

Article

Advancing Sustainable Urban Development: Navigating Complexity with Spherical Fuzzy Decision Making

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Abstract: This study explores the complexities of urban planning and addresses major issues by carefully weighing four options for smart city technology, community-based development, green infrastructure investment, and transit-oriented development. Unlike traditional evaluations, our study applies the novel SWARA-WASPAS model to spherical fuzzy sets (SFSs), thus identifying and navigating the uncertainty present in decision making. This methodological approach improves the accuracy of our assessment by providing detailed information about the advantages and disadvantages of each option. Our study offers useful insights for urban policymakers and planners using carefully weighted criteria and employing a methodical ranking procedure. The aim is to provide insights for decisions that promote equity, environmental consciousness, resilience, and symmetry in urban environments. The application of the SWARA-WASPAS approach not only advances the field but also provides a strong basis for informed decision making. This improves the accuracy of our evaluations and provides detailed insights into each option's pros and cons. Our study uses weighted criteria and systematic ranking to advise urban policymakers and planners. Our main goal is to help urban populations make resilient, environmentally responsible, equitable, and symmetrical decisions. Our research aims to further the conversation on sustainable urban development by offering a framework based on data that addresses the difficulties associated with dynamic urban environments. In the end, we want our humanized viewpoint to speak to a wider audience and inspire a shared dedication to creating cities that flourish in the face of changing urban environments.

Keywords: spherical fuzzy sets; SWARA-WASPAS; smart city; sustainable; urban landscapes



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1. Introduction

Achieving sustainable development is a challenge that cities throughout the world have never faced before due to the rapid growth of society and urbanization [1]. A common goal for the entire world is the pursuit of sustainable urban development [2], thus prompting a re-evaluation of city dynamics and sparking diverse lines of contemplation on the symmetry and balance within urban environments. At the core of this conceptual exploration lie three fundamental pillars: society, environment, and economy. Cities, grappling with intricate pressures and expectations, demand a reconceptualization and restructuring of the complex interplay between ecology, residents, economy, politics, and society, thus aiming for a balance and symmetry in their development. A greater dependence on the special qualities and opportunities that urban living offers is needed to respond to the changing terrain of urban sustainable development [3]. Using cloud computing in line with the Tapio Decoupling Principle, Shang and Luo [4] investigated ways to lessen the impact that cities have on the environment. This was carried out in their University of Texas at Austin study. Xiao et al. [5] presented a technique that may prove useful in managing urban climates and

improving energy efficiency. With the use of private vehicle behavior analysis, this technique forecasts the temperature of urban areas. In addition to fulfilling measurable physical criteria like air quality indices, ratios of green space, population densities, and resource usage, a vibrant and developing city needs to foster human connections and interpersonal exchanges to improve its general quality [6]. The framework for sustainable development in the twenty-first century, known as Agenda 21 (1992), integrates the environment into the social and economic spheres from the standpoint of the demands of human life. It highlights the fundamental role of a thriving life in sustainable development, thereby considering it the culmination of progress in both environmental and socioeconomic aspects. Aligned with this perspective, the World Health Organization (WHO) initiated the Healthy City (HC) project in 1997, thus aiming to materialize urban sustainable development [7]. Successive endeavors, such as Eco-City [8,9], Green City [10,11], Resilient City [12,13], Smart City [14], Inclusive City [15,16], and Livable City [17,18], echo a global shift towards sustainability in urban development [19]. An improved method to guarantee the dependability of vehicle-to-vehicle communication in difficult urban situations has been proposed by Sun et al. [20] as part of their research on distributed routing algorithms for intersection fog in vehicular ad hoc networks. Sun et al. [21] described an adaptive weighting technique aimed at improving the accuracy and robustness of multisensor-integrated navigation in urban environments.

The multifaceted nature of urban system sustainability encompasses various dimensions intricately woven into the fabric of modern urban living. These dimensions include, among others, resource utilization, environmental conservation, land use efficiency, responsible resource management, economic development sustainability, social well-being, thoughtful living space planning, energy efficiency, climate change resilience, symmetry in urban design, and waste reduction [22]. Each of these aspects plays a pivotal role in shaping the trajectory of urban development and the well-being of its inhabitants. Xiao et al. [23] investigated the aggregation effect of private cars through spatiotemporal trajectory analysis, thereby contributing to a deeper understanding of urban mobility patterns. Sun et al. [24] proposed a bus trajectory-based routing scheme for message delivery in urban vehicular ad hoc networks, thus enhancing communication efficiency in dynamic urban environments. Navigating the inherent complexity of urban systems requires a practical and all-encompassing approach. Navigating the intricate dimensions of cities and translating their diverse interconnected characteristics into actionable models is a complex undertaking that propels tangible development. In terms of the problem, it underlines that two major structural flaws must be corrected. First and foremost, the basic ideas of urban sustainability must be thoroughly examined. Second, it is critical to have a strategy for objectively and effectively investigating the symmetry and complex relationships between diverse components. These sustainability qualities become more complicated as cities grow and change at a rate unprecedented in the globe. In a world characterized by urbanization and environmental issues, cities and scholars are at the forefront of sustainable urban development debates. This makes it a critical global issue requiring a prompt response. However, this will need an awareness of the several aspects associated with rapid urbanization and ecological issues. Understanding these difficulties is insufficient; integrated frameworks that enable comprehensive and sustainable urban development policies must also be established. Given the importance of urbanization and environmental dangers, communication between cities and researchers is essential.

In the constantly shifting environment of urban development, the shared goal of transforming urban areas into foundations of health, sustainability, endurance, intelligence, inclusion, and livability is highly dependent on residents' personal experiences—an idea often encapsulated in the broader notion of quality of life (QOL). This complicated concept smoothly integrates sociological, economic, ecological, and symmetry considerations defining the fabric of urban life. Because of the world's pressing ecological issues, sustainable urban development is necessary, and a key success factor in this respect is the quality of life or QOL. Within this framework, attention is focused on the "Life-City" (LC) idea, an inven-

tive framework that goes above and beyond traditional guidelines for urban development. A city is not just a location to meet daily needs; it is also an ongoing process of improving the economy, environmental sustainability, and quality of life.

Xu and Wei [25] have addressed the dynamic pickup and delivery problem with trans-shipments and Last-In-First-Out (LIFO) constraints. In this study, effective logistics management is covered. Zhang et al. [26] suggest using an Adaptive Dynamic Surface Control for Electric Vehicles to improve the efficiency and dependability of hybrid energy sources. With this control system, energy management would be improved by the use of disturbance observers. Yang et al. [27] provided a unique method for predicting the flow of traffic propagation in urban road networks by utilizing multigraph convolutional networks. For planning and traffic control purposes, this approach may prove advantageous. Based on GPS data, Yang et al. [28] offered a method for accurately anticipating traffic. They achieved this by creating a model for temporal multispatial dependency graph convolutional networks-based region-level traffic prediction. The LC project altered the usual approach to urban planning by viewing cities as evolving ecosystems where life exists in tandem with larger environmental aims. This project acts as a catalyst for ongoing development, thus resulting in an atmosphere in which residents enjoy a vibrant and evolving urban landscape, as well as living in a physical location. Recognizing that increased human connection is critical for sustainable urban growth, the LC initiative seeks to create communities that actively encourage their residents' thriving well-being while simultaneously being flexible to environmental concerns. It aims to establish a symmetry between human needs and ecological sustainability, thus positioning the city as a living organism that adapts to its inhabitants' changing needs and plans. The Living City initiative promotes the transformative notion that urban living may be both sustainable and pleasurable for the wide spectrum of people it affects. The aforementioned study addresses a wide variety of decision-making-related issues.

1.1. Literature Review

By studying "fuzzy sets" (FSs), Zadeh [29] significantly enhanced the ability to make decisions in the face of uncertainty. His mathematical method is incredibly useful for resolving unclear data and provides a useful tool for situations requiring complex decision making. In the face of uncertainty, Zadeh's FSs offer a flexible yet uncomplicated approach to ambiguity analysis. Atanassov [30] made a significant advancement when he created "intuitionistic fuzzy sets" (IFSs), which comprise assessments of both membership and nonmembership traits. This enhanced adaptability is useful when making difficult choices. The addition of nonmembership components to IFSs is particularly relevant when making decisions when there is a substantial deficiency of high-quality information. Cuong [31] worked on "picture fuzzy sets" (PFSs), which added to the decision-making process. These visual representations enable a more realistic integration of human perspectives into decision models. Furthermore, Cuong and Hai's [31,32] developments in current operators and features boost the notion of PFSs and provide decision makers (DMs) with more accurate tools.

