.029, 0.878, 0.0878)	0.0780	7
S6	(0.0327, 0.0756, 0.0756)	0.0685	11
S7	(0.0309, 0.075, 0.075)	0.0677	12
S8	(0.06, 0.1036, 0.1036)	0.0963	2
S9	(0.0431, 0.089, 0.089)	0.0814	6
S10	(0.087, 0.1208, 0.1208)	0.1152	1
S11	(0.0529, 0.0983, 0.0983)	0.0907	3
S12	(0.0392, 0.0853, 0.0853)	0.0776	8

Table 13. Weight and ranking of the main criteria.

Criterion code	Fuzzy weight	Definite weight	Ranking
S	(0.1943, 0.3385, 0.3529)	0.3169	1
W	(0.0924,0.2732, 0.3154)	0.2495	2
O	(0.1646, 0.2364,0.2364)	0.2244	3
T	(0.1294, 0.2228, 0.2228)	0.2072	4

are the key determinants of success. Therefore, the high weighting of training is not only consistent with the quantitative data derived from the fuzzy FUCOM method but is also fully justifiable based on practical experience and field realities.

4.4 Determining the final ranking of the six-strategies using the fuzzy COCOSO method

Next, after weighing the strengths, weaknesses, opportunities, and threats, the strategies were evaluated and prioritized. The results of its implementation are presented step by step:

Step 1: Development of the decision matrix: The decision matrix was developed to evaluate the six strategies. The decision matrix of the fuzzy COCOSO method is a matrix with 47 sub-criteria and 6 research strategies. Experts evaluate each strategy in terms of each sub-criterion based on a fuzzy range. Then, the opinions are merged using the arithmetic mean method, which is given under the title of the decision matrix in Table 15.

Step 2: Normalization of decision matrix: Based on equation (15), the decision matrix was normalized, which is given in Table 16.

Step 3: Calculation of weight product (S) and weight power (P): The weight product (S) and weight power (P) are computed by equations (16) and (17). To measure S, the final weight of the sub-criteria must be multiplied by the normal matrix. Then, the row sum of the matrix numbers is taken. To compute P, the normal matrix figures must be raised to the power of the criteria weights, followed by taking the row sum of the matrix numbers. The results are presented in Tables 17 and 18, respectively.

Step 4: Evaluation of strategies based on three criteria: According to equations (18-23), the scores of the strategies are determined based on the three strategies, whose findings are given in Table 19.

Step 5: Final score and ranking of strategies: The final score of each strategy is determined and graded accordingly by equation (24). The results showed that the SO strategy was ranked first, the SW strategy was ranked second, the ST strategy was ranked third, the WO strategy was ranked fourth, the WT strategy was ranked fifth, and finally, the OT strategy was ranked sixth.

The final results presented in Table 20 indicate that the six strategies identified have been ranked based on the overall scores obtained from the combined fuzzy FUCOM–fuzzy COCOSO model. According to this table, the SO strategy, with a score of 4.826, occupies the first rank. Following this, the SW strategy, with

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Table 14. Final weight of sub-criteria.

