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Streamlining apartment provider evaluation: A spherical fuzzy multi-criteria decision-making model

Phi-Hung Nguyen [a,*], Thu-Hien Tran [b], Lan-Anh Thi Nguyen [a], Hong-Anh Pham [a], Mai-Anh Thi Pham [a]

[a] Research Center of Applied Sciences, Faculty of Business, FPT University, Hanoi 100000, Viet Nam
[b] Department of Business Management, National Taipei University of Technology, Taipei 10608, Taiwan

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ABSTRACT

In the context of the thriving real estate market in developing countries like Vietnam, understanding consumer preferences and effectively addressing them through a comprehensive multi-criteria decision-making (MCDM) framework is paramount for real estate providers. This study presents a two-stage MCDM model that integrates the Delphi technique and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based on Spherical Fuzzy Sets (SFSs). Initially, the SF-Delphi technique validates critical criteria influencing customers' apartment selection in Vietnam. Secondly, the SF-TOPSIS method evaluates the top ten apartment providers. To ensure robustness and validity, a comparative analysis compares the results with those from the Intuitionistic Fuzzy TOPSIS (IF-TOPSIS) and Fuzzy TOPSIS (F-TOPSIS) methods. Subsequently, five rank correlation coefficients (Spearman, Kendall, Goodman-Kruskal, Weighted rank measure of correlation, Weighted Similarity) are used to assess the relationships between various TOPSIS techniques applied to apartment suppliers in Vietnam. The correlation coefficients demonstrate strong agreement among the TOPSIS methods, with the smallest coefficient being 0.7778, surpassing the threshold of 0.7. This high level of consistency confirms the efficacy of the proposed TOPSIS approach with different Fuzzy Sets in reliably evaluating customers' preferences for apartment suppliers. Notably, the legal aspect's prominence underscores its critical role in shaping customer choices, emphasizing the significance of considering legal factors in the context of apartment supply and demand in Vietnam. Furthermore, using SFSs makes this approach particularly suited to capture consumer perceptions within the dynamic and uncertain business environment characterized by volatility, uncertainty, complexity, and ambiguity (VUCA).

1. Introduction

Access to affordable and sufficient housing is an inherent human right; however, this right often faces compromise in developing countries due to prevalent housing shortages [1]. Acquiring real estate in such nations poses formidable obstacles attributed to various factors. The absence of lucid regulations and established legal frameworks introduces uncertainty and elevates the risk of fraudulent activities, impeding buyers' ability to safeguard their interests. Furthermore, real estate costs in developing countries, particularly

* Corresponding author.
E-mail addresses: hungnp30@fe.edu.vn (P.-H. Nguyen), t112379401@ntut.edu.tw (T.-H. Tran), anhntl84@fe.edu.vn (L.-A. Thi Nguyen), anhpth5@fe.edu.vn (H.-A. Pham), anhptm16@fe.edu.vn (M.-A. Thi Pham).

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within urban locales characterized by high demand, can attain exorbitant levels, exacerbating the scarcity of affordable housing and leaving numerous residents grappling to secure appropriate living spaces. Moreover, challenges linked to infrastructure deficiencies, such as subpar transportation systems and unreliable utilities, also cast shadows on property values and overall habitability. These complexities impose hardships on real estate investors endeavouring to make well-informed choices, as well as individuals striving to locate housing options that are both affordable and fitting. This study's impetus emanates from the urgent concern about housing shortages in developing countries, encompassing locales like Vietnam. It is imperative to address the hurdles real estate investors and potential homeowners face in this context.

Vietnam is a developing country facing a severe housing shortage, particularly in its major cities. Vietnam is the 15th most populous country in the world, with a population of around 100 million. Despite this, the land area of Vietnam is relatively small, ranking only 65th globally [2]. This has led to a concentration of the population in urban areas, resulting in a high demand for housing. The housing shortage has reached crisis levels in Vietnam's major cities, such as Ho Chi Minh City and Hanoi. Based on the recent statistics on housing and real estate markets during the third quarter of 2022, a total of 4123 commercial homes have been completed, while 324,511 units are currently under construction and licensed to 24,324 apartments, as reported by the Ministry of Construction in Vietnam [3]. Despite the significant demand for housing in Vietnam, there is relatively little research on customers' decisions to purchase apartments, with most studies focused on evaluating customer satisfaction rather than the variables that influence their intention to purchase. Therefore, the need to address these challenges and provide practical decision-making tools for real estate investors and consumers is evident.

To tackle this issue, real estate businesses in Vietnam have been focusing on building apartments to meet the growing demand. However, there is a lack of comprehensive research on the variables that significantly influence customers' apartment selection decisions [4]. A system for measuring social housing quality in Vietnam was built by Le et al. [5], proposing 12 indicators, including location, distance to current social facilities, the building's master plan, public space, technical areas, the structure of space inside each apartment, etc. Meanwhile, Huynh [6] discovered that factors such as the apartment complex's land size, the size of its housing units, their grade, their age, their density, and their closeness to other densely populated places all had a large impact on apartment costs. The row house form is strongly chosen for single-family dwellings, according to Seo et al. [7], but a preference for apartments is also seen for future planning.

Given the complexity of the real estate market in developing countries, it is crucial to have effective decision-making tools that can help real estate investors make informed decisions. As demonstrated by previous studies, multi-criteria decision-making has been identified as an appropriate approach for complicated cases. However, previous research has not fully explored the decision to select an apartment from the perspective of multi-criteria decision-making and fuzzy theory. MCDM approaches, such as Analytic Hierarchy Process (AHP) [8], COPRAS (COmplex PRoportional ASsessment) [9], Simple Additive Weighting (SAW), grey relational analysis (GRA) [10], Delphi and Techniques for Order Preference by Similarity to an Ideal Solution (TOPSIS) methods [11], are commonly used to evaluate complex problems that involve multiple criteria.

However, traditional MCDM methods have limitations when dealing with vagueness and reluctance, which are common in real-world decision-making. To overcome these limitations, researchers have proposed using fuzzy sets [12], which can represent complex and uncertain information using fuzzy numbers. Since Zadeh [13] published the first fuzzy sets, numerous researchers have worked on numerous applications for handling multi-criteria judgments. Type-2 Fuzzy Sets (T2FS) [14], Intuitionistic Fuzzy Sets (IFS) [15], Hesitant Fuzzy Sets (HFS) [16], Pythagorean Fuzzy Sets (PFS) [17] and Spherical Fuzzy Sets (SFS) [18,19] have been commonly applied in recent publications. To be more precise, it is well-noted that SFSs are a recent development in fuzzy sets, enabling decision-makers to extrapolate different fuzzy set extensions [8,20–24]. SFSs were established by creating a membership function on a spherical surface and dependently assigning the parameters of that membership function with a broad domain. It is a mix of IFS, PFS, and HFS and can independently handle the decision-makers' reluctance to assign membership, non-membership, and hesitation values. With SFSs, decision-makers can define a membership function on a spherical surface and dependently assign the parameters of that membership function with a huge domain.

Despite the growing popularity of MCDM methods in the real estate industry, there remains a significant gap in research regarding their application in validating crucial factors and understanding apartment supplier selection trends in the housing sector, particularly in Vietnam. This makes it imperative to develop a thorough MCDM model that can precisely identify and rank the critical elements impacting Vietnamese clients' choice of apartments as well as rank the apartment providers in terms of importance. Furthermore, the existing literature on variables influencing customers' decisions in the real estate sector is inadequate, often relying on generic elements from other studies that may not be suitable for specific contextual studies in Vietnam. To address this issue, it is imperative to employ a technique that can effectively filter out irrelevant elements and ensure the inclusion of only the most relevant factors. In addition, the integration of SFSs and MCDM models in the context of apartment selection is an underexplored area of research. Traditional MCDM models may face challenges when dealing with complex and multidimensional issues, such as consumer perception. In addition, doing pairwise comparisons between several components can be error-prone and take time. Therefore, investigating the effectiveness of the spherical fuzzy decision-making approach becomes crucial in improving the accuracy and efficiency of apartment selection processes.

This study initiated by identifying the criteria and sub-criteria based on the most recent literature on the real estate and apartment market, as well as considering customer preferences. To ensure the validity of these sub-criteria, a survey questionnaire was meticulously developed and subsequently reviewed by experts in Vietnam. However, decision-making processes often encounter uncertainties stemming from the involvement of stakeholders with diverse interests. To effectively address these uncertainties and capitalize on the advantages of MCDM models and the spherical dimensions of SFSs, a two-stage MCDM model was proposed, namely SF-Delphi and SF-TOPSIS. By addressing the existing research gaps, this study makes notable contributions that can be highlighted as follows:

Firstly, the significance of the hybrid SF-Delphi and SF-TOPSIS models is emphasized. This study distinguishes itself as the first to utilize this novel hybrid approach to investigate the selection of apartment providers in the real estate industry, with a specific focus on Vietnam. Notably, the utilization of SFSs in this approach allows for separate definitions of membership, non-membership, and hesitant degrees. Additionally, the membership functions are defined on a spherical surface, providing experts with enhanced flexibility in expressing their preferences. This unique characteristic enables the incorporation of ambiguous and uncertain information when ranking the relative importance of various aspects, resulting in more precise and accurate findings.

Secondly, this study pioneers identifying the critical factors that significantly influence customers' choices in selecting apartments. The study sheds light on the key considerations that impact apartment selection decisions by selecting essential criteria and sub-criteria.

Finally, the organizational implications for stakeholders are highlighted. The insights derived from this study are valuable not only for the real estate industry but also for consumers, decision-makers, and investors across various industries. The implications offer guidance for evaluating and selecting apartment suppliers, facilitating stakeholders in making informed decisions.

This study is structured as follows: Section 2 provides a comprehensive review of the existing literature pertaining to the subject matter. In section 3, a detailed methodological framework is presented. Section 4 presents the findings of the analysis, providing insights into the factors influencing apartment selection and the order of priority for apartment suppliers in Vietnam. Moreover, section 5 offers a conclusion summarizing the key findings and also discusses the implications of the study's results for the real estate industry and decision-making processes.

2. Literature review

2.1. Literature review on real estate purchase decision

The multidimensional nature of real estate purchase decisions has been examined through various theoretical frameworks. Maslow's Hierarchy of Needs [25] posits that the fulfillment of basic physiological needs may dictate preferences in apartment selection. Complementary to this, the Theory of Planned Behavior [26] and Social Exchange Theory [27] accentuate the influence of social constructs and attitudes in the decision-making process. Rational Choice Theory [28] foregrounds the role of cost-benefit analyses, whereas Multi-Criteria Decision Analysis [29] furnishes an integrative methodology for assessing multiple evaluative dimensions. Notably, these theoretical paradigms are not mutually exclusive but offer overlapping lenses through which purchase decisions can be scrutinized [30].

Real estate purchase decisions are complex and involve multiple factors, including location, price, property type, and amenities [31]. By considering different perspectives, real estate providers can better understand their customers' needs and preferences and offer apartments that meet them. This can lead to higher customer satisfaction and a more successful real estate business.