Li et al. [33] proposed novel ideas, including extended reduced neutrosophic Einstein AOs and a unique distance metric for fuzzy collections of Cubic Picture Fuzzy Sets (CPFSs) [34,35]. Ashraf et al. [36] introduced the concept of SFSs, which go beyond PFSs and Pythagorean sets. This extension in SFSs enhances the precision of fuzzy set models, thus redefining membership degrees as $0 \leq P^2(x) + I^2(x) + N^2(x) \leq 1$, which deviates from the traditional formulation of $0 \leq P(x) + I(x) + N(x) \leq 1$ in PFSs. The authors explored the basic operations that affect SFSs and expanded upon them to add aggregated operators to further convey these ideas. Weighted averaging and weighted geometric aggregation operators are two examples of novel aggregation operators that they investigated, which show versatility in a variety of decision-making scenarios. By introducing fresh viewpoints and useful tools that significantly expand the precision and flexibility of decision-making models, their significant study expands the use of fuzzy set approaches.

The authors' investigation of these new ideas shows how dedicated they are to extending the possibilities of fuzzy set theory and its application to decision theory.

To enhance the decision-making process, Gündodu and Kahraman [37] developed a spherical fuzzy TOPSIS examination and presented the concept of SFSs. Kahraman and Gündodu [38] proceeded further to investigate decision making using SFSs and advanced to a more comprehensive understanding of their application. SFSs were employed by Mahmood et al. [39] to solve medical diagnostics and decision-making challenges, thus showcasing their adaptability to a range of domains. Ullah et al.'s study [40] examined similarity metrics for T-SFSs and offered insights into pattern identification applications. Furthermore, Gündodu and Kahraman [41] increased the amount of data on SFSs by presenting a novel spherical fuzzy analytical hierarchy approach and highlighting its use in renewable energy contexts. Taken collectively, these studies deepen our knowledge of the theory, methods, and real-world applications of SFSs in several fields. The SWARA approach was established in the study of Keršulienė et al. [42], which concentrated on choosing an equitable conflict settlement using a stepwise weight assessment ratio analysis. In their investigation of the fuzzy SWARA approach in multicriteria decision making (MCDM), Stević et al. [43] used SWARA to provide an unbiased assessment and yielded unsatisfactory findings. In a spherical fuzzy environment, Ghoushchi et al. [44] evaluated wind turbine failure scenarios utilizing SWARA-CoCoSo models, thus contributing to the renewable energy industry. Ayyildiz et al. [45] presented a methodology relevant to environmental management by integrating SWARA and DEA for the performance analysis of wastewater treatment plants. Ulutaş et al. [46] used the plithogenic SWARA approach to assess logistics risks. Wang et al. [47] suggested a multisensor system that uses measurement quality control to help cars navigate in urban environments. This technology increases navigation accuracy by carefully adhering to quality criteria while merging sensors. Zhang et al. [48] created a multitask learning framework aimed at improving environmental monitoring and management through semantic and instance segmentation in coastal urban spatial perception. An attention mechanism was incorporated into this framework. Xu and Guo suggested a novel approach for calibrating DVLs [49]. The foundation of this technique is a strong, invariant, extended Kalman filter. This technology improves the accuracy of the velocity estimation of underwater vehicles.

Zavadskas and Turskis [50] made significant advancements to MCDM by developing the WASPAS model. This innovative method can be especially helpful in navigating challenging circumstances, since it gives DMs a systematic and weighted framework for assessing and ranking options based on a wide range of criteria. Apart from its theoretical contributions, the WASPAS model has been effectively applied by academics and practitioners to tackle actual choice issues, thus demonstrating its practical significance across many fields. The work of Zavadskas and Turskis [51] shows how their work improves decision making in a variety of fields and not only supports the theoretical foundations of MCDM but also offers a useful and adaptable instrument to improve decision making. Ma et al. [52] demonstrated autonomous pipeline navigation of a cockroach biorobot with enhanced walking stimuli, thus showcasing advancements in bioinspired robotics for challenging environments. Xu et al. [53] investigated the influence of fintech, digitalization, and green technologies on sustainable development in CIVETS nations, thus providing evidence through comprehensive approaches. Liu et al. [54] presented SS-DID, a secure and scalable Web3 decentralized identity system utilizing multilayer sharding blockchain, thus enhancing privacy and scalability in decentralized systems. Pan et al. [55] applied location-allocation modeling to rational health planning, thus evaluating spatial accessibility improvement of tertiary hospitals in a metropolitan city of China and contributing to better healthcare resource allocation.

The accuracy of rankings within the WASPAS system was revisited by Baykasoglu and Gölcük [56] in their work. Their study investigated the validity and consistency of the WASPAS model for rating choice alternatives, thereby adding to the current discourse in the field of cybernetics. Our comprehension of the method's efficacy in real-world applications has

been improved by this study. Keshavarz et al. [57] presented a novel approach to decision making that utilizes Fermatean fuzzy sets and WASPAS. Their research was centered on evaluating suppliers for green buildings. Particularly in light of environmentally conscious activities in the construction sector, their paper offers insightful information about how the WASPAS model might be used to evaluate suppliers. Badalpur and Nurbakhsh [58] added to the body of literature by qualitatively analyzing risks using the WASPAS approach. Their case study, which centered on a road construction project in Iran, provides useful insights into the application of the model for assessing and controlling risks related to construction projects.

Using an integrated MCDM methodology, Seker and Aydin [59] evaluated hydrogen generation strategies in the presence of uncertainty. By assessing alternate models for producing hydrogen via the WASPAS approach, the work advances the science. Lin et al. [60] conducted asymptotic analysis for one-stage stochastic linear complementarity problems and applications, thereby offering theoretical insights into optimization problems with practical implications. Liu et al. [61] proposed mechanism design for blockchain storage sustainability, thus addressing challenges and providing solutions for sustainable blockchain systems. W. et al. [62] explored limited sensing and deep data mining for the development of citywide parking guidance systems, thus highlighting advancements in intelligent transportation systems. This work contributes to our understanding of decision-making difficulties in ambiguous contexts. To choose an overseas payment mechanism, Nguyen et al. [63] provided Spherical Fuzzy WASPAS-based Entropy Objective Weighting. Their study focused on decision making in global payment and finance systems, thus enhancing the objectivity of weighing models by combining the WASPAS method with SFSs.

These studies include the use of deep learning and edge cloud computing for risk assessment in China's international trade and investment [64], the MCDM model for evaluating road section safety [65], and the application of interval-valued picture fuzzy uncertain linguistic Dombi operators in industrial fund selection [66]. These studies demonstrate a variety of approaches to risk management and decision making in a variety of contexts. The study's findings offer important information that may be used to the field of decision making regarding renewable energy. Advanced decision-making methods, including Fermatean fuzzy aggregation operators [67] and Pythagorean fuzzy Hamacher aggregation operators [68], have been highlighted along with their applications and contributions to various fields, including the FMEA-QFD for risk assessment in distribution processes [69]. Dede and Zorlu [70] evaluated geoheritage by employing the entropy-based WASPAS model. They specifically focused on the Karcali Mountains, which are located in Turkey. Their research contributes to the subject of geoheritage evaluation by presenting a method for evaluating and rating geoheritage sites by utilizing the WASPAS model. They employed the WASPAS and TOPSIS methodologies to investigate these factors. Their research sheds light on the potential benefits and drawbacks of implementing cutting-edge technology in the construction industry, thereby providing valuable information that can be utilized by professionals in the field. Their research contributes to the advancement of the field of geoheritage assessment by providing a framework for evaluating and rating geoheritage sites based on the WASPAS methodology. The findings of their study provide practitioners in the construction industry with insights into the opportunities and challenges that are associated with the implementation of modern technology in the industry.

A major advancement in decision-making framework development has been the expansion of the SWARA-WASPAS approach to SFSs. This is especially true in cases when the interpart interactions are intrinsically complex and multidimensional. On the surface of a unit hypersphere, membership values can be established by applying SFS theory. A more nuanced and adaptable definition of ambiguity and uncertainty is provided by this expansion compared to the conventional method. Compared to regular fuzzy sets, SFSs provide DMs with a more holistic view of the choice environment by representing the complex interdependencies across decision criteria in a multidimensional space. This

enhancement allows the SWARA-WASPAS approach to handle complex and variable choice scenarios with more ease. Pattern recognition and similar domains often face such situations, since linear fuzzy sets can not capture relationships well enough. This expanded framework shows promise in enhancing decision quality and enabling more knowledgeable and efficient decision-making processes in complex and uncertain situations by combining the strengths of SFSs with SWARA-WASPAS' systematic and reliable decision-making methodology.