Criterion	Criterion weight	Sub-criterion	Relative weight of sub-criterion	Final weight of sub-criterion
Strength	0.3169	Using engineering software in design and construction control	0.0747	0.0237
		The existence of a dynamic engineering system and the efforts of engineers from Qom in this field	0.0774	0.0245
		Localization of software and technologies available worldwide	0.0870	0.0276
		The power of knowledge-based companies and its application in line with the goals of the provincial science and technology park	0.0838	0.0266
		Activities of the Smart City Research Center in Qom	0.0780	0.0247
		The existence of universities to create and develop new technologies	0.0685	0.0217
		Designing a native model of Qom's smart city by the Smart City Research Center	0.0677	0.0214
		Implementing the initial infrastructure for connecting IoT network hardware (Gateway and antennas) based on the LoRaWAN protocol to create a LoRa umbrella in five locations in Qom.	0.0963	0.0305
		University graduates of artificial intelligence	0.0814	0.0258
		Holding training courses and seminars in the engineering system organization and municipality of Qom	0.1152	0.0365
		The willingness of urban managers and planners (albeit limited) to adopt smart construction	0.0907	0.0288
		Private sector participation at the provincial level	0.0776	0.0246
Weakness	0.2495	Lack of reputable company representatives for spare parts warranty and repair of smart systems	0.0677	0.0169
		Lack of a single authority for controlling and monitoring smart systems	0.0675	0.0168
		High costs of smart equipment and technologies	0.1053	0.0263
		Lack of development of society's culture in using smart technology	0.0690	0.0172
		Lack of technical knowledge of infrastructure problems	0.0674	0.0168
		Lack of coordination between management organizations and related institutions	0.0718	0.0179
		Absence of a comprehensive, integrated, and strategic approach to smart city construction	0.1149	0.287
		Lack of knowledge and training of many contractors and engineers about new technologies	0.0814	0.0203
		Uncertainty about return on investment in smart projects by investors	0.0954	0.0238
		Lack of appropriate digital infrastructure, information technology, and the internet	0.0678	0.0169
		Lack of support from city officials, including the municipality, city council, and road and urban development engineering system	0.0681	0.0170
		Poor advertising and culture-building to promote awareness and encourage stakeholders' participation in accepting smart construction	0.1217	0.0304

Continued of table 14

Opportunity	0.2244	Increasing demand for sustainable buildings	0.1203	0.0270
		Population growth and housing needs	0.1113	0.0250
		Improving the quality of life	0.0814	0.0183
		Increasing the use of Building Information Modeling (BIM) in Iran's construction industry	0.0737	0.0165
		Developing the use of big data in various industries	0.0646	0.0145
		Providing governmental facilities to companies developing knowledge-based and new technologies in recent years in the country	0.0671	0.0151
		Changes in attitude and acceptance of managers of organizations interested in smartization	0.0688	0.0154
		Improving some approved laws or guidelines	0.0916	0.0206
		Facilitating the issuance of customs permits for the import of branded equipment and technology at the level of high-tech projects	0.0761	0.0171
		Attention of officials, policymakers, and the general public to the achievement of sustainable development	0.0728	0.0163
		Growth in the production of sustainable and quality materials in Iran	0.0996	0.0223
		Building and developing emerging technologies such as intelligence, robotics, augmented reality and virtual reality, and 3-D printing in construction worldwide	0.0709	0.0159
Threat	0.2072	Inflation	0.1085	0.0225
		Sanctions	0.0737	0.0153
		Failure to issue licenses for foreign companies to operate and cooperate with domestic companies by the government and regulatory bodies	0.0764	0.0158
		Lack of vision and smartization knowledge among senior and middle managers of beneficiary organizations	0.0809	0.0168
		Fluctuations in import and export costs	0.0882	0.0183
		Iranian families' failure to prioritize smart technology	0.1288	0.0267
		Construction market fluctuations	0.1038	0.0215
		Restrictions on imports of reputable brands	0.0726	0.0150
		Fluctuations in financial and currency markets	0.0717	0.0149
		Governmental budget constraints	0.0731	0.0152
		Limited human resources with expertise to use and implement emerging technologies	0.1203	0.0249

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Table 15. COCOSO's six-dimensional decision matrix.