Location is the most critical factor influencing housing purchase decisions. In the study by Seo et al. [7] uncontrolled urbanization in HCMC caused apartment prices to be more correlated with locational attributes, community density, and programs, whereas central government-supported urban infrastructure development in Hanoi caused prices to be more correlated with housing characteristics [32].

Price was the most crucial consideration when choosing a residential property, according to Zrobek and Trojanek's study on how environmental factors affected purchasers' decisions about where to buy a home in northern, western, and southern Poland [33]. Park et al. [34] found that price sensitivity varied depending on the buyer's income level, age, and previous experience in the real estate market. The study also revealed that consumers would pay more for properties with better amenities and locations. Property type is another factor influencing real estate purchase decisions. Several studies have examined the impact of property type on consumer behavior.

Yoo and Yoon [35] found that housing complexes with Huge community open areas have a greater percentage of unsold units, but the surplus decreases more rapidly. Simillarly, Dell'Anna et al. [36] highlighted a positive effect on housing unit values with proximity to natural green areas, city parks, and regional parks.

In the context of homebuying behavior in Taiwan, Tsou and Sun [37] suggest that demographic factors influence preferences for property acquisition. Specifically, young couples and families exhibit a proclivity for purchasing homes for personal occupancy. Conversely, middle-aged individuals and couples are more likely to purchase housing for investment purposes rather than for their own use. Despite a plethora of research on the determinants influencing real estate acquisition, existing literature presents lacunae, particularly with respect to emerging markets. The majority of studies have concentrated on consumer behavior in developed nations, thereby highlighting the necessity for focused inquiry in nascent markets.

2.2. [37]Literature review on the MCDM methods

The MCDM method, initially developed in the beginning of the nineteenth century, it was criticized due to the convergence, ambiguity, and vagueness of judgments obtained from repeated surveys [38]. To overcome these concerns, fuzzy sets were integrated into the method, with the latest advancement being the introduction of SFSs [39]. While extant literature on real estate acquisition commonly relies on factors identified through previous scholarly work, it is crucial to acknowledge that these influencing elements may vary across temporal and spatial dimensions. Among MCDM methods, Delphi technique has been identified as a systematic and participatory procedure of group decision-making intended to reach a consensus regarding complex issues [40]. However, the traditional Delphi method faced criticism for issues related to convergence, uncertainty, and the ambiguous nature of expert judgment [41]. These concerns arose because experts might have differing interpretations of criteria, leading to convergence issues in previous Delphi procedures. Additionally, the traditional Delphi approach is time-consuming due to the need for repeated interviews [42]. The Fuzzy Delphi Method was introduced to address these limitations incorporating fuzzy numbers and producing objective and realistic results even with a limited sample size [43,43]. Combining fuzzy logic with MCDM techniques has four benefits: (1) shortening questionnaire survey times; (2) avoiding distorting individual expert judgments; (3) expressing the semantic structure of anticipated items clearly; and (4) taking into account the fuzzy nature of the interview procedure [44]. For instance, fuzzy Delphi and AHP are combined to identify critical factors and determine the importance degree of each criterion [42]. In the context of sustainable product development, fuzzy Delphi is combined with Decision-Making Trial and Evaluation Laboratory (DEMATEL) for examining causal relationships [45]. Other studies have integrated fuzzy Delphi with the Grey Relation Analysis (GRA)-VIKOR method for optimal siting of electric vehicle charging stations [46], as well as proposed a three-staged model of fuzzy Delphi, fuzzy DEMATEL, and DANP to investigate critical factors influencing foreign direct investment (FDI) attraction in Vietnam [47].

In recent years, scholarly advancements in the domain of alternative selection have been notable. Nonetheless, the inherent complexities of real-world scenarios, characterized by ambiguity and uncertainty, present formidable obstacles for decision-makers tasked with making informed selections [48]. However, traditional MCDM models such as TOPSIS do not account for ambiguity and uncertainty in real-world scenarios, leading to its combination with fuzzy set theories, similar to the Delphi method, to address these challenges. The Fuzzy-TOPSIS method, as a result, has emerged with the advantage of being straightforward and consistent regardless of the number of possibilities and selection criteria [49]. By incorporating the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS), Fuzzy-TOPSIS identifies the best alternative that is closest to the FPIS and farthest from the FNIS [50]. Given that decisions based solely on speculation and personal opinions tend to be subjective and carry inherent risks, integrating factual information from scientific research and mathematical structures becomes crucial for decision support. The application of fuzzy TOPSIS facilitates the integration of both quantitative and qualitative criteria in decision-making, thereby reducing ambiguity and uncertainty associated with expert judgments on criteria, sub-criteria, and alternative assessments [51].

When Kutlu Gündoğdu et al. introduced the SF-TOPSIS method in 2019 [52], it became a more optimal approach than the previous fuzzy TOPSIS methods. This outstanding method's distinguishing feature is its more flexible and adaptable structure, which enables it to account for the hesitancy component of ambiguous information along with membership, and non-membership. In the real estate field, MCDM methods and SFSs approaches have been widely adopted in research studies. SFSs offer significant advantages in handling uncertainty and imprecision within multi-attribute decision-making problems [53]. They provide decision-makers with the flexibility to allocate hesitancies across a broader domain, incorporating various fuzzy set expansions into a unified theory. With SFS, experts can express degrees of membership, non-membership, and indeterminacy while maintaining these characteristics within the unit. The SF-Delphi method has proven to be an effective tool in decision-making for complex issues with limited accurate information. It offers flexibility, eliminates geographical barriers, promotes open debates, and focuses attention on relevant matters matters [54]. Several studies have successfully integrated SFS into MCDM models to address various real-world problems. For example, Nguyen [55] designed a two-phase MCDM approach combining SF-Delphi and SF-DEMATEL to analyze factors influencing employee satisfaction in the Vietnamese logistics service industry.

Akram et al. [56] employed SFSs in conjunction with the Elimination and Choice Translating Reality methods (ELECTRE) to discern

Table 1
List of related studies.

No.	Authors	Topics	Methods
1	Gokasar et al. [62]	Electric vehicle	Fuzzy RAFSI (Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval)
2	Gökmener et al. [63]	Site selection for floating photovoltaic system	Fuzzy OPA (Ordinal Priority Approach and Distance from Average Solution)
3	Gokasar et al. [64]	Autonomous vehicles with self-powered sensors	Fuzzy FUCOM (full consistency method), fuzzy ALWAS method (Aczel-Alsina weighted assessment)
4	Deveci et al. [65]	Traffic system's integration with Metaverse	Fuzzy Einstein based logarithmic methodology of additive weights, TOPSIS
5	Deveci et al. [66]	Public charging station type selection	the rough Dombi Bonferroni based MCDM model
6	Wang et al. [67]	Solar PV power plants site selection	Data Envelopment Analysis (DEA) method, Grey AHP, and Grey TOPSIS
7	Yadav et al. [68]	Optimal network selection in 5G	Improved method based on improved removal effects of criteria-TOPSIS (I-MEREC-TOPSIS)
8	Mehra et al. [69]	Selection of best fuel	AHP, TOPSIS
9	Wang et al. [70]	Bunkering port selection	Fuzzy Delphi–TOPSIS
10	Tong et al. [71]	Sustainable suppliers selection for SMEs	PROMETHEE II
11	Nguyen [11]	Package tour provider selection	Spherical fuzzy Delphi TOPSIS
12	Wang et al. [72]	Doctor selection	TOPSIS
13	Bachchhav et al. [73]	Spot-welding electrode material selection	AHP SAW TOPSIS
14	Kaur et al. [74]	Solar panel selection	Entropy TOPSIS
15	Sang et al. [75]	Electric bus charging station selection	DEMATEL, PROMETHEE
16	Kaur et al. [76]	Rehabilitation center selection	Fuzzy ELECTRE I, Fuzzy PROMETHEE

an optimal solution for advancing the digitalization of Istanbul's public transportation system, with a specific focus on alleviating environmental pollution. To complement this approach, the AHP was harnessed to ascertain the relative weights of diverse criteria integral to the evaluation process. Furthermore, within the framework of the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) technique family, Akram et al. [57] exhibited their prowess in integrating the SFSs framework to conceptualize innovative strategies for group decision. This pioneering methodology was also extended to the medical domain, where they skillfully employed it to pinpoint the most suitable site for establishing the Fangcang shelter hospital in Wuhan, tailored to manage patients afflicted by COVID-19 efficiently. Kutlu Gündoğdu and Kahraman [58] introduced the Spherical Fuzzy Weighted Aggregated Sum Product Assessment (SF-WASPAS) technique, refining the conventional WASPAS approach. This advanced methodology was applied to solve a complex industrial robot selection challenge, showcasing its practical utility. Additionally, Zahid et al. [58] introduced a streamlined version of the versatile and adaptable complex spherical fuzzy ELECTRE II method, designed for effectively choosing optimal technology for remediating cadmium-contaminated water. Meanwhile, Akram et al. [59] presented the Complex Spherical Fuzzy VIKOR method to rank primary objectives for a Facebook advertisement campaign. Numerous other studies have embraced fuzzy decision-making methodologies, incorporating SFS, to solve diverse challenges. For instance, SF-TOPSIS and SF-Delphi were utilized in tandem for the selection of package tour providers [11]. Moreover, conventional decision-making techniques were extended to encompass SFS, such as the SF-AHP approach implemented in the site selection process for renewable energy projects [53], industrial robot selection [60], and the conceptualization of drone-based urban logistics strategies [61].

The highlighted content discusses various aspects of MCDM models and their applications in alternative selection [62–76]. It begins by noting the extensive use of MCDM models in research across different topics, as indicated in Table 1. The systematic assessment of choices based on factors such as benefit, cost, decision criteria, and personal opinions is highlighted as a key advantage of MCDM techniques. Among these techniques, TOPSIS stands out for quantifying the performance measures of alternatives. The complexity of decision-making in uncertain and ambiguous environments is acknowledged, leading to the combination of traditional MCDM models with fuzzy set theories akin to the Delphi method. The emergence of the Fuzzy-TOPSIS method is mentioned, highlighting its simplicity and consistency regardless of the number of possibilities and criteria. This method incorporates fuzzy positive and negative ideal solutions to identify the best alternative. The importance of integrating factual information derived from scientific research and mathematical structures into decision support is emphasized. Fuzzy TOPSIS is presented as a powerful approach that integrates both quantitative and qualitative criteria, reducing ambiguity and uncertainty associated with expert judgments on criteria, sub-criteria, and alternative assessments. Moving on to group decision-making, the limitations of traditional PROMETHEE and ELECTRE-based methods are discussed. Their inadequate handling of uncertainty, subjective weight assignments, and complexity in decision ranking are identified as drawbacks that can lead to inaccurate or suboptimal decisions. The limited capability of these methods in handling fuzzy information is also noted. In contrast, Delphi and TOPSIS models explicitly incorporate fuzzy sets and fuzzy similarity measures, offering a more flexible and accurate representation of fuzzy information. This enhanced capability to handle uncertainties and ambiguities contributes to a more robust and adaptable decision-making process.