1.2. Motivation and Contribution

1. Research Motivation:

- The escalating complexity of urban expansion and the challenges it brings forth prompt the need for fresh perspectives in decision making, particularly when evaluating various urban development options.
- Rapid urbanization necessitates innovative approaches to decision making to keep pace with evolving urban landscapes.

2. Study Focus:

- Investigates four potential urban development strategies: community-based growth, smart city technology, green infrastructure investment, and transit-oriented development.
- Aims to address fundamental challenges associated with urban growth through the development of a sophisticated evaluation framework.
- Introduces the SWARA-WASPAS model applied to SFSs as a means to overcome the decision-making uncertainties inherent in standard evaluations.

3. Contributions:

- Introduces the SWARA-WASPAS model applied to SFSs as a novel and sophisticated tool for analyzing urban development options.
- Enhances evaluation accuracy and provides detailed insights into the advantages and disadvantages of each option.
- Provides valuable insights for urban planners and policymakers through systematic criteria weighting and ranking methodology.
- Promotes decisions that foster equity, resilience, and environmental consciousness in urban environments.
- Advances the field of urban planning by incorporating the SWARA-WASPAS approach into decision-making processes.

4. Research Impact:

- Sparks meaningful conversations about sustainable urban development.
- Develops a data-driven framework to navigate complex urban landscapes.
- Takes a humanized approach to engage a diverse audience.
- Aims to inspire collective dedication to creating thriving cities amidst changing urban environments.

1.3. Paper Organization

The work is organized logically, with Section 2 providing a thorough examination of SFS ideas and procedures. This section provides a strong foundation by outlining the fundamental ideas, formulas, and characteristics of SFSs. Moving on, Section 3 presents the SWARA-WASPAS model, which combines the WASPAS method for aggregation with the SWARA method for determining criteria weight. Comprehensive explanations are provided for methodological purposes. In Section 4, an evaluation of complex problems associated with dynamic urban landscapes by utilizing the SWARA-WASPAS model is presented. In Section 5, the significance of the model in forming frameworks for decision making is emphasized as it explores the findings, conclusion, and directions for future research. The symbols used in the paper are represented in Table 1.

Table 1. Symbols and abbreviations used in the paper.

Symbol	Description
Z	Universal set
$\mu_{\beta}(\eta_{\beta})$	Degree of positive membership
$\nu_{\beta}(\eta_{\beta})$	Degree of negative membership
$\tau_{\beta}(\eta_{\beta})$	Degree of neutral membership
$S(\eta_{\beta})$	Score function
SFSs	Spherical fuzzy set
SFNs	Spherical fuzzy numbers
(EEH)	Exceptionally high
(VVH)	Very high
(HH)	High
(MMH)	Moderately high
(FF)	Fair
(MML)	Moderately low
(L)	Low
(VVL)	Very low
(EEL)	Exceptionally Low
$(D^{\eta_{\beta}})$	Criteria coefficient
W	Weight of criteria calculated by SWARA
AAlt	Alternatives
Ccr	Criteria

2. Preliminaries

This section aims to establish a foundation for understanding the technique and framework employed in this study by providing definitions of keywords and introducing basic concepts. We employ several definitions, including FS, IFS, PFS, and SFS, in the course of our analysis and conclusion. Furthermore, we provide functions and methods related with these sets that are essential for ranking and aggregating SFNs.

Definition 1 ([29]). Let us consider a set called $\mathbb{E}$ within the universal set Z . This set is referred to as a fuzzy set and is defined as

$$\mathbb{E} = \{(x, \eta \cdot z) : x \in Z\},$$

where $\eta \cdot z$ indicates the degree of membership (DoM) of the element z in the universal set Z .

Definition 1 provides the foundation for the idea of a fuzzy set, where each element has a DoM representing its association with the set.

Definition 2 ([30]). An IFS within the set W is characterized by the following expression:

$$\chi = \left\{ \langle \check{z}, \eta^Y(\check{z}), \omega^{\eta_{\beta}}(\check{z}) \rangle \mid \check{z} \in W \right\}, \quad (1)$$

where $\zeta^{\eta_{\beta}}(\check{z}), \omega^{\eta_{\beta}}(\check{z}) \in [0, 1]$, thus ensuring that $0 \leq \eta^Y(\check{z}) + \omega^{\eta_{\beta}}(\check{z}) \leq 1$ for all $\check{z} \in W$. The pair $F = (\eta^Y_F, \omega^{\eta_{\beta}}_F)$, referred to as IFN, encapsulates the entirety of this research, thus adhering to the conditions $\zeta^{\eta_{\beta}}_F, \omega^{\eta_{\beta}}_F \in [0, 1]$ and $\zeta^{\eta_{\beta}}_F + \omega^{\eta_{\beta}}_F \leq 1$.

Definition 2 extends the concept of FS to IFSs, which include both DoM and DoNM, thus offering a better than FS framework for handling uncertainty in MCDM.

Definition 3 ([31]). Let us consider a PFS defined on a universe Z , with the denotation $\mathbb{E}$. The structure looks like this:

$$A = \{\langle z, \eta z, qz, \theta z \mid z \in Z \rangle\},$$

where $qz \in [0, 1]$ and $\eta z \in [0, 1]$ denote the degree of positive membership (PMD) of Z in $\mathbb{E}$. $\theta z \in [0, 1]$ denotes the degree of negative membership of Z in $\mathbb{E}$, while indicates the degree of neutral membership (NuMD) of Z in $\mathbb{E}$. For any $z \in Z$, the following condition holds: $0 \leq \eta z + qz + \theta z \leq 1$.

The PFS further generalize the IFS by introducing an NuMD, thus providing an additional dimension for handling neutrality in MCDM scenarios.

Definition 4 ([36,38,39]). A “spherical fuzzy set” (SFS) within the domain Θ is expressed as

$$\chi = \{\langle \check{Y}, \mu_{\beta}(\check{\eta}_{\beta}), \nu_{\beta}(\check{\eta}_{\beta}), \tau_{\beta}(\check{\eta}_{\beta}) \mid \check{Y} \in \Theta \rangle\}, \quad (2)$$

where $\mu_{\beta}(\check{\eta}_{\beta}), \nu_{\beta}(\check{\eta}_{\beta}), \tau_{\beta}(\check{\eta}_{\beta}) \in [0, 1]$, thus ensuring that $0 \leq \mu_{\beta}^2(\check{\eta}_{\beta}) + \nu_{\beta}^2(\check{\eta}_{\beta}) + \tau_{\beta}^2(\check{\eta}_{\beta}) \leq 1$ for all $\check{Y} \in \Theta$. This triplet is denoted as $\check{\eta}_{\beta} = (\mu_{\tau_{\check{\eta}_{\beta}}}, \nu_{\tau_{\check{\eta}_{\beta}}}, \tau_{\tau_{\check{\eta}_{\beta}}})$ throughout this paper, thus representing a Spherical Fuzzy Number (SFN) and adhering to the conditions $\mu_{\tau_{\check{\eta}_{\beta}}}, \nu_{\tau_{\check{\eta}_{\beta}}}, \tau_{\tau_{\check{\eta}_{\beta}}} \in [0, 1]$ and $\mu_{\tau_{\check{\eta}_{\beta}}}^2 + \nu_{\tau_{\check{\eta}_{\beta}}}^2 + \tau_{\tau_{\check{\eta}_{\beta}}}^2 \leq 1$.

The SFS introduces a more flexible structure by allowing degrees of the PMD, NMD, and NuMD, which are constrained by a spherical relationship, thus enabling the capacity to cover more domain. It is a generalization of all sets.

Definition 5 ([36]). When using the SFNs to solve actual problems, ranking them is essential. In order to do this, let the “score function” (SF) matching SFN $\check{\eta}_{\beta} = (\mu_{\tau_{\check{\eta}_{\beta}}}, \nu_{\tau_{\check{\eta}_{\beta}}}, \tau_{\tau_{\check{\eta}_{\beta}}})$ be defined as

$$S(\check{\eta}_{\beta}) = \frac{2 + \mu_{\tau_{\check{\eta}_{\beta}}} - \nu_{\tau_{\check{\eta}_{\beta}}} - \tau_{\tau_{\check{\eta}_{\beta}}}}{3} \quad (3)$$

Nevertheless, in a number of situations, the previously stated function appears incapable of classifying the SFNs, thus making it impossible to determine which is larger. Because of this, $\check{\eta}_{\beta}$ has an accuracy function H that is defined as

$$H(\check{\eta}_{\beta}) = \mu_{\tau_{\check{\eta}_{\beta}}} - \tau_{\tau_{\check{\eta}_{\beta}}} \quad (4)$$

The SF and accuracy functions are essential for ranking SFNs, thus allowing for effective comparison and decision making.