	S1	S2	...	T10	T11
SO	(5.3, 7.3, 9.3)	(4.7, 6.7, 8.7)	...	(4.8, 6.8, 8.8)	(5,7,9)
ST	(4.9, 6.9, 8.9)	(4.9, 6.9, 8.9)	...	(2.4, 3.9, 5.9)	(3.1, 4.7, 6.7)
WO	(3.7, 5.3, 7.3)	(3.3, 4.9, 6.9)	...	(3.9, 5.7, 7.7)	(3.2, 4.7, 6.7)
WT	(3.5, 4.8, 6.8)	(2.9. 4.6. 6.6)	...	(3.1. 4.5, 6.5)	(3.1, 4.7, 6.7)
SW	(5.2,7.2, 9.2)	(5.2, 7.2, 9.2)	...	(5,7,9)	(4.9, 6.9. 8.9)
OT	(3.3, 4.7, 6.7)	(3.7, 5.3, 7.3)	...	(3.6, 5.5, 7.5)	(3.1, 4.6, 6.6)

Table 16. Normalized COCOSO's six-dimensional decision matrix.

	S1	S2	...	T10	T11
SO	(0.333, 0.667, 1)	(0.286, 0.603, 0.921)	...	(0.364, 0.667, 0.97)	(0.322, 0.661, 1)
ST	(0.267, 0.6, 0.933)	(0.317, 0.635, 0.952)	...	(0, 0.227, 0.53)	(0, 0.271, 0.61)
WO	(0.67, 0.333, 0.667)	(0.063,0.317, 0.635)	...	(0.227, 0.5, 0.803)	(0.017, 0.271, 0.61)
WT	(0.033, 0.25, 0.583)	(0,0.27, 0.587)	...	(0.1060, 0.318, 0.621)	(0, 0.271, 0.61)
SW	(0.317, 0.65, 0.983)	(0.365, 0.683, 1)	...	(0.394, 0.697, 1)	(0.3050, 0.644, 0.983)
OT	(0, 0.233, 0.567)	(0.127, 0.381, 0.698)	...	(0.182, 0.47, 0.773)	(0, 0.254, 0.593)

a score of 4.660, ranks second and shows a relatively significant gap compared to the other strategies. The ST strategy, scoring 3.809, is placed third, while the WO (3.485) and WT (3.338) strategies occupy the fourth and fifth ranks, respectively. The lowest rank belongs to the OT strategy, with a score of 3.259. This distribution of scores highlights several important points:

1. **Quantitative and precise differentiation of strategies:** The results of the fuzzy COCOSO model demonstrate a clear and measurable distinction among the different strategies. As observed, the SO and SW strategies, with the highest scores, lead the ranking, whereas the other strategies (ST, WO, WT, and OT) receive lower scores. This significant difference reflects the capability of the fuzzy COCOSO model to represent the actual differences in the effectiveness of each strategy concerning the interaction between internal and external factors. Accordingly, the model accurately captures each strategy's sensitivity to the criteria weights and their relative importance within a fuzzy environment, distinguishing strategies with the greatest potential to achieve technology adoption objectives from less effective strategies. Moreover, the model's integration of three collective logics—additive, multiplicative, and compensatory—enables a comprehensive and balanced evaluation of the strategies' impacts, allowing decision-makers to prioritize and plan operational strategies with greater confidence. Overall, the analysis of the fuzzy COCOSO outputs indicates that the model not only creates a quantitative distinction among strategies but also enhances evidence-based strategic decision-making under fuzzy conditions.

2. **Independence of results from the traditional structure:** Although traditional SWOT matrices often suggest that SO strategies should rank highest, the findings of this study indicate that strategy prioritization is not directly determined by the traditional SWOT framework. As the data in the table show, the SW strategy, with a score of 4.660, ranks second and is only slightly behind many SO-based strate-

Table 17. Weighted product of six strategies.