Considering the ambiguity and uncertainty faced by decision-makers, this study proposes a model that combines the latest fuzzy theory, SFSs, with Delphi and TOPSIS methods to investigate apartment supplier selection in Vietnam.

2.3. Literature review on criteria affecting apartment selection

Over the past few decades, numerous authors have delved into consumer behavior research, which significantly impacts business development. Social, dynamic, and demographic factors, such as age, gender, and education, play a vital role in influencing people's purchasing decisions [77]. Understanding customer behavior in the real estate sector is crucial for providing relevant solutions, satisfying consumers, and generating substantial revenues [78].

Table 2
Criteria affecting apartment selection.

Main Criteria	Sub-Criteria	References
Prices (PR)	PR1 - System of Installment Payment	[83]
	PR2 - Availability of Bank Loans	
	PR3 - Reasonable Price	
Project Facilities (PF)	PF1 - Play Ground for the Children under the projects	[84,83]
	PF2 - Lift Facilities & Generator in the Apartment	
	PF3 - Car Parking Facilities	
Living Space (LS)	LS1 - Quantity of bedrooms	[84]
	LS2 - Quantity of bathroom	
	LS3 – Total area	
Location and Communication (LC)	LC1 – Residential Living Environment	[84,83]
	LC2 - Near to Educational Facilities	
	LC3 – Near to Workplace	
Environmental (EV)	EV1 - Noise and Sound of Adjacent Area	[84,85]
	EV2 – Environment Pollution of the Area	
	EV3 - Density of Population	
Legal (LE)	LE1 - Apartment legal status (have a pink book)	[85]
	LE2 - Term of use of housing	
	LE3 - Home buying procedures	

Several studies have identified factors influencing consumers' apartment purchase decisions. For instance, Singh et al. [78] emphasized the importance of the apartment's structure and design in shaping consumers' decisions. Kamal et al. [79] highlighted that land problems, urbanization, and population pressures can influence buying attitudes. Islam et al. [80] investigated perceived physical quality, access to money, and favorable government policies, to predict behavior intentions [80].In Vietnam, Nguyen et al. [81] discovered a positive correlation between household income and people's satisfaction, while education showed a negative correlation with satisfaction. This finding was attributed to higher-income households affording better-quality furniture and homes, and educators having higher standards and goals [82].Similarly, Bhat et al. [82] encompassed a wide range of dwelling unit options, exploring factors like tenure, housing type, number of bedrooms, bathrooms, storeys, square footage, lot size, housing costs, neighborhood density, and commute time. The research underlined the significant influence of both location and dwelling characteristics on the housing decisions of foreigners in Turkey. In a study focused on apartment preferences,

Through an extensive review of literature, experts have identified key evaluation criteria that significantly influence customers when choosing an apartment, as summarized in Table 2.

Prices: Price plays a crucial role in customers' purchasing decisions, reflecting the value they place on the product or service [86, 84]. Nguyen et al. [87] found that the price of real estate is the most critical factor influencing customers' decisions.

Living Space: Living space encompasses factors like room size, kitchen, bathrooms, and bedrooms. It has a significant impact on consumers' housing choices [88]. Besides location, households also consider the number of bedrooms, bathrooms, square footage, and housing expenses when deciding on a place to live [85].

Project Facilities: Project Facilities refer to amenities and utilities within the apartment complex, such as swimming pools, spas, gyms, and canteen [1]. Ac. Projects with various facilities are preferred by customers, leading to increased interest [86].

Location and Communication: Customers prefer apartments in locations with good infrastructure and communication facilities, providing easy access to shopping centres, hospitals, and schools [85]. The location factor significantly influences homebuyers' decisions, and the residential location often shapes housing preferences [89].

Environmental: Increasingly, customers prioritize environmental concerns. The surrounding environment is crucial for homebuyers, impacting their peace and quality of life by considering factors like noise, traffic, pollution, and population density [84,85]. Residential satisfaction is closely related to homeowners' contentment with their surroundings, including green spaces, pollution levels, upkeep, and cleanliness [90].

Legal: Legal factors, such as regulations on home ownership, usage terms, purchasing procedures, property taxes, and fees, can influence the decision to purchase a home [89]. Nguyen et al. [87] found that the "Legal" aspect significantly affected customers' choices of apartments in Vietnam. Trust and satisfaction in real estate transactions can be inspired by proper legal documentation for both buyers and sellers. Delays in obtaining legal papers, like the "pink book" in Vietnam, may be experienced for newly built projects, which take around five years to complete from the transfer date to buyers.

3. Spherical fuzzy sets preliminaries

Kutlu Gündoğdu and Kahraman proposed the Spherical Fuzzy Sets (SFSs) as an advanced three-dimensional extension of existing fuzzy sets—namely, intuitionistic fuzzy sets, Pythagorean fuzzy sets (PFS), and Picture fuzzy sets (PiFS) to manage uncertainty in expert appraisals [91]. nlike intuitionistic fuzzy sets, which restrict the sum of membership and non-membership degrees to the [0,1] interval, SFSs offer greater flexibility. SFSs present three dimensions that encapsulate membership, non-membership, and hesitation degrees within the [0,1] interval, thus offering a more nuanced approach to handling uncertainties compared to both type-1 and type-2 fuzzy sets, as well as PFS [92].

Definition 1. Spherical fuzzy sets (SFSs) $\widetilde{U}_s$:

Let and A_2 represent two distinct universes of discourse. Consider $\widetilde{U}_s$ and $\widetilde{V}_s$ are two SFSs corresponding to A_1 and A_2 as presented by Equations (1) and (2):

$$\widetilde{U}_s = \left(x, \left(\alpha_{\tilde{U}_s}(x), \beta_{\tilde{U}_s}(x), \gamma_{\tilde{U}_s}(x)\right) | x \in A_1\right) \tag{1}$$

where.

$\alpha_{\tilde{U}_s}(x) : A_1 \in [0,1], \beta_{\tilde{U}_s}(x) : A_1 \in [0,1], \gamma_{\tilde{U}_s}(x) : A_1 \in [0,1]$ and:

$$0 \leq \alpha^2_{\tilde{U}_s}(x) + \beta^2_{\tilde{U}_s}(x) + \gamma^2_{\tilde{U}_s}(x) \leq 1, \text{with } \forall x \in A_1 \tag{2}$$

For each x in the A_1 , the functions $\alpha_{\tilde{U}_s}(x)$, $\beta_{\tilde{U}_s}(x)$ and $\gamma_{\tilde{U}_s}(x)$ denote the degrees of membership, non-membership, and hesitancy of x to $\widetilde{U}_s$, respectively.

Definition 2. Let $\widetilde{U}_s = (\alpha_{\tilde{U}_s}, \beta_{\tilde{U}_s}, \gamma_{\tilde{U}_s})$ and $\tilde{V}_s = (\alpha_{\tilde{V}_s}, \beta_{\tilde{V}_s}, \gamma_{\tilde{V}_s})$ be two SFSs by Equations (3) and (4):

$$\widetilde{V}_s = \left(x, \left(\alpha_{\tilde{V}_s}(x), \beta_{\tilde{V}_s}(x), \gamma_{\tilde{V}_s}(x)\right) | x \in A_2\right) \tag{3}$$

where.

$\alpha_{\tilde{V}_s}(x) : A_2 \in [0,1], \beta_{\tilde{V}_s}(x) : A_2 \in [0,1], \gamma_{\tilde{V}_s}(x) : A_2 \in [0,1]$ and:

$$0\leq \alpha^2_{\tilde{V}_s}(x)+\beta^2_{\tilde{V}_s}(x)+\gamma^2_{\tilde{V}_s}(x)\leq 1, \text{with } \forall x\in A_2 \tag{4}$$

The following list of SFSs math operations is provided by Equations (5)–(10):

Union

$$\widetilde{U}_s\cup\widetilde{V}_s=\left(\max(\alpha_{\tilde{U}_s},\alpha_{\tilde{V}_s}),\min(\beta_{\tilde{U}_s},\beta_{\tilde{V}_s}),\min\left(\sqrt{1-\left((\max(\alpha_{\tilde{U}_s},\alpha_{\tilde{V}_s}))^2+\left(\min(\beta_{\tilde{U}_s},\beta_{\tilde{V}_s})\right)^2\right)},\max(\gamma_{\tilde{U}_s},\gamma_{\tilde{V}_s})\right)\right) \tag{5}$$

Intersection

$$\widetilde{U}_s\cap\widetilde{V}_s=\left(\min\{\alpha_{\tilde{U}_s},\alpha_{\tilde{V}_s}\},\max\{\beta_{\tilde{U}_s},\beta_{\tilde{V}_s}\},\max\left(\sqrt{1-\left((\min\{\alpha_{\tilde{U}_s},\alpha_{\tilde{V}_s}\})^2+\left(\max(\beta_{\tilde{U}_s},\beta_{\tilde{V}_s})\right)^2\right)},\min(\gamma_{\tilde{U}_s},\gamma_{\tilde{V}_s})\right)\right) \tag{6}$$

Addition

$$\widetilde{U}_s\oplus\widetilde{V}_s=\left(\sqrt{\alpha^2_{\tilde{U}_s}+\alpha^2_{\tilde{V}_s}-\alpha^2_{\tilde{U}_s}\alpha^2_{\tilde{V}_s}},\beta_{\tilde{U}_s}\beta_{\tilde{V}_s},\sqrt{(1-\alpha^2_{\tilde{V}_s})\gamma^2_{\tilde{U}_s}+(1-\alpha^2_{\tilde{U}_s})\gamma^2_{\tilde{V}_s}-\gamma^2_{\tilde{U}_s}\gamma^2_{\tilde{V}_s}}\right) \tag{7}$$

Multiplication

$$\widetilde{U}_s\otimes\widetilde{V}_s=\left(\alpha_{\tilde{U}_s}\alpha_{\tilde{V}_s},\sqrt{\beta^2_{\tilde{U}_s}+\beta^2_{\tilde{V}_s}-\beta^2_{\tilde{U}_s}\beta^2_{\tilde{V}_s}},\sqrt{\left(1-\beta^2_{\tilde{V}_s}\right)\gamma^2_{\tilde{U}_s}+\left(1-\beta^2_{\tilde{U}_s}\right)\gamma^2_{\tilde{V}_s}-\gamma^2_{\tilde{U}_s}\gamma^2_{\tilde{V}_s}}\right) \tag{8}$$

Multiplication by α scalar; λ > 0

$$\lambda\widetilde{U}_s=\left(\sqrt{1-(1-\alpha^2_{\tilde{U}_s})^\lambda},\beta^\lambda_{\tilde{U}_s},\sqrt{(1-\alpha^2_{\tilde{U}_s})^\lambda-(1-\alpha^2_{\tilde{U}_s}-\gamma^2_{\tilde{U}_s})^\lambda}\right) \tag{9}$$

Power of $\widetilde{U}_s$; λ > 0

$$\widetilde{U}^\lambda_s=\left(\alpha^\lambda_{\tilde{U}_s},\sqrt{1-\left(1-\beta^2_{\tilde{U}_s}\right)^\lambda},\sqrt{\left(1-\beta^2_{\tilde{U}_s}\right)^\lambda-\left(1-\beta^2_{\tilde{U}_s}-\gamma^2_{\tilde{U}_s}\right)^\lambda}\right) \tag{10}$$