Now, we will present some operational rules to aggregate the SFNs.

Definition 6 ([36]). Let $\check{\eta}_{\beta_1} = \langle \mu_{\tau_{\check{\eta}_{\beta_1}}}, \nu_{\tau_{\check{\eta}_{\beta_1}}}, \tau_{\tau_{\check{\eta}_{\beta_1}}} \rangle$ and $\check{\eta}_{\beta_2} = \langle \mu_{\tau_{\check{\eta}_{\beta_2}}}, \nu_{\tau_{\check{\eta}_{\beta_2}}}, \tau_{\tau_{\check{\eta}_{\beta_2}}} \rangle$ be two SFNs; then,

$$\check{\eta}_{\beta_1}^z = \left\langle \tau_{\tau_{\check{\eta}_{\beta_1}}}, \nu_{\tau_{\check{\eta}_{\beta_1}}}, \mu_{\tau_{\check{\eta}_{\beta_1}}} \right\rangle \quad (5)$$

$$\check{\eta}_{\beta_1} \vee \check{\eta}_{\beta_2} = \left\langle \max\{\mu_{\tau_{\check{\eta}_{\beta_1}}}, \mu_{\tau_{\check{\eta}_{\beta_2}}}\}, \min\{\nu_{\tau_{\check{\eta}_{\beta_1}}}, \nu_{\tau_{\check{\eta}_{\beta_2}}}\}, \min\{\tau_{\tau_{\check{\eta}_{\beta_1}}}, \tau_{\tau_{\check{\eta}_{\beta_2}}}\} \right\rangle \quad (6)$$

$$\check{\eta}_{\beta_1} \wedge \check{\eta}_{\beta_2} = \left\langle \min\{\mu_{\tau_{\check{\eta}_{\beta_1}}}, \mu_{\tau_{\check{\eta}_{\beta_2}}}\}, \max\{\nu_{\tau_{\check{\eta}_{\beta_1}}}, \nu_{\tau_{\check{\eta}_{\beta_2}}}\}, \max\{\tau_{\tau_{\check{\eta}_{\beta_1}}}, \tau_{\tau_{\check{\eta}_{\beta_2}}}\} \right\rangle \quad (7)$$

$$\check{\eta}_{\beta_1} \oplus \check{\eta}_{\beta_2} = \left\langle \sqrt{\mu^2 \tau_{\check{\eta}_{\beta_1}} + \mu^2 \tau_{\check{\eta}_{\beta_2}} - \mu^2 \tau_{\check{\eta}_{\beta_1}} \mu^2 \tau_{\check{\eta}_{\beta_2}}}, \nu \tau_{\check{\eta}_{\beta_1}} \nu \tau_{\check{\eta}_{\beta_2}}, \tau \tau_{\check{\eta}_{\beta_1}} \tau \tau_{\check{\eta}_{\beta_2}} \right\rangle \quad (8)$$

$$\check{\eta}_{\beta_1} \otimes \check{\eta}_{\beta_2} = \left\langle \mu \tau_{\check{\eta}_{\beta_1}} \mu \tau_{\check{\eta}_{\beta_2}}, \sqrt{\nu^2 \tau_{\check{\eta}_{\beta_1}} + \nu^2 \tau_{\check{\eta}_{\beta_2}} - \nu^2 \tau_{\check{\eta}_{\beta_1}} \nu^2 \tau_{\check{\eta}_{\beta_2}}}, \sqrt{\tau^2 \tau_{\check{\eta}_{\beta_1}} + \tau^2 \tau_{\check{\eta}_{\beta_2}} - \tau^2 \tau_{\check{\eta}_{\beta_1}} \tau^2 \tau_{\check{\eta}_{\beta_2}}} \right\rangle \quad (9)$$

$$\sigma \check{\eta}_{\beta_1} = \left\langle \sqrt{1 - (1 - \mu^2 \tau_{\check{\eta}_{\beta_1}})^\sigma}, \nu \tau_{\check{\eta}_{\beta_1}}^\sigma, \tau \tau_{\check{\eta}_{\beta_1}}^\sigma \right\rangle \quad (10)$$

$$\check{\eta}_{\beta_1}^\sigma = \left\langle \mu \tau_{\check{\eta}_{\beta_1}}^\sigma, \sqrt{1 - (1 - \nu^2 \tau_{\check{\eta}_{\beta_1}})^\sigma}, \sqrt{1 - (1 - \tau^2 \tau_{\check{\eta}_{\beta_1}})^\sigma} \right\rangle \quad (11)$$

Definition 7 ([71]). Let $\check{\eta}_{\beta_1} = \langle \mu \tau_{\check{\eta}_{\beta_1}}, \nu \tau_{\check{\eta}_{\beta_1}}, \tau \tau_{\check{\eta}_{\beta_1}} \rangle$ and $\check{\eta}_{\beta_2} = \langle \mu \tau_{\check{\eta}_{\beta_2}}, \nu \tau_{\check{\eta}_{\beta_2}}, \tau \tau_{\check{\eta}_{\beta_2}} \rangle$ be two SFNs, and let $\sigma, \sigma_1, \sigma_2 > 0$ be the real numbers; then, we have

1. $\check{\eta}_{\beta_1} \oplus \check{\eta}_{\beta_2} = \check{\eta}_{\beta_2} \oplus \check{\eta}_{\beta_1}$
2. $\check{\eta}_{\beta_1} \otimes \check{\eta}_{\beta_2} = \check{\eta}_{\beta_2} \otimes \check{\eta}_{\beta_1}$
3. $\sigma(\check{\eta}_{\beta_1} \oplus \check{\eta}_{\beta_2}) = (\sigma \check{\eta}_{\beta_1}) \oplus (\sigma \check{\eta}_{\beta_2})$
4. $(\check{\eta}_{\beta_1} \otimes \check{\eta}_{\beta_2})^\sigma = \check{\eta}_{\beta_1}^\sigma \otimes \check{\eta}_{\beta_2}^\sigma$
5. $(\sigma_1 + \sigma_2) \check{\eta}_{\beta_1} = (\sigma_1 \check{\eta}_{\beta_1}) \oplus (\sigma_2 \check{\eta}_{\beta_2})$
6. $\check{\eta}_{\beta_1}^{\sigma_1 + \sigma_2} = \check{\eta}_{\beta_1}^{\sigma_1} \otimes \check{\eta}_{\beta_2}^{\sigma_2}$

3. Spherical Fuzzy SWARA-WASPAS Model

Step 1: Introduce the SFNs dataset, where each alternative (AAlt_k with $k = 1, 2, \dots, r$) undergoes evaluation across a set of criteria (Ccr_k with $k = 1, 2, \dots, s$). DMs input decision matrices, which are denoted by $\text{Cr} = [\text{Ccr}_{ij}]_{s \times r}$.

$$\begin{array}{c} \text{AAlt}_1 \\ \text{AAlt}_2 \\ \vdots \\ \text{AAlt}_n \end{array} \begin{bmatrix} \begin{array}{ccc} \text{Ccr}_1 & \text{Ccr}_2 & \text{Ccr}_{H^{\eta_\beta}} \end{array} \\ \begin{array}{ccc} (\text{JA}_{11}, \text{JA}_{11}, \text{JA}_{11}) & (\text{JA}_{12}, \text{JA}_{12}, \text{JA}_{12}) & \dots & (\text{JA}_{1m}, \text{JA}_{1m}, \text{JA}_{1q}) \end{array} \\ \begin{array}{ccc} (\text{JA}_{21}, \text{JA}_{21}, \text{JA}_{21}) & (\text{JA}_{22}, \text{JA}_{22}, \text{JA}_{22}) & \dots & (\text{JA}_{2q}, \text{JA}_{2q}, \text{JA}_{2q}) \end{array} \\ \begin{array}{ccc} \vdots & \vdots & \ddots & \vdots \end{array} \\ \begin{array}{ccc} (\text{JA}_{p1}, \text{JA}_{p1}, \text{JA}_{p1}) & (\text{JA}_{p2}, \text{JA}_{p2}, \text{JA}_{p2}) & \dots & (\text{JA}_{pq}, \text{JA}_{pq}, \text{JA}_{pq}) \end{array} \end{bmatrix}$$

In the context of the SFNs dataset, Ccr_{ij} is defined as $(\text{JA}_{ij}, \text{JA}_{ij}, \text{JA}_{ij})$, where $(i = 1, 2, \dots, r)$ and $(j = 1, 2, \dots, s)$ denote the SFN that contains data related to alternatives across DM criteria. Eight linguistic terms, included in Table 2, describe each choice. Moreover, the linguistic expressions connected to expertise, as listed in Table 3, supplement these phrases and add to a rich variety of linguistic expressions that enhance the overall depiction of the information evaluation process.