	S1	S2	...	T10	T11	S
SO	(0.008, 0.016, 0.024)	(0.007,0.015,0.023)	...	(0.006, 0.01, 0.015)	(0.008, 0.016, 0.025)	(0.313, 0.625, 0.948)
ST	(0.006, 0.014, 0.022)	(0.008,0.016,0.023)	...	(0, 0.003, 0.008)	(0, 0.007, 0.015)	(0.165, 0.448, 0.771)
WO	(0.002, 0.008, 0.016)	(0.002,0.008, 0.016)	...	(0.003, 0.008, 0.012)	(0, 0.007, 0.015)	(0.094, 0.354, 0.677)
WT	(0.001,0.006, 0.014)	(0, 0.007, 0.014)	...	(0.002, 0.005, 0.009)	(0, 0.007, 0.015)	(0.086, 0.338, 0.661)
SW	(0.007, 0.015, 0.023)	(0.009, 0.017, 0.025)	...	(0.006, 0.011, 0.015)	(0.008, 0.016, 0.025)	(0.284, 0.59, 0.913)
OT	(0, 0.006, 0.013)	(0.003, 0.009, 0.017)	...	(0.003, 0.007, 0.012)	(0, 0.006, 0.015)	(0.077, 0.328, 0.652)

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Table 18. Weighted power of six strategies.

	S1	S2	...	T10	T11	P
SO	(0.947, 0.99,1)	(0.97, 0.988, 0.988)	...	(0.985, 0.994, 1)	(0.972, 0.99, 1)	(44.876, 46.525, 46.947)
ST	(0.969, 0.988, 0.998)	(0.972, 0.989, 0.999)	...	(0, 0.978, 0.99)	(0, 0.968, 0.988)	(29.797, 46.115, 46.714)
WO	(0.938, 0.974,0.99)	(0.935, 0.972, 0.989)	...	(0.978, 0.99, 0.997)	(0.903, 0.968, 0.988)	(38.849, 45.955, 46.607)
WT	(0.923, 0.968, 0.987)	(0, 0.968, 0.987)	...	(0.967, 0.983, 0.993)	(0, 0.968, 0.988)	(32.374, 45.901, 46.581)
SW	(0.973, 0.99, 1)	(0.976, 0.991, 1)	...	(0.986, 0.995, 1)	(0.971, 0.989, 1)	(44.719, 46.461, 46.906)
OT	(0, 0.966, 0.987)	(0.951, 0.977, 0.991)	...	(0.974, 0.989, 0.996)	(0, 0.966, 0.987)	(29.577, 45.862, 46.564)

gies, performing nearly at the level of the selected SO strategy. This emphasizes that the ranking is the result of a quantitative, data-driven, fuzzy multi-criteria analysis that considers the weights and real impacts of internal and external factors rather than merely their positions within the traditional SWOT framework. In other words, the fuzzy COCOSO model successfully captures the complex interactions among internal and external factors and their relative influence on strategy selection, making prioritization an independent process free from the constraints of the linear traditional structure.

3. **Emphasis of the model on more influential factors:** The lower scores of the WT (3.338) and OT (3.259) strategies indicate that, under the current conditions, these strategies possess lower strategic efficiency considering the relative weights and importance of threats and weaknesses and their susceptibility to influence. In other words, the fuzzy COCOSO model accurately highlights the superiority of strategies aligned with more influential factors and key opportunities, while placing less impactful strategies in lower positions. This ranking also aligns with risk-based decision-making logic, as less effective strategies (WT and OT) are more likely to fail or yield limited returns when confronted with weaknesses and threats, whereas SO and SW strategies demonstrate the greatest capacity for value creation and resilience against uncertainty.

4. **Consistency of results with fuzzy FUCOM weights:** The weighting of criteria in the fuzzy FUCOM stage played a pivotal role in shaping the final strategy scores. As the weight analysis indicates, factors related to strengths and opportunities—especially in certain key sub-criteria—carried higher weights, which directly resulted in SO and SW strategies, which leverage strengths and opportunities, receiving higher final rankings. These results demonstrate that the combined fuzzy FUCOM–fuzzy COCOSO model can represent the true impact of criteria weights on strategy ranking and ensures strong consistency between criteria weighting and the quantitative outputs of the model. In other words, this analysis emphasizes that the superior strategies were selected based on data-driven weights and precise fuzzy analysis rather than conjecture or traditional structure, highlighting the model's high capability in strategy prioritization.