Definition 3. For these SFSs $\widetilde{U}_s=(\alpha_{\tilde{U}_s},\beta_{\tilde{U}_s},\gamma_{\tilde{U}_s})$ and $\tilde{V}_s=(\alpha_{\tilde{V}_s},\beta_{\tilde{V}_s},\gamma_{\tilde{V}_s})$, the followings are valid under the condition $\mu,\mu_1,\mu_2>0$, by Equation (11)–(16):

$$\widetilde{U}_s\oplus\widetilde{V}_s=\widetilde{V}_s\oplus\widetilde{U}_s \tag{11}$$

$$\widetilde{U}_s\widetilde{V}_s=\widetilde{V}_s\widetilde{U}_s \tag{12}$$

$$\mu(\widetilde{U}_s\oplus\widetilde{V}_s)=\mu\widetilde{U}_s\oplus\mu\widetilde{V}_s \tag{13}$$

$$\mu_1\widetilde{U}_s\oplus\mu_2\widetilde{U}_s=(\mu_1\oplus\mu_2)\widetilde{U}_s \tag{14}$$

$$(\widetilde{U}_s\widetilde{V}_s)^\mu=\widetilde{U}^\mu_s\bullet\widetilde{V}^\mu_s \tag{15}$$

$$\widetilde{U}^{\mu_1}_s\widetilde{U}^{\mu_2}_s=\widetilde{U}^{\mu_1+\mu_2}_s \tag{16}$$

Definition 4. Spherical weighted arithmetic mean (SWAM) concerning $\omega=(\omega_1,\omega_2,\ldots,\omega_n)$; $\omega_i\in[1,0]$; $\sum_{i=1}^n\omega_i=1$, SWAM [93] is defined by Equation (17):

$$SWAM_\omega\left(\widetilde{U}_{S1},\ldots,\ddot{U}_{Sn}\right)=\omega_1\widetilde{U}_{S1}+\omega_2\widetilde{U}_{S2}+\ldots+\omega_n\widetilde{U}_{Sn}=\left(\sqrt{1-\prod_{i=1}^n\left(1-\alpha^2_{\tilde{U}_{Si}}\right)^{\omega_i}},\prod_{i=1}^n\beta^{\omega_i}_{\tilde{U}_{Si}},\sqrt{\prod_{i=1}^n\left(1-\alpha^2_{\tilde{U}_{Si}}\right)^{\omega_i}-\prod_{i=1}^n\left(1-\alpha^2_{\tilde{U}_{Si}}-\gamma^2_{\tilde{U}_{Si}}\right)^{\omega_i}}\right) \tag{17}$$

Definition 5. Spherical weighted geometric mean (SWGM) concerning $\omega=(\omega_1,\omega_2,\ldots,\omega_n)$; $\omega_i\in[1,0]$; $\sum_{i=1}^n\omega_i=1$, SWGM [93] is defined by Equation (18):

$$SWGM_{\omega}\left(\widetilde{U}_{S1},\ldots,\ddot{U}_{Sn}\right)=\widetilde{U}_{S1}^{\omega_1}+\widetilde{U}_{S2}^{\omega_2}+\ldots+\widetilde{U}_{Sn}^{\omega_n}=\left(\prod_{i=1}^{n}\alpha_{\widetilde{U}_{Si}}^{\omega_1},\sqrt{1-\left(1-\beta_{\widetilde{U}_{Si}}^{2}\right)^{\omega_i}},\sqrt{\prod_{i=1}^{n}\left(1-\beta_{\widetilde{U}_{Si}}^{2}\right)^{\omega_i}-\prod_{i=1}^{n}\left(1-\beta_{\widetilde{U}_{Si}}^{2}-\gamma_{\widetilde{U}_{Si}}^{2}\right)^{\omega_i}}\right) \tag{18}$$

4. Methodology

Fig. 1 outlines a two-stage hybrid method that integrates Delphi, TOPSIS, and SFSs for addressing complex decision-making problems. The first stage uses the SF-Delphi method to determine the weights of fuzzy criteria through iterative expert consensus. The second stage employs the SF-TOPSIS to rank alternatives based on their proximity to ideal solutions. This framework provides a comprehensive and nuanced approach to decision-making under conditions of uncertainty.

Phase I. The SF-Delphi approach is utilized to streamline the analysis by minimizing both time and expert inputs, while converting spherical fuzzy evaluations into precise data. A panel comprising real estate and academic professionals ranks apartment criteria using spherical fuzzy scales. This method, newly modified by Nguyen [11], provides a targeted and efficient mechanism for expert consensus in evaluating important criteria.

Step 1. Experts must rank the criteria using the linguistic terms listed in Table 3.

The SWGM operator is used to obtain the significance vector for each factors using Equation (18)- (19):

$$\widetilde{U}^{agg}=\begin{bmatrix}(\alpha_{11},\beta_{11},\gamma_{11}) & \cdots & (\alpha_{1m},\beta_{1m},\gamma_{1m})\\ \vdots & \ddots & \vdots\\ (\alpha_{n1},\beta_{n1},\gamma_{n1}) & \cdots & (\alpha_{nm},\beta_{nm},\gamma_{nm})\end{bmatrix} \tag{19}$$

Step 2. The equation calculates the score function using Equation (20):

$$\text{Score}(d_i)=\left(2\alpha_{ij}-\gamma_{ij}\right)^2-\left(\beta_{ij}-\gamma_{ij}\right)^2 \tag{20}$$

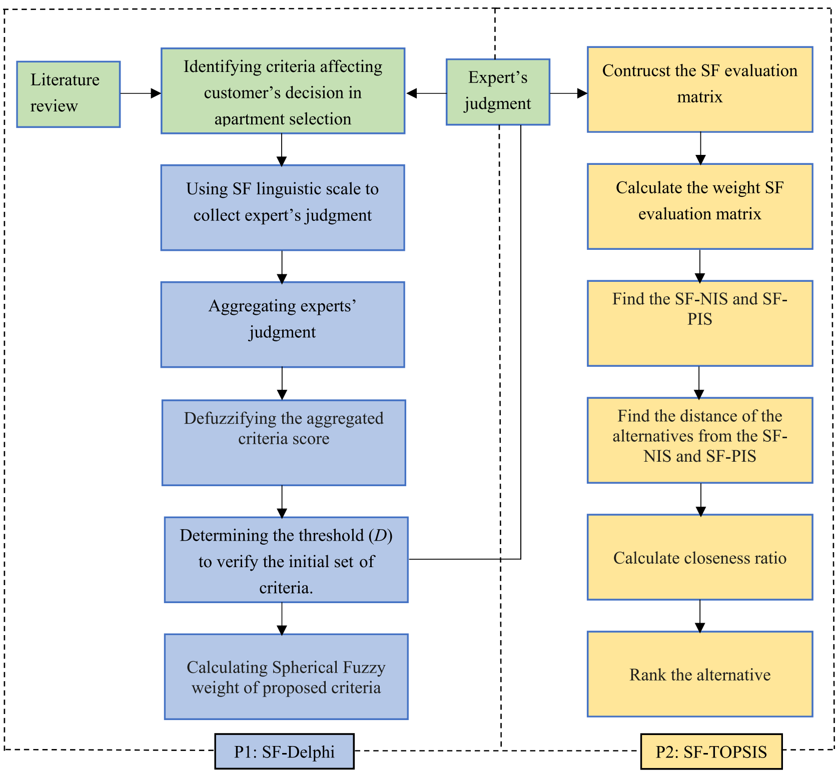

Fig. 1. Research framework.

Table 3
Spherical linguistic expressions.

Linguistic scale	Code	(α, β, γ)
Utmost Importance	AMI	(.9, .1, .1)
Very High Significance	VHI	(.8, .2, .2)
High Significance	HI	(.7, .3, .3)
Moderate Importance	SMI	(.6, .4, .4)
Equivalent Importance	EI	(.5, .5, .5)
Moderately Low Importance	SLI	(.4, .6, .4)
Low Significance	LI	(.3, .7, .3)
Very Low Significance	VLI	(.2, .8, .2)
Minimal Importance	ALI	(.1, .9, .1)

Step 3. Validate the list of critical criteria. The threshold is attained by Equation (21):

$$D_i = \sum_{i=1}^{n} \frac{d_i}{m} \tag{21}$$

If $d_i < D$, criterion C_i is removed, and if $d_i > D$, criterion C_i is valid.

Phase II. Evaluating the alternatives' rankings using the SF-TOPSIS method [11].

Step 1: The SWGM is employed to aggregate the assessments of multiple decision-makers, as formalized in Equation (18). This aggregation results in a consolidated spherical fuzzy decision matrix, encapsulating the collective viewpoints of the decision-makers, as delineated in Equation (22).

$$\widetilde{D} = (C_i(\tilde{A}_i))_{mxn} = \begin{bmatrix} (\alpha_{11}, \beta_{11}, \gamma_{11}) & (\alpha_{12}, \beta_{12}, \gamma_{12}) & \cdots & (\alpha_{1n}, \beta_{1n}, \gamma_{1n}) \\ (\alpha_{21}, \beta_{21}, \gamma_{21}) & (\alpha_{22}, \beta_{22}, \gamma_{22}) & \cdots & (\alpha_{1n}, \beta_{1n}, \gamma_{1n}) \\ \vdots & \vdots & \cdots & \vdots \\ (\alpha_{m1}, \beta_{m1}, \gamma_{m1}) & (\alpha_{m2}, \beta_{m2}, \gamma_{m2}) & \cdots & (\alpha_{mn}, \beta_{mn}, \gamma_{mn}) \end{bmatrix} \tag{22}$$

Step 2: The spherical fuzzy linguistic assessments attributed to the criteria by various decision-makers are aggregated. Subsequently, the aggregated criteria weights are normalized utilizing Equation (23) to yield a standardized representation.

$$\overline{\omega}_j^s = \frac{\omega_j^s}{\sum_{i=1}^{n} \omega_j^{s\bullet}} \tag{23}$$

Step 3: To ascertain the Spherical Fuzzy Positive Ideal Solution (SF-PIS) and the Spherical Fuzzy Negative Ideal Solution (SF–NIS), score values are derived through Equations (24)–(26). Specifically, Equation (24) is employed to compute the decision matrix for the SF-PIS, aiming to capture the upper bounds of the evaluation scores. Concurrently, Equation (25) facilitates the determination of the corresponding Spherical Fuzzy Numbers (SFN), utilizing crisp maximum values.

$$A^* = \{C_j, max_i \langle Score(C_j(\widetilde{A}_i)) \rangle | j = 1, 2, \ldots, n\}, \tag{24}$$

$$\widetilde{A}^* = \{C_1, (\alpha_1^*, \beta_1^*, \gamma_1^*), C_2, (\alpha_2^*, \beta_2^*, \gamma_2^*), \ldots, C_n, (\alpha_n^*, \beta_n^*, \gamma_n^*)\} \tag{25}$$

The decision matrix for the SF-NIS is ascertained via Equation (26), which identifies the minimal evaluation scores. Subsequently, Equation (27) is deployed to establish the corresponding SFN based on these crisp minimal values.

$$A^- = \{C_j, min_i \langle Score(C_j(\widetilde{A}_i)) \rangle | j = 1, 2, \ldots, n\}, \tag{26}$$

$$\widetilde{A}^- = \{C_1, (\alpha_1^-, \beta_1^-, \gamma_1^-), C_2, (\alpha_2^-, \beta_2^-, \gamma_2^-), \ldots, C_n, (\alpha_n^-, \beta_n^-, \gamma_n^-)\} \tag{27}$$

Step 4. To compute the distances between each alternative A_i.