Data Collection Experts: A team of knowledgeable subject matter experts, comprising environmental analysts, urban planners, and community participation professionals, gathered the case data used in this study. The urban planners were in charge of gathering information on regulations and plans for municipal growth, while the environmental analysts were in charge of analyzing the myriad factors that affected the environment. The specialists in community engagement served as mediators to gather community comments and ideas on the many options that may be taken into consideration for urban development. A deeper comprehension of the problems associated with sustainable urban planning has been made possible by these individuals' knowledge and experience.

Table 2. Descriptive terms for evaluation in the case study.

Evaluation Descriptor	Description	Membership Values (SFSs)
Exceptionally High (EEH)	Represents the highest level of the criterion under evaluation, thus signifying exceptional achievement in sustainable urban development.	(0.95, 0.02, 0.03)
Very High (VVH)	Denotes performance that is noticeably above average and in line with the advantages of community-based development, smart city technology, green infrastructure investment, and transit-oriented development.	(0.90, 0.10, 0.10)
High (HH)	Indicates remarkable performance that exceeds expectations, thus showcasing the strengths of the urban development alternatives under consideration.	(0.80, 0.15, 0.20)
Moderately High (MMH)	Shows above-average performance with room for development and acknowledges the advantages of the options that were considered.	(0.70, 0.25, 0.30)
Fair (FF)	Reflects satisfying minimum needs with negligible benefits or drawbacks, thus encapsulating the well-balanced standards of the options for urban development.	(0.65, 0.30, 0.40)
Moderately Low (MML)	Indicates subpar performance with potential for improvement, thus highlighting regions where the options for urban development could need to be improved.	(0.60, 0.40, 0.50)
Low (L)	Indicates performance below expectations with significant room for improvement, thus highlighting areas of concern in the evaluated alternatives.	(0.50, 0.45, 0.55)
Very Low (VVL)	Indicates subpar performance with few favorable criteria, thus pointing to problems or shortcomings with the options for urban development.	(0.40, 0.50, 0.60)
Exceptionally Low (EEL)	Represents the lowest level of the analyzed criterion, thus highlighting regions where the urban development choices fall short or are of grave concern.	(0.30, 0.55, 0.65)

Table 3. Key stakeholders and roles in sustainable urban development and data collection experts.

Stakeholder	Role	Key Decisions/Responsibilities
City Planner	Strategic Coordinator	Leading overall coordination and strategic planning for sustainable urban development alternatives.
EEH	FF	HH
Environmental Analyst	Expert in Sustainability	Assessing and evaluating the environmental impact of each alternative.
FF	HH	MML
Community Engagement Officer	Public Involvement Specialist	Encouraging community involvement in decision making.
MML	HH	VVL

Step 2: Calculate the weights of the DM by applying the scoring function found in Equation (3). After that, enter the scores that were acquired into the given Equation (12).

$$Sco_{ij} = \frac{\sum_i^3 \left(\frac{2 + \mu_{\eta_{\beta_j}} - \nu_{\eta_{\beta_j}} - \tau_{\eta_{\beta_j}}}{3} \right)}{\sum_j^3 \left(\sum_i^3 \left(\frac{2 + \mu_{\eta_{\beta_j}} - \nu_{\eta_{\beta_j}} - \tau_{\eta_{\beta_j}}}{3} \right) \right)} \quad (12)$$

Step 3: Compute the combined decision matrix $M = [M_{ij}]_{q \times p}$ by utilizing the prescribed formula in Equation (13).

$$SFWG(S_1, S_2, \dots, S_s) = \left(\prod_{j=1}^s (\eta_{\eta_{\beta_j}} + \varrho_{\eta_{\beta_j}})^{\omega_{\eta_{\beta_j}}} - \prod_{j=1}^s \varrho_{\eta_{\beta_j}}^{\omega_{\eta_{\beta_j}}}, \prod_{j=1}^s \varrho_{\eta_{\beta_j}}^{\omega_{\eta_{\beta_j}}}, \sqrt[n]{1 - \prod_{j=1}^s (1 - \theta_{\eta_{\beta_j}})^{\omega_{\eta_{\beta_j}}}} \right) \quad (13)$$

Equation (13) represents the SFWG aggregation operator, which combines multiple SFSs $(S_1, S_2, \dots, S_s)$ into a single aggregated set. Each SFS (S_j) is characterized by its PMD, NMD, and NuMD $(\eta_{\eta_{\beta_j}})$, $(\varrho_{\eta_{\beta_j}})$, and $(\theta_{\eta_{\beta_j}})$, respectively, with weights $(\omega_{\eta_{\beta_j}})$.

Step 4: We break the model down into its numerous components so that we may determine which criteria are regarded as being the most significant in MCDM.

SWARA Method:

The SWARA methodology was developed by Kersulienė et al. [42] to provide DMs with a structured approach to rating and assessing choices. DMs can evaluate the relative relevance of each criterion by first offering their thoughts and then analyzing each criterion in order of its original potential worth. Because it is a crucial component that has an effect on decision making in the long term, the next step is to evaluate the order of relevance of each of the qualifications. This is particularly beneficial in complex situations, since it helps DMs to make better, more informed choices. The SWARA idea enables DMs to rationally analyze and rank possibilities, which is especially helpful in challenging situations.

Step 4.1: One could make use of the Equation (14) to ascertain the score values of the aggregated decision matrix (ADM). The scoring function that is described in Equation (3) should be used to determine the weights of the ADM criteria. Incorporate the outcomes of the evaluation into the Equation (15) that has been provided.

$$S(F) = \left(\frac{2 + \mu\eta_{\beta\check{Y}} - \nu\eta_{\beta\check{Y}} - \tau\eta_{\beta\check{Y}}}{3} \right). \quad (14)$$

Step 4.2: Make use of the scoring function described in Equation (3) in order to compute the weights of the ADM criteria by using the formula. Apply the scores that were assessed to the Equation (15) that has been provided.

$$\varpi_{ij} = \frac{\sum_i^3 \left(\frac{2 + \mu\eta_{\beta\check{Y}} - \nu\eta_{\beta\check{Y}} - \tau\eta_{\beta\check{Y}}}{3} \right)}{\sum_j^3 \left(\sum_i^3 \left(\frac{2 + \mu\eta_{\beta\check{Y}} - \nu\eta_{\beta\check{Y}} - \tau\eta_{\beta\check{Y}}}{3} \right) \right)} \quad (15)$$

Step 4.3: First, criteria are ranked by perceived relative relevance by DMs. Equation (16) is used to calculate the criteria coefficient ($D^{\eta_{\beta}}$) for each criteria.

$$D^{\eta_{\beta}}_j = \begin{cases} 1 & \text{if } j = 1 \\ \varpi^{\eta_{\beta}}_{ij} + 1 & \text{if } j > 1 \end{cases} \quad j = 1, \dots, n \quad (16)$$

Step 4.4: Equation (17) is used in this phase to calculate the preliminary weight of a criterion for each criteria.

$$H^{\eta_{\beta}}_j = \begin{cases} 1 & \text{if } j = 1 \\ \frac{\varpi^{\eta_{\beta}}_j}{D^{\eta_{\beta}}_j} & \text{if } j > 1 \end{cases} \quad j = 1, \dots, q \quad (17)$$

Step 4.5: Equation (18) is used to determine the relative weight of a criterion for each criteria.

$$W_j = \frac{H^{\eta_{\beta}}_j}{\sum_{j=1}^n H^{\eta_{\beta}}_j} \quad (18)$$

WASPAS

Step 5: Determine the scores for each alternative based on the values in the aggregated matrix using Equation (14).

Step 6: Standardize the cost criteria and benefit criteria through the application of Equation (19). This process involves adjusting the values to a common scale, thus facilitating a fair and comparative assessment of both cost-related and benefit-related factors.

$$W^{\eta_{\beta}}_{ij} = \begin{cases} \frac{K^{\eta_{\beta}}_{ij}}{\max_i K^{\eta_{\beta}}_{ij}}, & j \in \text{Cr}_b \\ \frac{i}{\max_i K^{\eta_{\beta}}_{ij}}, & j \in \text{Cr}_c \end{cases} \quad (19)$$

Standardizing the cost and benefit criteria in Equation (19) promotes fair and comparable decision making across several aspects. The optimal alternative is assigned a value of one by dividing the original value by the highest criteria across all options ($(K^{\eta\beta}_{ij})$). Higher standardized values result from scaling cost criteria in the other direction, thus dividing the original value by the maximum value ($(j \in Cr_c)$). This is because predicted lower costs increase values. Zero to one can be set up, with one being the cheapest. Standardized values $W^{\eta\beta}_{ij}$ establish uniformity in the cost–benefit analysis of options.