Therefore, the results in Table 20 indicate that strategy ranking is based not on the classical assumptions of the SWOT model but on the quantitative and coherent outputs of the fuzzy multi-criteria model (fuzzy FUCOM–fuzzy COCOSO). This underscores that strategic decision-making in the present study is grounded in actual data, weights extracted from fuzzy analysis, and quantitative interactions among internal and external factors, rather than merely the traditional fourfold SWOT framework. Consequently, the use of this combined method enhances the scientific and practical validity of the study and increases the reproducibility and reliability of strategic decisions. In other words, the employed model, in addition to providing precise differentiation among strategies, has reliably implemented evidence-based and quantitative fuzzy analysis in a highly uncertain and multi-criteria environment.

Table 19. The scores of the six strategies.

Strategy	K_a	K_b	K_c	Non-fuzzy K_a	Non-fuzzy K_b	Non-fuzzy K_c
SO	(0.159, 0.169, 0.217)	(5.585, 9.69, 13.9)	(0.944, 0.984, 1)	0.181	9.725	0.976
ST	(0.105, 0.167, 0.215)	(3.145, 7.376, 11.592)	(0.626, 0.972, 0.991)	0.162	7.371	0.863
WO	(0.137, 0.166, 0.214)	(2.536, 6.151,10.369)	(0.813, 0.967, 0.987)	0.172	6.352	0.922
WT	(0.114, 0.165, 0.214)	(2.211, 5.937, 10.156)	(0.678, 0.965, 0.986)	0.164	6.101	0.877
SW	(0.158, 0.168, 0.216)	(5.196, 9.233, 13.444)	(0.94, 0.982, 0.998)	0.181	9.291	0.973
OT	(0.104, 0.165, 0.213)	(2, 5.817, 10.037)	(0.619, 0.964, 0.986)	0.161	5.951	0.856

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Table 20. The final score and ranking of the six strategies.

Strategy	Final score (K)	Ranking
SO	4.826	1
ST	3.809	3
WO	3.485	4
WT	3.338	5
SW	4.660	2
OT	3.259	6

4.5 Sensitivity analysis and validity test of the proposed approach

4.5.1 Sensitivity analysis

In this section, in order to maintain the stability of the ranking of the options, sensitivity analysis is performed based on changes in the weight of the criteria, as well as sensitivity analysis based on changes in the analysis method.

- Scenario 1 (S1) = Strengths, Weaknesses, Opportunities and Threats criteria were determined based on the Fuzzy Focal Point method (default scenario).
- Scenario 2 (S2) = Strengths criterion weight is the highest (70 percent) and Weaknesses, Opportunities and Threats criteria weight is 30 percent.
- Scenario 3 (S3) = Weaknesses criterion weight is the highest (70 percent) and Strengths, Opportunities and Threats criteria weight is 30 percent.
- Scenario 4 (S4) = Opportunity criterion weight is the highest (70 percent) and Strengths, Weaknesses and Threats criteria weight is 30 percent.
- Scenario 5 (S5) = Threat criterion weight is the highest (70 percent) and Strengths, Weaknesses and Opportunity criteria weight is 30 percent.

The results of the sensitivity analysis are given in figure 2. According to figure 1, the SO strategy has ranked first under all scenarios and the SW strategy has ranked second.

Figure 2 illustrates the ranking position changes of each strategy across the scenarios. The vertical axis represents the rank (from 1 to 6), and the horizontal axis corresponds to the sensitivity analysis scenarios.

1) The SO (Strength–Opportunity) and SW (Strength–Weakness) strategies consistently maintained ranks 1 and 2, respectively, in all scenarios. This indicates the high stability and reliability of these strategies when facing variations in model parameters.

2) The ST (Strength–Threat) strategy exhibited a sudden increase in rank, reaching position 6 in scenario S4, which suggests that under certain conditions, this strategy may gain significantly greater importance.