For the SF-NIS by Equation (28):

$$D(A_i, A^-) = \sqrt{\frac{1}{2n} \sum_{i=1}^{n} \left((\alpha_{A_i} - \alpha_{A^-})^2 + (\beta_{A_i} - \beta_{A^-})^2 + (\gamma_{A_i} - \gamma_{A^-})^2 \right)}, \tag{28}$$

For the SF-PIS by Equation (29):

$$D(A_i, A^*) = \sqrt{\frac{1}{2n} \sum_{i=1}^{n} \left((\alpha_{A_i} - \alpha_{A^*})^2 + (\beta_{A_i} - \beta_{A^*})^2 + (\gamma_{A_i} - \gamma_{A^*})^2 \right)}. \tag{29}$$

Step 5. Calculating:

The maximum distance to the SF-NIS by Equation (30):

$$D_{max}(A_i, A^-) = max_{1 \le i \le m} D(A_i, A^-), \tag{30}$$

The minimum distance to the SF-PIS by Equation (31):

$$D_{min}(A_i, A^*) = min_{1 \le i \le m} D(A_i, A^*). \tag{31}$$

Step 6. The most favorable alternative is selected based on ascending values of the closeness ratio. This revised closeness ratio is quantified through the application of Equation (32).

$$ClosenessRaion_{A_i} = \xi(A_i) = \frac{D(A_i, A^*)}{D_{min}(A_i, A^*)} - \frac{D(A_i, A^-)}{D_{max}(A_i, A^-)} \tag{32}$$

5. Case study

5.1. SF-Delphi results

This research evaluated the top 10 most prestigious companies in the real estate sector in 2022 (Table 4) based on 18 crucial criteria that influence apartment selection by residents (Table 2). The investigation was conducted in two phases. Phase I involved collecting demographic data, while in phase II, experts were asked to indicate how much they agreed with the suggested criteria, taking into account their experience and area of expertise. Survey questionnaires (as shown in Appendix Section 1) were created using Google Forms and sent to experts between August and November 2022. The study received reliable assessments from 10 experts, including three university lecturers with over eight years of experience in teaching and researching real estate and seven senior managers with more than ten years of experience in the industry.

To carry out the evaluation, experts were asked to provide their assessments (Table 5). Their judgments were then transformed into spherical scales using the SWGM operator as described in Equation (18)- (19). It effectively transformed the experts' judgments into spherical scales, allowing for a more accurate and precise evaluation of the criteria. The threshold value of 1.496 was applied to eliminate less important criteria, ultimately leading to the dropping of PF2 and LC1. This demonstrates the importance of carefully considering and analyzing the criteria to obtain the most relevant and significant factors for evaluation. Therefore, the proposed approach provides a useful framework for evaluating and selecting real estate companies based on key criteria. Investors and potential buyers can use it to make informed investment or purchase decisions.

Following the elimination of two less important criteria, the council of 10 experts evaluated the remaining 16 criteria using spherical linguistic terms, as presented in Table 6 and Fig. 2. To derive the spherical fuzzy relative preference weights for each selected criterion, the SWAM operator was employed, as described in Equation (17). The SWAM operator combines the experts' assessments and aggregates their opinions to obtain the overall preference weights. By considering the experts' subjective judgments and taking into account the spherical nature of the fuzzy sets, the SWAM operator provides a comprehensive and accurate representation of the relative importance of the criteria. It allows for the incorporation of experts' diverse perspectives while accounting for the inherent uncertainties and ambiguities in decision-making. The resulting spherical fuzzy relative preference weights serve as a valuable input for the subsequent stages of the decision-making process, facilitating the evaluation and ranking of the alternatives.

Defuzzified weights were computed via Equation (20), resulting in 16 criteria weights enumerated in Table 7. These ascertained weights serve as proxies for expert preferences, illuminating the comparative significance of each criterion. Such weights are instrumental in the ensuing stages of the recommended hybrid methodology, steering both evaluation and decision-making.

Table 4
Real Estate Investor information.

Alternatives	Companies
A1	Hung Thinh Land
A2	Novaland Group
A3	Bimland JSC
A4	Ha Do Group JSC
A5	DIC – Construct Development and Investment Consultancy Company
A6	Phat Dat Real Estate Development Corporation
A7	Ecopark Corporation JSC
A8	Vinhomes Group JSC
A9	Khang Dien House Trading and Investment JSC
A10	Nam Long Investment Corporation

Table 5
Evaluation of experts (EP).

	EP1	EP2	EP3	EP4	EP5	EP6	EP7	EP8	EP9	EP10
PR1	VHI	VHI	VHI	VHI	VHI	HI	VHI	AMI	HI	SMI
PR2	VHI	AMI	VHI	HI	AMI	HI	SMI	HI	HI	VHI
PR3	SMI	HI	AMI	VHI	HI	VHI	AMI	VHI	VHI	HI
PF1	HI	HI	EI	VHI	VHI	VHI	VHI	HI	VHI	HI
PF2	HI	VHI	HI	SMI	SMI	EI	EI	AMI	SMI	EI
PF3	VHI	VHI	VHI	SMI	VHI	SMI	AMI	VHI	HI	VHI
LS1	VHI	SMI	AMI	VHI	SMI	AMI	AMI	HI	HI	VHI
LS2	AMI	VHI	SMI	AMI	SMI	VHI	HI	VHI	HI	VHI
LS3	AMI	VHI	SMI	SMI	AMI	VHI	AMI	HI	HI	VHI
LC1	VHI	SMI	HI	SMI	SMI	EI	HI	SMI	HI	EI
LC2	VHI	AMI	VHI	HI	AMI	SMI	VHI	HI	VHI	HI
LC3	AMI	VHI	VHI	HI	VHI	VHI	AMI	HI	SMI	SMI
EV1	VHI	HI	AMI	HI	AMI	HI	VHI	HI	SMI	VHI
EV2	HI	VHI	VHI	HI	HI	AMI	HI	HI	VHI	VHI
EV3	VHI	AMI	HI	VHI	AMI	AMI	HI	SMI	AMI	EI
LE1	VHI	VHI	AMI	HI	VHI	HI	VHI	AMI	HI	AMI
LE2	HI	AMI	VHI	HI	AMI	HI	AMI	HI	HI	VHI
LE3	SMI	HI	VHI	VHI	HI	VHI	AMI	VHI	VHI	HI

Table 6
SF-Delphi results.

Criteria	SFNs (α, β, γ)	Score	Decision
PR1	(.766, .245, .249)	1.644	Admitted
PR2	(.754, .259, .264)	1.550	Admitted
PR3	(.765, .249, .254)	1.625	Admitted
PF1	(.748, .256, .257)	1.536	Admitted
PF2	(.607, .408, .423)	.626	Rejected
PF3	(.754, .260, .267)	1.542	Admitted
LS1	(.762, .258, .266)	1.581	Admitted
LS2	(.753, .264, .271)	1.525	Admitted
LS3	(.762, .258,.266)	1.581	Admitted
LC1	(.624, .384, .394)	.728	Rejected
LC2	(.765, .249, .254)	1.625	Admitted
LC3	(.753,.264, .271)	1.525	Admitted
EV1	(.754, .259, .264)	1.550	Admitted
EV2	(.757, .250, .252)	1.594	Admitted
EV3	(.757, .273, .290)	1.498	Admitted
LE1	(.796, .216, .218)	1.888	Admitted
LE2	(.775, .238, .241)	1.714	Admitted
LE3	(.756, .255, .259)	1.567	Admitted
Threshold (D_i)		1.490	

This study highlights the significance of specific criteria, namely LE1 - Apartment legal status, PR3 - Reasonable price, LE3 - Home buying procedures, LS1 - Quantity of bedrooms, and LE2 - Term of use of housing, based on the evaluation of professionals. The Legal (LE) group emerges as the most important set of criteria when selecting apartments in Vietnam, as evidenced by the defuzzified weights obtained. According to the rankings obtained through SF-Delphi, LE1 is identified as the most crucial criterion, followed by PR3, LE3, LS1, LE2, PR1, LS3, LC2, PR2, EV3, EV2, EV1, LS2, LC3, PF3, and PF4. This finding aligns with the current real estate market in Vietnam, which has seen an increase in legal disputes associated with property transactions in recent years. Additionally, experts recognize the importance of reasonable price (PR3) and the quantity of bedrooms (LS1) as decision-making criteria. These findings indicate that consumers in Vietnam's real estate market are becoming more discerning in their choices and are placing greater emphasis on the legal status of properties, as well as practical considerations such as price and the number of bedrooms.

5.2. SF-TOPSIS results

In this section, we will discuss the ranking of real estate investors using the SF-TOPSIS method. Initially, we employed the SWAM operator (eq. (17)) to aggregate a spherical fuzzy decision matrix based on the judgment of the decision-makers, as presented in Table 8. We then calculated the weighted normalized matrix, which is shown in Table 9. The score function values, SF-PIS, and SF-NIS were obtained and listed in Table 10. Finally, the ranking of alternatives based on their closeness ratios was presented in Table 11.

Based on the analysis, alternative A8 achieved the highest closeness ratio score of 0.804, making it the most preferred alternative. On the other hand, alternative A4 obtained the lowest closeness ratio of 0.089, indicating that it is the least preferred option. The ranking of the alternatives was determined through surveys and data analysis, resulting in the following order of preferences: A8 > A7

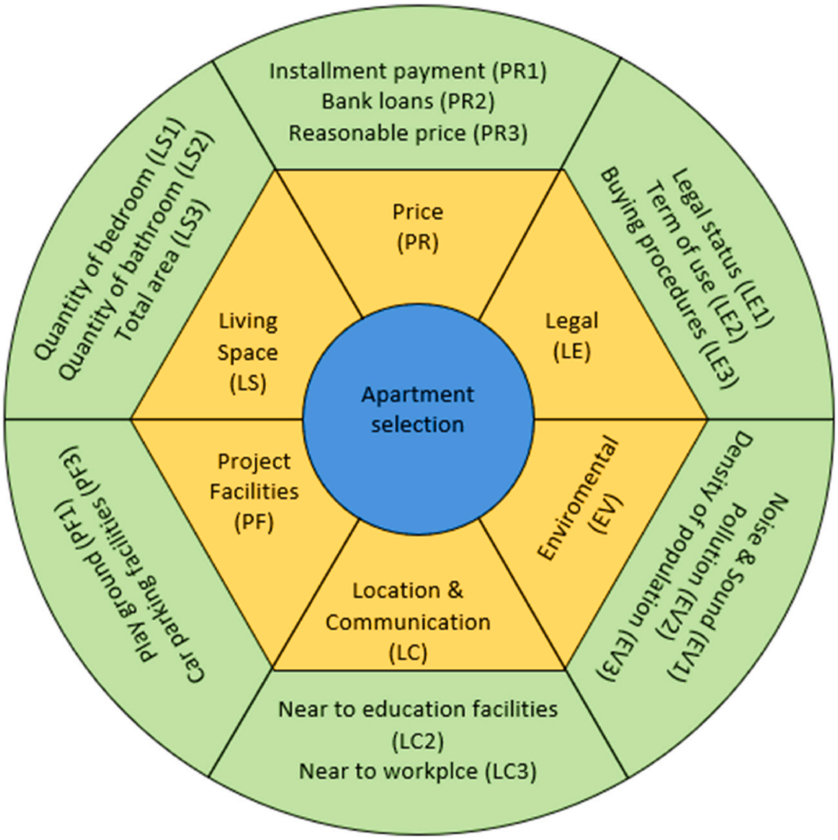

Fig. 2. Final results of the SF-Delphi technique.