Step 7: To obtain the additive relative relevance in weighted normalized data for each option, use Equation (20). This equation assesses the degree of relevance among options based on their normalized and weighted criteria.

$$H^1_i = \sum_{j=1}^n W^{\eta\beta}_{ij} \cdot \omega_j \quad (20)$$

H^1_i signifies the additive relative importance of each alternative.

The Equation (20) can calculate the relative relevance of each alternative (H^1_i). To do this, utilize the normalized weights of the criteria for each alternative ($W^{\eta\beta}_{ij}$) and their corresponding weights (ω_j). MCDM weights and normalizes the candidate performance across multiple criteria to choose the optimal alternative. Provide a numerical indicator of how well each alternative satisfies the specified requirements in the particular situation.

Step 8: For determining the multiplicative relative relevance of the weighted normalized data for each option, it is necessary to compute Equation (21). The use of this equation, which applies a multiplicative approach for combining both the weighted and normalized criteria, makes the process of evaluating the overall importance of the information easier to understand.

$$H^2_i = \prod_{j=1}^n W^{\eta\beta}_{ij}{}^{\omega_j} \quad (21)$$

Step 9: The following piece provides an explanation of the combined generalization criterion (Q), which is specified by Equation (22). It is possible to include both additive and multiplicative approaches due to the structure of it. For the purpose of evaluating alternatives, this criterion provides a comprehensive procedure that involves adding and multiplying components.

$$H^{\eta\beta}_i = \frac{1}{2} \left(\sum_{j=1}^n W^{\eta\beta}_{ij} \cdot \omega_j + \prod_{j=1}^n W^{\eta\beta}_{ij}{}^{\omega_j} \right) \quad (22)$$

Step 10: The objective of Equation (23) is to enhance the precision of ranking rankings. This model is essential in order to produce assessments of the possibilities that are more exact and precise, as well as to boost the accuracy of the ranking decision-making process.

$$H^{\eta\beta}_i = \lambda^F \sum_{j=1}^n W^{\eta\beta}_{ij} \cdot \omega_j + (1 - \lambda^F) \prod_{j=1}^n W^{\eta\beta}_{ij}{}^{\omega_j} \quad (23)$$

A flowchart (see Figure 1) is employed to visually illustrate the method, thus presenting its step-by-step logic and decision-making process.

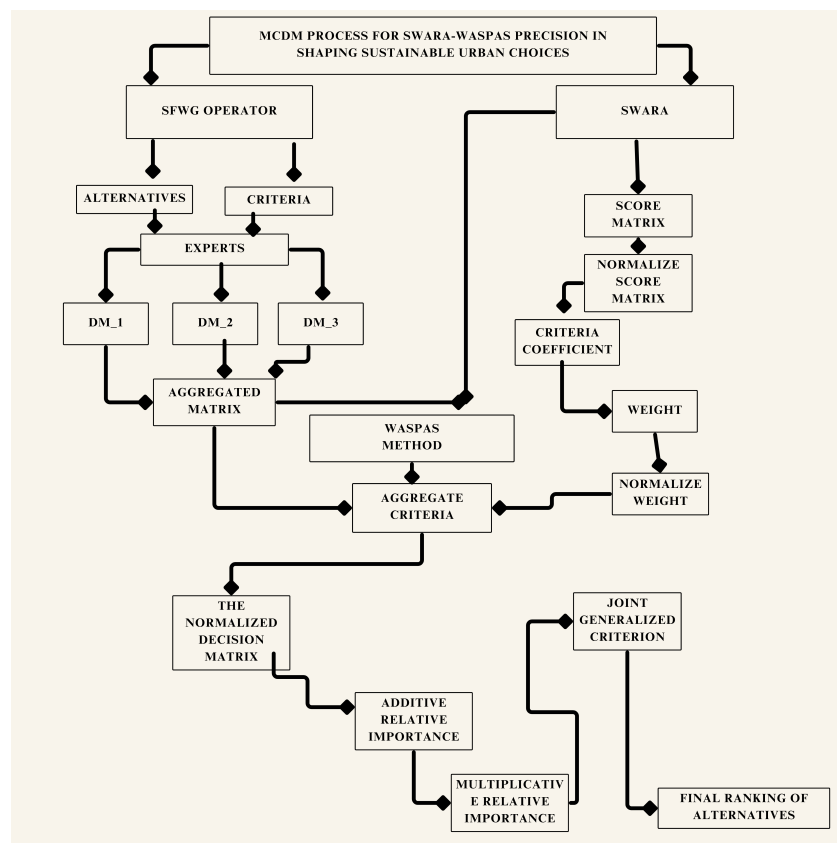


Figure 1. The working process of the algorithm.

4. Case Study

Our goal is to create a worldwide transformation and 21st century urbanization sustainable development strategy. Classic urban design is questioned when economics increase. We now want social inclusion, environmental conservation, and economic growth. Industry, migration, and globalization have increased megacity expansion, thereby causing traffic, infrastructure, and environmental issues. This case study suggests urban development adjustments to solve these issues. The goals include resilient, equitable, and sustainable urban expansion. These are the goals. Everything must be considered in urban planning. Different solutions improve urban problems and the environment in modern urbanization. This case study uses specific criteria to evaluate these options and their pros and cons. This study examines new urban development methods in light of a changing society and urban environment. City challenges and remedies are explored. Future city sustainability demands flexibility and planning. Four complicated urban development network options exist. Green infrastructure investment (GII), the smart city, and transit-oriented development are included. Redevelopment and urbanization are promising. Multiple solutions interact, thus making this case study complex. We assess their strengths and weaknesses. This informative look at urban development approaches reveals how society's wants and surroundings evolve. This research examines city concerns and solutions for adaptable, foresighted urban futures.

4.1. Definition of Alternatives

1. **Transit-Oriented Development (TOD) (AAlt₁):** Innovative urban transportation is TOD. This innovative idea creates efficient, accessible transit hubs. TOD promotes sustainable urban living in high-density, mixed-use zones with public transit. TOD is evaluated for transit connectivity, environmental sustainability, infrastructural capacity, community participation, economic viability, technological integration, equity, inclusion, and resilience, not just urban density. TOD's comprehensive, forward-

thinking urban development strategy prioritizes the community, environment, and resident well-being.

2. **Green Infrastructure Investment (AAlt₂):**
Green Infrastructure Investment prioritizes urban vegetation. Parks and sustainable landscaping benefit air, water, biodiversity, and urbanites' lives. Assessed are urban density, environmental impact, infrastructure capacity, community participation, economic viability, technological integration, equity, inclusion, and resilience. Strong economies promote community and environmental sustainability in cities.
3. **Smart City Technologies (AAlt₃):**
Smart City Technologies boost urbanization. Integrating cutting-edge technology improves urban management, sustainability, and resident quality of life. Infrastructure, density, environment, economics, community equity, inclusivity, resilience, and technical integration are needed for smart cities. Technology can make a city healthy, sustainable, and inclusive.
4. **Community-Based Development (AAlt₄):**
Planning and executing urban development initiatives empowers communities. Cities are built on values and social interaction under the bottom-up paradigm. Community-Based Development assessments consider urban density, environmental effect, infrastructure capacity, community engagement, economic viability, technological integration, equity, inclusion, and resilience. This promotes community-driven sustainable urbanization.

4.2. Definition of Criteria

1. **Urban Density (Ccr₁):**
Any alternative's population density and sprawl management depend on urban density. Each option's capacity to build a small, connected city, while conserving space is assessed. Each option is assessed for its ability to raise population density in chosen metropolitan regions, improve land use, and reduce sprawl-related environmental impacts. Residential growth–space balance is promoted by dense urbanization.
2. **Environmental Impact (Ccr₂):**
Environmental impact evaluations must consider every development's ecological benefits. This includes carbon emission reduction, air and water quality improvements, and wildlife preservation. Each alternative is given to reduce environmental impact and improve sustainability. Environmental Impact guidelines promote ecofriendly urban development for ecological success.
3. **Infrastructure Capacity (Ccr₃):**
Infrastructure capacity for each option, current and future. Transport, utilities and other vital services must be assessed for urban expansion plan compatibility. The Infrastructure Capacity assessment examines infrastructure's ability to resist and adapt to the chosen alternative, thus making durable, well-designed urban infrastructure crucial for development.
4. **Community Engagement (Ccr₄):**
Community engagement means locals plan, decide, and act, thus assessing residents' inclusive and empowering municipal development engagement. This review emphasizes community involvement, decision-making transparency, and urban development stakeholders' client symbiotic relationship. A higher community engagement score indicates more open and collaborative urban space planning and administration.
5. **Economic Viability (Ccr₅):**
All solutions are considered for economic viability. This benchmark analyzes area economic growth, employment, and property values. We evaluate every urban strategy for profitability. Economics helps DMs analyze the pros and disadvantages of each option to meet economic needs and urban financial progress.
6. **Technological Integration (Ccr₆):**
Technological integration analyzes how well each option uses modern tech. Smart

solutions and technology increase urban administration, infrastructural efficiency, and citizen quality of life. Technology integration helps decision makers assess each urban development strategy's adaptability and exercise foresight to construct tech-powered cities.