3) Conversely, the OT (Opportunity–Threat) strategy dropped from rank 6 in scenarios S1 through S3 to lower positions in S4 and S5, indicating high sensitivity to changes in the weighting of criteria.

4) The WT (Weakness–Threat) strategy remained mostly at rank 5, with only a slight decline in scenario S4.

5) The WO (Weakness–Opportunity) strategy-maintained rank 4 up to scenario S3, but rose to rank 3 in scenario S4, highlighting the adaptive potential of this strategy under specific environmental conditions.

Overall, the sensitivity analysis demonstrates that the SO and SW strategies exhibit the highest degree of stability and consistency under varying conditions, making them reliable options for strategic planning in the adoption of smart technologies in urban construction. In contrast, the ST and OT strategies showed the greatest variability

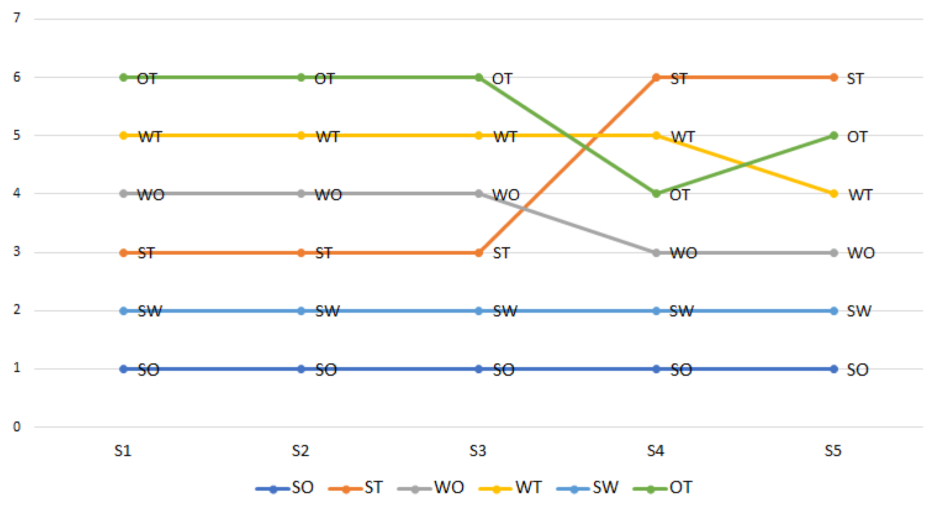

Figure 2. Sensitivity analysis based on 6 strategies.

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in rankings, indicating that environmental and technical uncertainties should be carefully considered when evaluating these options in final decision-making. And then, the research results are validated using two methods: Fuzzy TOPSIS [47] and Fuzzy SAW [48]. The final results are given in Table 21, which shows that the ranking of these two methods is exactly in line with the ranking of the research method.

Table 21. Comparison of rankings across 6 strategies.

	Fuzzy COCOSO	Fuzzy TOPSIS	Fuzzy- SAW
SO	1	1	1
ST	3	3	3
WO	4	4	4
WT	5	5	5
SW	2	2	2
OT	6	6	6

4.5.2 Validity test of the proposed approach using real-world data and expert evaluation

The proposed hybrid model was designed, implemented, and validated using real-world data and expert opinions from managers and specialists within the Municipality of Qom Province. The process of evaluating the model's effectiveness and reliability was conducted as follows:

1) **Utilization of Real Data from the Municipality of Qom:**

   • SWOT factors (Strengths, Weaknesses, Opportunities, and Threats) were identified through field interviews with 12 senior managers and experts from the Qom Municipality. These factors were derived from organizational performance documents, urban development plans, and environmental analyses within the municipality's operational scope.

   • Following the extraction of these factors, they were prioritized and rated using fuzzy logic, based on expert judgment, and subsequently employed as input data for the fuzzy FUCOM model.

2) **Validation of Model Effectiveness:**

   • The final strategies resulting from the model (SWOT-FUCOM-COCOSO) were compared with the approved operational programs and policies of the Qom Municipality.