Table 7
The weight and ranking of each criterion.

Criteria	SF-weights (α,β,γ)	Defuzzied weight	Ranking
PR1	(.76, .24, .20)	.312	6
PR2	(.75, .24, .21)	.295	9
PR3	(.77, .22, .19)	.343	2
PF1	(.72, .27, .23)	.238	16
PF3	(.70, .25, .21)	.241	15
LS1	(.74, .24, .18)	.317	4
LS2	(.73, .27, .21)	.270	13
LS3	(.76, .21, .20)	.311	7
LC2	(.74, .24, .19)	.300	8
LC3	(.73, .23, .22)	.266	14
EV1	(.73, .24, .20)	.278	12
EV2	(.73, .26, .19)	.279	11
EV3	(.74, .24, .21)	.280	10
LE1	(.78, .20, .18)	.359	1
LE2	(.76, .23, .20)	.313	5
LE3	(.74, .21, .17)	.329	3

> A2 > A3 > A10 > A6 > A5 > A9 > A1 > A4.

The SF-Delphi method and SF-TOPSIS method have provided valuable insights into the criteria for apartment selection and the ranking of real estate investors, respectively. Real estate providers in Vietnam can utilize the results of these methods to tailor their offerings and marketing strategies better to meet the needs and preferences of potential customers. For instance, they can focus on promoting apartments with a legal status (LE1) and reasonable prices (PR3), as these criteria were ranked as the most important by the experts. Additionally, highlighting the number of bedrooms (LS1) and the term of use of housing (LE2), which were also deemed significant factors in apartment selection, can be advantageous.

Moreover, the ranking of real estate investors can provide useful information for potential partners and clients in the real estate industry. Knowing which investors are considered the most favorable by experts can guide business decisions and facilitate

Table 8
Aggregate the judgments of decision-makers.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
PR1	(.60, 0.44, 0.32)	(.55, .47, .35)	(.45, .58, .31)	(.72, .28, .28)	(.68, .35, .24)	(.53, .50, .34)	(.45, .58, .34)	(.28, .75, .24)	(.80, .20, .20)	(.71, .29, .29)
PR2	(.75, 0.26, 0.24)	(.77, .23, .24)	(.57, .47, .28)	(.78, .22, .24)	(.60, .43, .29)	(.81, .20, .20)	(.69, .31, .32)	(.59, .42, .42)	(.79, .21, .21)	(.80, .20, .20)
PR3	(.63, 0.38, 0.40)	(.74, .26, .24)	(.61, .40, .39)	(.75, .25, .26)	(.67, .34, .30)	(.65, .36, .33)	(.51, .49, .45)	(.75, .26, .25)	(.57, .44, .40)	(.60, .40, .40)
PF1	(.58, 0.43, 0.41)	(.54, .46, .45)	(.77, .24, .24)	(.62, .39, .37)	(.61, .40, .35)	(.64, .37, .39)	(.42, .61, .32)	(.69, .32, .30)	(.79, .21, .22)	(.40, .60, .40)
PF3	(.76, 0.25, 0.23)	(.48, .55, .38)	(.60, .41, .40)	(.64, .39, .31)	(.59, .44, .30)	(.66, .36, .28)	(.67, .38, .23)	(.72, .29, .27)	(.74, .26, .27)	(.38, .64, .39)
LS1	(.64, 0.38, 0.34)	(.56, .45, .41)	(.70, .31, .30)	(.58, .44, .39)	(.72, .29, .27)	(.61, .41, .32)	(.75, .25, .27)	(.61, .41, .32)	(.65, .37, .36)	(.48, .55, .38)
LS2	(.80, 0.20, 0.23)	(.64, .37, .34)	(.68, .33, .35)	(.67, .34, .30)	(.66, .34, .34)	(.64, .38, .28)	(.65, .37, .35)	(.69, .33, .24)	(.68, .33, .30)	(.70, .30, .30)
LS3	(.72, 0.29, 0.33)	(.48, .53, .38)	(.61, .41, .31)	(.70, .30, .32)	(.64, .37, .33)	(.62, .39, .35)	(.58, .44, .32)	(.66, .36, .32)	(.58, .42, .44)	(.59, .41, .41)
LC2	(.64, 0.37, 0.34)	(.73, .27, .25)	(.67, .35, .27)	(.60, .43, .33)	(.66, .35, .30)	(.69, .33, .32)	(.61, .41, .33)	(.61, .41, .33)	(.58, .46, .29)	(.72, .28, .30)
LC3	(.70, 0.32, 0.32)	(.75, .26, .23)	(.65, .35, .36)	(.69, .32, .30)	(.73, .28, .27)	(.63, .41, .24)	(.68, .33, .34)	(.57, .46, .38)	(.47, .58, .31)	(.83, .17, .18)
EV1	(.70, 0.31, 0.30)	(.62, .39, .41)	(.74, .27, .27)	(.68, .34, .32)	(.68, .33, .30)	(.67, .36, .28)	(.68, .34, .30)	(.62, .40, .31)	(.65, .36, .35)	(.79, .21, .22)
EV2	(.67, 0.34, 0.35)	(.81, .20, .22)	(.70, .31, .32)	(.71, .30, .31)	(.75, .25, .25)	(.73, .28, .30)	(.67, .33, .34)	(.64, .39, .30)	(.74, .26, .27)	(.61, .39, .39)
EV3	(.76, 0.24, 0.26)	(.67, .34, .38)	(.68, .33, .35)	(.76, .25, .29)	(.69, .31, .33)	(.68, .33, .33)	(.68, .34, .30)	(.78, .23, .21)	(.72, .28, .29)	(.47, .56, .30)
LE1	(.80, 0.20, 0.23)	(.75, .25, .26)	(.71, .29, .30)	(.79, .21, .23)	(.70, .31, .33)	(.74, .27, .29)	(.76, .25, .24)	(.73, .27, .28)	(.80, .20, .20)	(.66, .34, .35)
LE2	(.77, 0.24, 0.25)	(.78, .22, .24)	(.75, .26, .28)	(.75, .25, .26)	(.80, .20, .23)	(.72, .28, .29)	(.75, .25, .26)	(.73, .28, .29)	(.75, .25, .26)	(.73, .27, .30)
LE3	(.81, 0.19, 0.20)	(.69, .31, .32)	(.74, .26, .27)	(.79, .21, .22)	(.69, .32, .32)	(.79, .21, .23)	(.77, .24, .25)	(.75, .26, .25)	(.76, .24, .25)	(.76, .25, .27)

collaborations. Furthermore, the findings from these methods contribute to a better understanding of the market landscape for real estate providers and investors, enabling them to make informed decisions that align with customer preferences and industry trends.

5.3. Discussions

This research presents a unique framework combining SF-Delphi and SF-TOPSIS was employed as a valuable tool for evaluating ten real estate alternatives in Vietnam and 16 apartment selection criteria. Through a survey conducted with ten experts, it was determined that six categories (price, project facilities, living space, location and communication, environmental, and legal) are the most critical factors considered by individuals when choosing an apartment. The study's findings concluded that legal criteria hold the highest significance in influencing the decision to select an apartment. Specifically, LE1 - Apartment legal status, LE3 - Home buying procedures, and LE2 - Term of use of house were ranked first, third, and fifth, respectively. These results align with the prevalence of apartment ownership disputes between residents and real estate investors in Vietnam, highlighting the crucial role of legal considerations in the decision-making process.

The study also found that the financials of the house are a major factor in how buyers choose a home, with PR3- Reasonable Price criteria ranked second and PR1- System of Installment Payment ranked sixth. Living Space is the clients' next area of interest, with LS1- Quantity of bedrooms and LS3- Total area ranking fourth and seventh, respectively. The study found that environment, location & communication are also important to apartment buyers. Our findings are consistent with the study of [94–96]. Our findings, however, differ slightly from those of the study of Nam et al. [97], which believed that the legal criteria only affected the behavior of home buyers on a similar level. PR3- Reasonable price and PR1- System of installment payment of group price are the following important criteria determined to be strongly influenced by the decision to select the apartment … Financials of the house are a major factor in how buyers choose a home, according to previous studies. When buying an apartment, purchasers consider credit options, an installment payment plan, the availability of bank loans, and a reasonable price [84]. This result is consistent with previous studies [98–100] with the PR3- Reasonable Price criteria ranked second and PR1- System of Installment Payment ranked sixth. Living Space is the clients' next area of interest, with LS1- Quantity of bedrooms and LS3- Total area ranking fourth and seventh, respectively. This outcome is consistent with the study findings of [87]. The next is environmental and location & communication. Apartment buyers favor locations with good communication options and a pleasant environment [84]. Among the six proposed factor groups, Project Facilities is considered the least significant, with PF1- Playground and PF3- Car Parking Facilities ranked 15th and 16th, respectively. It contradicts the study [84] but is consistent with Nguyen et al. [87]. Regarding real estate providers, the SF- TOPSIS approach ranked A8-Vinhomes Group as the most prominent company among the available companies, followed by A2- Novaland Group and A7-

Table 9
Weighted decision matrix.