7. **Equity and Inclusivity (Ccr₇):**

All urban development decisions must consider social justice and inclusivity. Address diversity in resources, opportunities, and life quality. Policymakers can evaluate this alternate place's fairness and inclusivity to determine its ability to build a socially equitable urban environment where growth benefits everyone. Urban policy promotes diversity and inclusion.

8. **Resilience (Ccr₈):**

The ability of any option to respond and weather unexpected obstacles is measured by resilience. Beyond close evaluation, this criterion considers urban development methods' long-term sustainability and flexibility. Projected population growth, evolving technology, and climate change are carefully considered.

The procedure can be broken down into the following steps:

Step 1: Experts leverage the dataset on SFNs by integrating the descriptive terms outlined in Table 2 for every alternative denoted as AAlt_r (with $p = 1, 2, \dots, r$). This process involves a thorough consideration of diverse criteria Ccr, as elucidated in Tables 4.

Table 4. DM's evaluation table with 4 alternatives and 8 criteria.

DMs	Alternatives	Ccr ₁	Ccr ₂	Ccr ₃	Ccr ₄	Ccr ₅	Ccr ₆	Ccr ₇	Ccr ₈
DM ₁	AAlt ₁	EEH	VVH	HH	HH	VVL	MMH	MML	MMH
	AAlt ₂	EEL	VVH	HH	EEL	MMH	VVL	MML	MMH
	AAlt ₃	MMH	MML	EEL	FF	EEH	VVL	FF	HH
	AAlt ₄	VVL	VVH	MML	VVL	MMH	EEL	FF	MMH
DM ₂	AAlt ₁	MML	VVL	MMH	EEH	EEL	HH	VVH	HH
	AAlt ₂	VVH	MMH	MML	FF	EEL	VVL	EEH	HH
	AAlt ₃	FF	EEL	VVH	MMH	MML	HH	VVL	HH
	AAlt ₄	VVL	MMH	HH	EEL	EEH	MML	VVH	HH
DM ₃	AAlt ₁	MMH	MML	HH	VVL	VVH	EEH	EEL	MML
	AAlt ₂	VVH	MMH	VVL	MML	EEL	FF	MML	HH
	AAlt ₃	FF	MML	HH	EEL	VVH	VVL	MMH	EEL
	AAlt ₄	VVL	EEL	VVH	MMH	FF	EEH	MML	HH

Step 2: Using the given scoring function in Equation (3), obtain the weights of the DMs. After that, enter these computed scores into Equation (12), and Table 5 will show the numbers that result.

Step 3: Using the formula shown in Equation (13), calculate the ADM $M = [M_{ij}]_{q \times p}$. Table 6 presents the resulting results in detail and offers a detailed illustration of the amalgamation process.

Step 4.1: The ADM's score value is calculated by utilizing Equation (3).

$$\text{Score} = \begin{bmatrix} 0.742 & 0.512 & 0.303 & 0.078 & 0.216 & 0.623 & 0.247 & -0.309 \\ 0.454 & 0.210 & -0.307 & 0.328 & 0.637 & 0.654 & 0.328 & 0.045 \\ 0.748 & 0.423 & -0.222 & 0.439 & 0.551 & 0.259 & 0.357 & 0.366 \\ 0.450 & 0.346 & 0.439 & 0.430 & 0.437 & 0.663 & -0.044 & 0.348 \end{bmatrix}$$

Table 5. Key stakeholders and roles in sustainable urban development.

Stakeholder	Role	Key Decisions/Responsibilities	Weights
City Planner	Strategic Coordinator	Leading overall coordination and strategic planning for sustainable urban development alternatives.	
EEH	FF	HH	0.5604
Environmental Analyst	Sustainability Expert	Assessing and analyzing the environmental impact of each alternative.	
FF	HH	MML	0.2744
Community Engagement Officer	Public Involvement Specialist	Facilitating community participation in decision-making processes.	
MML	HH	VVL	0.1653

Table 6. ADM.

CCr _i	AAlt ₁	AAlt ₂	AAlt ₃	AAlt ₄
Ccr ₁	⟨0.510, 0.316, 0.381⟩	⟨0.810, 0.200, 0.219⟩	⟨0.610, 0.436, 0.525⟩	⟨0.640, 0.290, 0.230⟩
Ccr ₂	⟨0.640, 0.253, 0.243⟩	⟨0.511, 0.389, 0.465⟩	⟨0.748, 0.241, 0.200⟩	⟨0.752, 0.442, 0.516⟩
Ccr ₃	⟨0.591, 0.421, 0.525⟩	⟨0.541, 0.418, 0.398⟩	⟨0.390, 0.361, 0.491⟩	⟨0.911, 0.266, 0.321⟩
Ccr ₄	⟨0.642, 0.441, 0.521⟩	⟨0.733, 0.324, 0.323⟩	⟨0.711, 0.280, 0.379⟩	⟨0.490, 0.443, 0.231⟩
Ccr ₅	⟨0.891, 0.300, 0.336⟩	⟨0.791, 0.318, 0.591⟩	⟨0.870, 0.230, 0.252⟩	⟨0.590, 0.0395, 0.557⟩
Ccr ₆	⟨0.761, 0.435, 0.321⟩	⟨0.621, 0.343, 0.362⟩	⟨0.541, 0.321, 0.513⟩	⟨0.780, 0.246, 0.2331⟩
Ccr ₇	⟨0.780, 0.329, 0.199⟩	⟨0.650, 0.234, 0.326⟩	⟨0.490, 0.405, 0.395⟩	⟨0.260, 0.440, 0.523⟩
Ccr ₈	⟨0.650, 0.343, 0.434⟩	⟨0.530, 0.121, 0.421⟩	⟨0.760, 0.386, 0.425⟩	⟨0.490, 0.357, 0.355⟩

Step 4.2: Equation (3) defines the scoring function that should be used to determine the weights of the criteria in the ADM. After that, add these scores to the specified Equation (15).

$$\text{initial weights} = (0.2350 \quad 0.1235 \quad 0.0496 \quad 0.1862 \quad 0.1248 \quad 0.1741 \quad 0.0433 \quad 0.03425)$$

Step 4.3: Equation (16) can be used to find the criteria coefficient ($D^{j\beta}$) for each criterion.

$$D^{j\beta} = [1.00 \quad 1.154 \quad 1.265 \quad 1.223 \quad 1.282 \quad 1.213 \quad 1.039 \quad 1.052]$$

Step 4.4: Calculate the weight of each criteria for each criterion using Equation (17).

$$[1.0000 \quad 0.652 \quad 0.275 \quad 0.28 \quad 0.67 \quad 0.543 \quad 0.461 \quad 0.453]$$

Step 4.5: Compute the relative weight of each criterion using Equation (18).

$$\text{Weights} = [0.1613 \quad 0.1844 \quad 0.1410 \quad 0.1418 \quad 0.1211 \quad 0.0128 \quad 0.0321 \quad 0.03250]$$

4.3. WASPAS

Step 5: Utilizing Equations (19), normalize the cost and benefit criteria. Table 7 displays the values following normalization. **Step 8, 9, and 10:** To calculate the additive relative importance, multiplicative relative importance, and joint generalized criterion (Q) in the weighted normalized data for each alternative, use the Formulas (20), (21), and (22), respectively. The values that were obtained are shown in Table 8.

Table 7. Normalized decision matrix.