   • The results demonstrated a high degree of alignment between the model's outputs and the municipality's strategic orientations, and in some cases, the model contributed to identifying opportunities or threats beyond those documented in existing municipal records.

   • Additionally, a final evaluation session was held with selected members of the Qom Municipality's Strategic Council, during which the model's applicability and accuracy were confirmed.

3) **Model Reliability:**

   • In the criterion-weighting phase using the fuzzy FUCOM method, the Full Consistency Ratio (FCR) was calculated for each of the SWOT factor sets. All resulting values were below 0.05, indicating acceptable consistency in expert judgments and stability in the decision-making process.

   • Furthermore, to assess the model's reliability, a portion of the evaluations was repeated with the same experts after a two-week interval (test-retest), revealing negligible and statistically insignificant differences in the final results—demonstrating the model's reliability and reproducibility.

4) **Expert Validation of Model Output in the Urban Context:**

   • The strategic outputs of the model were compiled into a report and presented to the strategic planning team of the municipality. Upon review by several senior managers, these strategies were considered implementable recommendations for future municipal planning initiatives in Qom.

   The proposed hybrid model has been validated both through real-world field data and domain-specific expertise from the Qom Municipality, and it has also been evaluated and confirmed in terms of mathematical consistency, fuzzy reliability, and strategic applicability. These findings indicate that the model possesses high operational effectiveness and reliability within real urban decision-making environments.

5. Conclusion and practical analysis

The present study evaluated strategies for the adoption of smart technologies in the urban construction industry of Qom under conditions of uncertainty, using a fuzzy integrated SWOT–MCDM model. In this model, strategies include Strength–Opportunity (SO), Strength–Threat (ST), Weakness–Opportunity (WO), Weakness–Threat (WT), Opportunity–Threat (OT), and Weakness–Threat with an opportunity-creation approach (WS), which were weighted using the fuzzy FUCOM method and prioritized with the fuzzy COCOSO method. The detailed structure of these strategies, including their strategic logic, key actions, and implementation linkages, is summarized in Table 22.

The study's findings not only provide high-level managerial recommendations but also generate deep technical insights directly relevant to the practical adoption of smart technologies. Specifically, the relevance of these findings to technical barriers, infrastructure requirements, and key smart city technologies can be examined along three main dimensions:

1. **Technologies and Infrastructure:** Critical technologies, including BIM, IoT, engineering software, Augmented Reality (AR), and Virtual Reality (VR), are suggested within the SO, ST, and OT strategies. Additionally, the establishment of city-scale

Table 22. Strategies, Key Actions, and Their Linkages.