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
PR1	(0.45, 0.49, 0.35)	(.42, .52, .38)	(.34, .62, .34)	(.54, .37, .32)	(.51, .42, .29)	(.40, .54, .37)	(.34, .61, .36)	(.21, .76, .27)	(.61, .31, .27)	(.54, .37, .33)
PR2	(0.56, 0.35, 0.30)	(.58, .32, .30)	(.43, .51, .32)	(.58, .32, .30)	(.45, .48, .33)	(.61, .31, .28)	(.52, .38, .36)	(.44, .47, .44)	(.59, .31, .28)	(.60, .31, .28)
PR3	(0.49, 0.43, 0.42)	(.58, .34, .30)	(.47, .45, .41)	(.58, .33, .31)	(.52, .40, .33)	(.50, .42, .36)	(.40, .53, .46)	(.58, .34, .30)	(.44, .48, .42)	(.46, .45, .42)
PF1	(0.41, 0.50, 0.44)	(.39, .52, .47)	(.55, .36, .32)	(.44, .46, .40)	(.44, .47, .39)	(.46, .44, .42)	(.30, .64,35)	(.49, .41, .35)	(.57, .34, .30)	(.29, .64, .42)
PF3	(0.54, 0.35, 0.30)	(.34, .59, .40)	(.42, .47, .42)	(.45, .45, .35)	(.41, .49, .34)	(.46, .43, .33)	(.47, .44, .29)	(.51, .38, .32)	(.52, .36, .32)	(.26, .67, .40)
LS1	(0.47, 0.44, 0.36)	(.42, .50, .42)	(.52, .38, .33)	(.43, .49, .40)	(.54, .36, .31)	(.45, .46, .34)	(.56, .34, .31)	(.45, .46, .35)	(.48, .43, .38)	(.35, .59, .39)
LS2	(0.59, 0.33, 0.30)	(.47, .45, .38)	(.50, .42, .38)	(.49, .43, .35)	(.49, .43, .37)	(.47, .46, .33)	(.48, .44, .38)	(.51, .42, .30)	(.50, .42, .34)	(.51, .40, .35)
LS3	(0.55, 0.35, 0.37)	(.36, .56, .40)	(.46, .45, .34)	(.53, .36, .36)	(.49, .41, .36)	(.47, .44, .38)	(.44, .48, .36)	(.50, .41, .36)	(.44, .46, .46)	(.45, .45, .43)
LC2	(0.48, 0.43, 0.37)	(.54, .36, .30)	(.50, .42, .31)	(.44, .48, .36)	(.49, .42, .34)	(.51, .40, .36)	(.45, .47, .34)	(.45, .46, .36)	(.43, .51, .33)	(.54, .36, .34)
LC3	(0.51, 0.39, 0.36)	(.55, .34, .30)	(.48, .41, .39)	(.51, .39, .35)	(53, .36, .33)	(.46, .46, .30)	(.50, .39, .380	(.41, .50, .41)	(.34, .61, .35)	(.60, .28, .27)
EV1	(0.51, 0.39, 0.34)	(.45, .45, .43)	(.54, .36, .32)	(.50, .41, .36)	(.50, .40, .34)	(.49, .42, .33)	(.49, .41, .34)	(.46, .46, .35)	(.48, .42, .38)	(.58, .32, .29)
EV2	(0.49, 0.42, 0.38)	(.59, .32, .28)	(.51, .40, .360	(.52, .39, .350	(.55, .36, .30)	(.53, .37, .34)	(.49, .41, .37)	(.46, .46, .34)	(.54, .36, .32)	(.44, .46, .41)
EV3	(0.56, 0.34, 0.32)	(.50,41, .41)	(.50, .40, .39)	(.56, .34, .34)	(.51, .39, .37)	(.50, .40, .37)	(.50, .41, .34)	(.58, .33, .29)	(.53, .37, .34)	(.35, .59, .34)
LE1	(0.62, 0.29, 0.28)	(.58, .32, .30)	(.55, .35, .33)	(.62, .29, .28)	(.54, .36, .34)	(.57, .33, .33)	(.59, .32, .29)	(.57, .33, .32)	(.62, .28, .28)	(.51, .39, .38)
LE2	(0.58, 0.32, 0.31)	(.59, .32, .30)	(.57, .34, .33)	(.57, .34, .31)	(.61, .30, .29)	(.55, .36, .33)	(.57, .34, .31)	(.55, .35, .34)	(.57, .33, .32)	(.55, .35, .34)
LE3	(0.60, 0.28, 0.26)	(.52, .37, .35)	(.55, .33, .31)	(.59, .30, .27)	(.52, .37, .35)	(.59, .30, .28)	(.57, .32, .29)	(.56, .32, .30)	(.57, .32, .29)	(.56, .32, .30)

Ecopark Corporation. These results are consistent with recent reports of Vietnam Report Company in ranking ten reputable real estate companies based on financial capacity, communication reputation, and survey of related subjects [101].

By utilizing the SF-Delphi and SF-TOPSIS methods, The results may be useful to Vietnamese real estate investors as well as potential purchasers, helping them make informed decisions based on the most crucial factors and mitigating potential legal risks associated with apartment ownership.

5.4. *Comparative analysis*

In this section, we conducted an assessment to evaluate the reliability, accuracy, and effectiveness of the proposed strategies. We compared the ranking of apartment providers in Vietnam using the SF-TOPSIS method with two other methods: Intuitionistic Fuzzy TOPSIS (IF-TOPSIS) and Fuzzy TOPSIS (F-TOPSIS). Ordinary fuzzy sets have gained attraction in several scientific domains since Zadeh established them [13]. Subsequently, scholars developed several extensions to traditional fuzzy sets to overcome their limitations and drawbacks. One such extension is the Intuitionistic Fuzzy Set (IFS), introduced by Atanassov in 1986 [102]. IFS allows for the degrees of membership and non-membership of elements in a fuzzy set to be defined. Building upon IFS, SFS provides decision-makers with the ability to incorporate additional fuzzy sets by establishing a membership utility on the spherical surface and assigning membership function specifications to a broader domain [93]. In Appendix Section 2 and Section 3, we present the IF-TOPSIS and F-TOPSIS methods. Table 12, Figs. 3–4 provide a comparison of the results obtained using these three methods. The comparison reveals that the rankings of apartment suppliers are similar across the methods. Although there are some slight differences in the rankings, Tables 3 and 4 demonstrate that the changes in the rankings follow a similar pattern. These differences can be attributed to the defined linguistic evaluation scales and the equations utilized in each method.

To sum up, the comparison results indicate that the proposed SF-TOPSIS method yields rankings of apartment providers that are consistent with those obtained using the IF-TOPSIS and F-TOPSIS methods. This reinforces the reliability and validity of the SF-TOPSIS approach in assessing and ranking apartment providers in Vietnam.

To be more precise, we want to create a pairwise comparison of the results of the three methodologies' rankings. This comparison is performed by calculating the correlation coefficient and presented in Table 12.

Where:

R_{xi} and R_{yi} mean the place in the ranking for *ith* element in respectively ranking x and ranking y.

Ns is the number of compatible pairs.

Nd is the number of non-compliant pairs.

Table 10
The results of score function and SF-PIS and SF-NIS

	PR1	PR2	PR3	PF1	PF3	LS1	LS2	LS3	LC2	LC3	EV1	EV2	EV3	LE1	LE2	LE3
A1	−.010	.063	.005	−.003	.053	.007	.082	.032	.008	.021	.026	.010	.058	.117	.075	.120
A2	−.017	.076	.077	.004	−.032	−.006	.004	−.024	.057	.059	.000	.093	.007	.078	.083	.028
A3	−.079	−.025	.002	.053	−.002	.034	.012	.002	.025	.007	.046	.022	.013	.049	.057	.059
A4	.047	.080	.074	−.002	.000	−.007	.015	.030	−.007	.023	.015	.027	.049	.112	.065	.103
A5	.032	−.009	.030	−.004	−.018	.049	.010	.013	.017	.041	.021	.058	.020	.039	.101	.027
A6	−.028	.106	.016	.001	.008	−.002	.004	.004	.022	.002	.016	.035	.017	.060	.044	.098
A7	−.063	.024	.000	−.081	.009	.060	.005	−.008	−.006	.013	.019	.013	.021	.092	.065	.076
A8	−.244	−.001	.074	.016	.031	−.001	.030	.016	−.002	−.008	−.001	.001	.083	.063	.045	.070
A9	.111	.096	−.003	.071	.039	.008	.018	.000	−.022	−.068	.007	.047	.036	.121	.065	.077
A10	.041	.103	.001	−.032	−.050	−.039	.026	.000	.039	.111	.082	−.001	−.066	.018	.045	.067
$A^{*}best$	.111	.106	.077	.071	.053	.060	.082	.032	.057	.111	−.001	.001	.007	.121	.101	.120
$A^{-}worst$	−.244	−.025	−.003	−.081	−.050	−.039	.004	−.024	−.022	−.068	.082	.093	.083	.018	.044	.027

Table 11
The results of PIS, NIS's distances, closeness ratio and alternative's ranking.

	D (A_i, A^*)	D (A_i, A^-)	Closeness Ratio	Ranking
A1	.118	.170	.135	9
A2	.154	.143	.599	3
A3	.146	.136	.560	4
A4	.114	.172	.089	10
A5	.122	.154	.255	7
A6	.127	.144	.350	6
A7	.162	.135	.705	2
A8	.174	.137	.804	1
A9	.134	.188	.182	8
A10	.161	.172	.502	5

Table 12
Comparative analysis.

Alternatives	Rank			Closeness Ratio		
	SF-TOPSIS	IF-TOPSIS	FUZZY TOPSIS	SF-TOPSIS	IF-TOPSIS	FUZZY TOPSIS
A1	.135	.378	.409	9	9	7
A2	.599	.630	.722	3	2	2
A3	.560	.595	.585	4	4	4
A4	.089	.324	.286	10	10	9
A5	.255	.439	.365	7	8	8
A6	.350	.489	.410	6	6	6
A7	.705	.628	.593	2	3	3
A8	.804	.712	.810	1	1	1
A9	.182	.455	.239	8	7	10
A10	.502	.565	.541	5	5	5

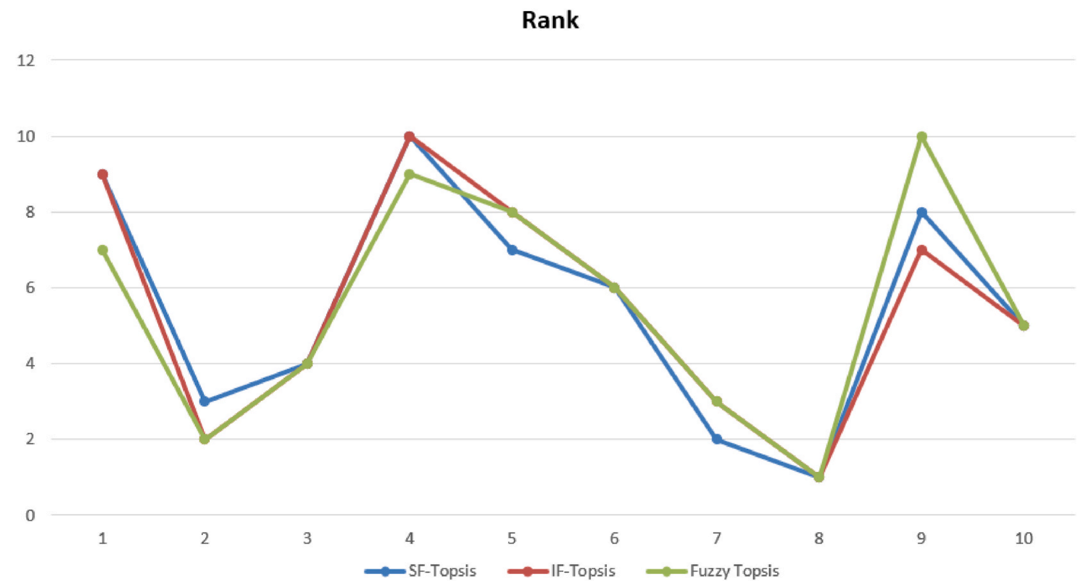

Fig. 3. Comparative analysis based on rank.

n is the number of all pairs.