Strategy Category	Strategic Logic	Key Actions	Linkage to Strategy
SO (Strength–Opportunity)	Maximizing existing construction industry capabilities to leverage smart city technological and infrastructural opportunities. Rapid technology deployment and transformation of potential capacity into real value.	- Collaborate with universities and research centers to develop skills in AI, BIM, robotics, and sustainable energy. - Strengthen digital and IoT infrastructure for smart projects. - Develop the smart construction market considering housing demand and quality of life. - Implement training and awareness programs with the municipality and engineering organization. - Utilize government incentives to attract investment in smart technologies.	Key actions directly leverage existing strengths and opportunities, aligning with strategic goals: human capacity building, infrastructure enhancement, and market exploitation to accelerate technology adoption.
WO (Weakness–Opportunity)	Compensate for current industry deficiencies by exploiting technological and policy opportunities. Enhance internal capacity and reduce gaps with smart city standards.	- Skill-based training programs for engineers and contractors. - Develop digital platforms for managing smart projects. - Attract foreign or government investment to expand IoT and big data infrastructure.	Key actions address current weaknesses and exploit technological opportunities to strengthen internal capacity and prepare the industry.
ST (Strength–Threat)	Use internal capabilities to mitigate environmental threats and enhance industry resilience.	- Utilize local expertise and knowledge-based companies to reduce dependence on foreign equipment. - Develop risk management frameworks for smart projects. - Establish local standards for technology adaptation. - Strengthen public–private partnerships to reduce financial risks. - Promote a culture of smart technology adoption.	Key actions target environmental threats by empowering internal resources and reducing dependencies, aligning with the strategy's resilience logic.
WT (Weakness–Threat)	Simultaneously reduce internal weaknesses and external threats by creating minimal capacity required for smart city transition. Focus on risk mitigation and preparedness.	- Basic capacity-building programs for construction industry staff. - Develop a cautious roadmap for smart technologies. - Financial risk management in technology-based projects.	Key actions directly reduce weaknesses and threats, aligned with the strategic goal of increasing preparedness and lowering risk.
OT (Opportunity–Threat)	Exploit technological opportunities to neutralize environmental threats.	- Implement BIM, IoT, AR/VR, engineering software, and smart management systems to reduce project risks. - Develop IoT connectivity infrastructure based on LoRaWAN or low-power networks. - Enhance efficiency through automation and smart construction processes.	Key actions leverage opportunities to mitigate environmental threats and create value under uncertain conditions.
WS (Weakness–Threat with Opportunity-Creation)	Transform weaknesses and threats into new opportunities through structural redesign, policy reforms, and process improvements.	- Redesign project organizational structures for smart technology adaptation. - Define supportive mechanisms to reduce investor risks. - Establish urban innovation centers to address skill and technical gaps.	Key actions convert weaknesses and threats into opportunities through structural and policy innovation, aligned with the strategy's opportunity-creation logic.

LoRaWAN-based connectivity infrastructure to support sensors and IoT hardware is included in the OT, SO, and WT strategies. These recommendations address technical challenges such as unstable network connectivity, data transmission limitations, and the need for low-power communication protocols.

2. **Human Capacity and Skill Development:** Adoption of smart technologies is not feasible without enhancing the skills of specialists, contractors, and urban managers. The SO, WO, and OT strategies emphasize training programs, university–industry collaborations, and the development of specialized human resources in BIM, IoT, and digitalization, directly targeting the shortage of personnel familiar with these technologies.

3. **Reducing Dependence and Managing Technological Risks:** The ST, OT, and WT strategies focus on domestic production of smart equipment, development of local standards, and establishing risk management frameworks. These measures target environmental threats and enhance the industry's resilience against technological and financial fluctuations.

Determine the importance and priority of implementing these strategies, fuzzy FUCOM was applied for weighting, and fuzzy COCO-SO was used for prioritization. Results indicated that SO and SW strategies hold the highest importance, specifically:

- Utilizing existing technological and operational capabilities to exploit smart technology opportunities.
- Reducing internal weaknesses through skill development, digital infrastructure enhancement, and bridging technical knowledge gaps. Thus, the findings are not limited to general managerial recommendations but have direct practical applications for policymakers and urban managers, including:
  - Precise planning for implementing BIM, IoT,

AR/VR, and LoRaWAN networks.

- Guiding technological investments based on the real priorities of each technology.
- Developing digital and communication infrastructures aligned with smart city technical needs.
- Empowering human resources and improving technological literacy in the construction industry.
- Enhancing project resilience against financial, technical, and economic constraints.

In summary, this study effectively bridges In summary, this study effectively bridges the gap between high-level strategic analyses and the operational and technical requirements of smart construction by integrating SWOT with fuzzy MCDM methods, providing actionable, technologically informed, and implementable guidance for smart city development in Qom.

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Authors contributions
All authors contributed equally to the conception, design, execution, and writing of this work. All authors read and approved the final manuscript.

Availability of data and materials
The authors declare that the data supporting the findings of this study are available within the paper.

Conflict of interests
The authors assert that they do not have any identifiable conflicting financial interests or personal relationships that might be perceived to influence the work presented in this paper.

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