In this study, five rank correlation coefficients (Spearman, Kendall, Goodman-Kruskal, Weighted rank measure of correlation, Weighted Similarity) were utilized to assess the relationships between various TOPSIS techniques used for evaluating apartment suppliers in Vietnam. The key finding revealed that the legal aspect significantly influences customers' decision-making processes. The correlation coefficients demonstrated a strong agreement between the different TOPSIS methods, with the smallest coefficient being 0.7778 (as shown in Table 13). Importantly, this value surpassed the threshold of 0.7, indicating a high level of consistency in the proposed TOPSIS method with different types of Fuzzy Sets. These results underscore the effectiveness of the approach and suggest that customers' preferences for apartment suppliers can be reliably evaluated using the TOPSIS techniques. The prominence of the legal

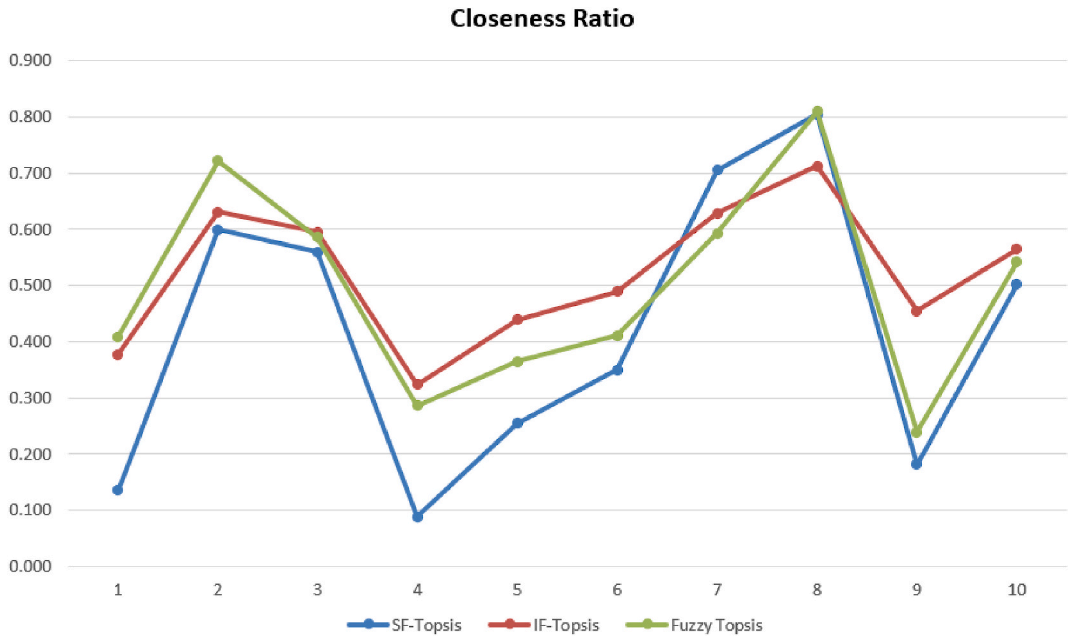

Fig. 4. Comparative analysis based on the closeness ratio.

Table 13
The results of the rank correlation.

Coefficient	Formula	SF-TOPSIS & IF-TOPSIS	SF-TOPSIS & F-TOPSIS	IF-TOPSIS & F-TOPSIS
Spear-man [103]	$r_s = \frac{6 \bullet \sum (R_{xi} - R_{yi})^2}{n \bullet (n^2-1)}$	.9758	.9152	.9273
Kendall [104]	$\tau = 2 \bullet \frac{N_s - N_d}{n \bullet (n-1)}$	.9778	.7778	.7778
Goodman-Kruskal [105]	$G = \frac{N_s - N_d}{N_s + N_d}$	.9111	.7778	.7778
Weighted rank measure of correlation [106]	$r_w = \frac{6 \bullet \sum_{i=1}^{n} (R_{xi} - R_{yi})^2 \bullet ((n - R_{xi}+1) + (n - R_{yi}+1))}{n^4 + n^3 - n^2 - n}$	.9708	.9603	.9537
WS [107]	$WS = 1 - \sum_{i=1}^{n} \left(2^{-R_{xi}} \bullet \frac{\lvert R_{xi} - R_{yi} \rvert}{max\{\lvert 1 - R_{xi} \rvert, \lvert N - R_{yi} \rvert\}}\right)$	.9490	.9955	.9479

aspect emphasizes its importance in shaping customer choices, highlighting the significance of considering legal factors in the context of apartment supply and demand in Vietnam. According to the research findings, the top three most preferred apartment suppliers in Vietnam, as determined by all three TOPSIS techniques, are A8, A2, and A7. This indicates that the proposed TOPSIS method, when employing different types of Fuzzy Sets, yields very similar results for evaluating the apartment suppliers.

6. Conclusion, implications, limitations, and future research

6.1. Conclusion

In conclusion, this study successfully utilized the spherical fuzzy MCDM model, integrating multiple decision-making methods, to assess ten real estate alternatives and sixteen apartment selection criteria in Vietnam. The results provide valuable insights for real estate companies and policymakers to develop sustainable plans and policies that align with people's demands in the real estate industry. The initial stage of the study employed the SF-Delphi technique, involving ten experts, to validate and rank the sixteen crucial criteria for apartment selection. The SF-TOPSIS technique was then used to rank the top ten most popular real estate alternatives in Vietnam based on pairwise comparisons of factors and alternatives. The combination of these methods yielded highly accurate results, eliminating uncertainties associated with human judgment.

The findings revealed that among the six factors considered (price, project facilities, living space, location, environment, and legal), the highest priority assigned by both customers and professionals was to the criteria LE1 (Apartment legal status), PR3 (Reasonable price), LE3 (Home buying procedures), LS1 (Quantity of bedrooms), and LE2 (Term of use of house). This highlights the importance of legal considerations in the decision-making process, given the prevalence of apartment ownership disputes in Vietnam. Furthermore, a comparative analysis was conducted to evaluate the reliability, accuracy, and effectiveness of the proposed SF-TOPSIS method. The rankings of apartment providers obtained using the SF-TOPSIS method were compared with those obtained using the IF-TOPSIS and F-TOPSIS methods. The comparison showed that the rankings were similar across the methods, with slight differences attributable to the defined linguistic evaluation scales and equations used in each method. The correlation coefficient analysis further confirmed the similarity of results obtained from the different fuzzy sets.

6.2. Implications

In terms of managerial implications, the findings of this research provide valuable insights for real estate companies in developing effective marketing strategies to promote their apartments. By understanding the importance of various criteria in apartment selection, companies can tailor their offerings to meet the specific needs and preferences of their target customers. For example, if the quality of the neighborhood and building amenities are identified as important criteria, developers can emphasize these aspects in their marketing campaigns to attract customers who prioritize these factors. Similarly, if proximity to public transportation is crucial, companies can focus on developing apartments in locations that offer convenient access to transportation hubs. Understanding the significance of apartment size, companies can design and market spacious apartments to cater to customers who value living space. By considering the varying importance of criteria across different demographic groups, companies can develop targeted marketing strategies that effectively reach specific customer segments. For instance, if younger customers prioritize amenities like gyms and swimming pools, companies can highlight these features in their advertising efforts. Incorporating the insights from this research into their marketing strategies allows real estate companies to gain a competitive edge and attract more customers.

From a theoretical perspective, this study contributes to the literature on MCDM and apartment selection by identifying the most important criteria and their relative importance. The research also highlights the usefulness of the spherical fuzzy TOPSIS method in real estate decision-making, demonstrating its applicability to complex decision problems. By identifying the key criteria that influence customers' apartment selection decisions, the study enhances our understanding of how customers make complex decisions in real-world contexts. Moreover, it underscores the importance of considering customers' perspectives when designing marketing strategies and real estate products that cater to their needs. The findings shed light on the role of decision-making models in providing insights into customer preferences and priorities. Additionally, the study demonstrates the potential of MCDM methods to be applied in other industries and domains, indicating their usefulness in facilitating more informed decision-making.

6.3. Limitations and future research

The drawbacks of this study offer significant perspectives for other research endeavors seeking to delve deeper into the apartment selection procedure. Firstly, future research should involve a larger number of experts to increase the dependability and generalizability of the results. The small sample size of experts in this study may limit the generalizability of the findings to a larger population. Increasing the number of experts can enhance the robustness and reliability of the research outcomes.

Secondly, future studies should consider incorporating the "weight" of the experts' opinions by taking into account their level of training and experience. This consideration can improve the validity of the findings and provide a more nuanced understanding of the experts' assessments. By assigning appropriate weights to the experts' opinions, future studies can account for variations in expertise and ensure that more knowledgeable experts have a greater influence on the results.

Thirdly, while this study highlighted the significance of the criteria, it did not explore the interrelationships between these criteria or the direction of their influence. Future research could investigate the relationships and dependencies among the criteria to provide a more comprehensive understanding of the decision-making process. Other multiple-criteria decision-making (MCDM) methods such as Interpretive Structural Modeling (ISM), DEMATEL, Analytic Network Process (ANP), or Structural Equation Modeling (SEM) can be employed to analyze the complex interactions and dependencies among the criteria.

Moreover, future studies can explore how the importance of criteria varies across different demographic groups, such as age, income, and education level. Understanding these variations can help in tailoring marketing strategies and real estate offerings to specific customer segments, further enhancing the effectiveness of decision-making processes.

Additionally, investigating the impact of external factors, such as economic conditions, government policies, and cultural differences, on apartment selection decisions can provide valuable insights. These external factors can significantly influence customers' decision-making processes, and studying their effects can contribute to a more comprehensive understanding of apartment selection.

Furthermore, considering the actual living environment and other contextual factors that may influence customers' decisions can be an interesting avenue for future research. Exploring these factors can provide a deeper understanding of the apartment selection process and uncover additional variables that influence customers' choices.

Finally, conducting longitudinal studies that follow customers' decision-making processes over time can provide a more comprehensive understanding of how preferences and priorities evolve. Longitudinal studies can capture changes in decision-making patterns and provide valuable insights into the dynamic nature of customers' choices.

By addressing these limitations and exploring these avenues for future research, a more thorough knowledge of the variables impacting apartment selection decisions can be obtained. This knowledge can offer valuable insights for real estate companies and policymakers in improving their strategies and decision-making processes.

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Data availability Statement

Data will be made available on request.

CRediT authorship contribution statement

Phi-Hung Nguyen: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Thu-Hien Tran:** Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Lan-Anh Thi Nguyen:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hong-Anh Pham:** Writing – original draft, Visualization, Validation, Resources, Investigation, Formal analysis, Data curation. **Mai-Anh Thi Pham:** Writing – original draft, Visualization, Validation, Resources, Formal analysis, Data curation.

Declaration of competing interest

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

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Appendix A. Supplementary data

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