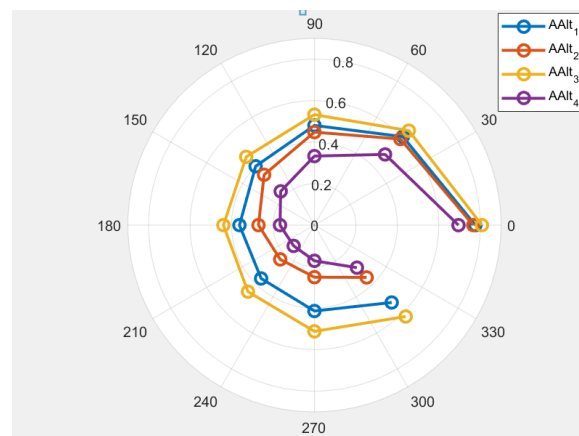
Alternative	CCcr ₁	CCcr ₂	CCcr ₃	CCcr ₄	CCcr ₅	CCcr ₆	CCcr ₇	CCcr ₈
AAlt ₁	1	0.2253	0.5162	0.5797	0.4231	0.4740	0.1467	0.3493
AAlt ₂	0.5799	1	0.4575	−0.3229	−0.1924	0.2868	0.1544	0.4806
AAlt ₃	0.4101	−0.2520	0.4344	0.0506	0.7577	1	0.3897	0.2870
AAlt ₄	0.3000	0.3176	0.4375	0.2279	0.5125	0.5044	1	0.2089

Table 8. Final ranking of alternatives.

Alternative	Q ¹	Q ²	Q	Ranking
AAlt ₁	0.7260	0.7880	0.7950	0.6606
AAlt ₂	0.7230	0.7180	0.8231	0.8726
AAlt ₃	0.7430	0.8170	0.7120	0.8457
AAlt ₄	0.7120	0.8110	0.7650	0.7217

4.4. Sensitivity Analysis

When the parameter λ^F fluctuated from 0.1 to 0.8, the order of options (from AAlt₁ to AAlt₄) remained constant, as can be shown by looking at the sensitivity of decision outcomes in Table 9. The decision-making model's consistency has been demonstrated by the stability of AAlt₂, which was consistently favored over AAlt₃, followed by AAlt₄ and lastly AAlt₁. Figure 2 provides a graphical representation that illustrates the model's flexibility by showing the subtle effects of various λ^F values on the SFS framework's decision-making process. The decision-making model's dependability and adaptability have been confirmed by these results throughout a wide range of λ^F values, thus guaranteeing solid and steady results.

**Figure 2.** Illustrating fluctuations with evolving parameter (λ^F).**Table 9.** The impact of the parameter λ^F on the decision outcome.

λ^F	AAlt ₁	AAlt ₂	AAlt ₃	AAlt ₄	Ranking
$\lambda^F = 0.1$	0.2212	0.4919	0.3602	0.3240	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.2$	0.3215	0.5519	0.4632	0.4280	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.3$	0.4542	0.5902	0.5252	0.5040	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.4$	0.5292	0.6764	0.6162	0.5943	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.5$	0.6606	0.8726	0.8457	0.7217	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.6$	0.6910	0.8909	0.8606	0.7824	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.7$	0.7213	0.9122	0.8936	0.8814	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁
$\lambda^F = 0.8$	0.7430	0.9809	0.9306	0.8927	AAlt ₂ > AAlt ₃ > AAlt ₄ > AAlt ₁

4.5. Comparative Analysis

In delving deep into the intricate realm of decision-making procedures within SFNs, our research embarked on a comprehensive journey, thus meticulously assessing their feasibility and effectiveness. Our methodological approach has been characterized by thorough scrutiny and robust validation procedures, thus instilling a high degree of reliability in our study. The careful application of rigorous methodologies not only ensures the solidity of our results but also establishes a sturdy foundation for the conclusive insights we derive. The main conclusions, summarized in the brief format in Table 10, provide a broad overview of the scope and complexity of our study. These subtle insights, extracted from a thorough investigation, are intended to provide DMs with a sophisticated comprehension of the complex dynamics related to different decision-making processes inside SFNs. Essentially, the goal of our research is to equip DMs with real and meaningful knowledge that will guide their efforts in integrating SFSs and add to the body of knowledge on decision making inside the SFS framework.

Table 10. Comparison of newly proposed AOs with those already existing.

Authors	Methodology	Ranking of Alternatives	Optimal Alternative
Ali [72]	CRITIC-MARCOS	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_1} \succ AA_{Alt_4}$	AA_{Alt_2}
Gündoğdu and Kahraman [37]	TOPSIS method	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_4} \succ AA_{Alt_1}$	AA_{Alt_2}
Akdag AND Menekse [73]	CRITIC-REGIME	$AA_{Alt_2} \succ AA_{Alt_4} \succ AA_{Alt_3} \succ AA_{Alt_1}$	AA_{Alt_2}
Anafi et al. [74]	CRITIC-MAUT	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_1} \succ AA_{Alt_4}$	AA_{Alt_2}
Gorcun2024 et al. [75]	TOP-DEMATEL	$AA_{Alt_2} \succ AA_{Alt_1} \succ AA_{Alt_4} \succ AA_{Alt_3}$	AA_{Alt_2}
Zhang et al. [76]	TODIM method	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_4} \succ AA_{Alt_1}$	AA_{Alt_2}
Akram et al. [77]	Extended MABAC method	$AA_{Alt_2} \succ AA_{Alt_1} \succ AA_{Alt_3} \succ AA_{Alt_4}$	AA_{Alt_2}
Ali and Naeem [78]	VIKOR method	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_4} \succ AA_{Alt_1}$	AA_{Alt_2}
Fan et al. [79]	COPRAS	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_1} \succ AA_{Alt_4}$	AA_{Alt_2}
Proposed	SWARA-WASPAS	$AA_{Alt_2} \succ AA_{Alt_3} \succ AA_{Alt_4} \succ AA_{Alt_1}$	AA_{Alt_2}

In evaluating urban development alternatives, the SWARA-WASPAS model emerges as a standout choice. When compared to well-established methods like CRITIC-REGIME, CRITIC-MARCOS, TODIM, TOPSIS, and TOP-DEMATEL, SWARA-WASPAS consistently outshines them, thus showcasing its versatility across various methodologies. Notably, AA_{Alt_2} consistently secured the top spot, thus affirming the efficacy of SWARA-WASPAS in guiding decision making for urban development selections. This pattern highlights the reliability and practicality of SWARA-WASPAS, thus positioning it as a superior approach in the landscape of urban development decision making. The SWARA-WASPAS model on SFSs is unique among models for evaluating the feasibility of suggested city layouts; hence, for this specific enquiry, we chose to employ it. To begin with, the SWARA-WASPAS model provides a thorough and rigorous framework that is intended to account for the inherently complex and uncertain character of the decision-making processes that take place in metropolitan areas. Our technique has the capacity to perform a thorough examination of a broad range of criteria and alternatives by utilising the WASPAS and SWARA (Stepwise Weight Assessment Ratio Analysis) methodologies. This makes it possible to comprehend the trade-offs being thought about at a more advanced level. Moreover, our model better captures and expresses the intrinsic vagueness and ambiguity seen in urban development settings, since it uses SFSs. This is due to the fact that fuzzy sets can be included in our model. Using SFSs instead of rigid crisp sets can result in better and more reliable conclusions. This is because SFSs offer a representation of DMs' preferences and uncertainty that is more adaptable and realistic. There are some advantages that our technique offers over current approaches that are frequently used in urban decision making, such as MCDM methodologies or conventional fuzzy decision-making models. In contrast to the MCDM techniques, the SWARA-WASPAS model analyzes each criterion and how it affects decision outcomes step by step. The relative importance of each criterion and their interactions within the model are considered in this evaluation. Furthermore, our model's use of SFSs

creates a more flexible and adaptable framework that enables it to take into account a variety of choice circumstances. This is in contrast to conventional fuzzy decision-making models, which could find it challenging to handle complex and ambiguous decision scenarios.

4.6. Discussion

This study offers a thorough analysis of the many urban development strategies that could be used by applying the SWARA-WASPAS model within the context of SFSs. Improved decision-making tools that can effectively navigate the multitude of criteria and uncertainties inherent in urban planning operations are desperately needed, especially in light of the rapidly urbanizing world and the growing complexity of urban development. This paper presents a case study that highlights the difficulties encountered when trying to integrate autonomous sensors into municipal planning procedures. The inherent uncertainties and complexity of urban surroundings complicate the evaluation process, which must consider a variety of factors in addition to technological feasibility, environmental effect, and economic viability. This makes the review process even more challenging. This paper applied the SWARA-WASPAS paradigm to SFSs and suggests a comprehensive decision-making mechanism that tackles these issues. The model provides a scientific approach to analysing alternatives for urban development by including the SWARA method (used to weigh criteria) and the WASPAS strategy (used to rank alternatives). The model's resilience and dependability are further enhanced by the addition of SFSs, which provide a more flexible and realistic way to describe decision-making uncertainty. It has been found that in a range of contexts, there is a consistent preference for a particular alternative, AAlt₂. Due to the model's dependability and flexibility in a range of decision-making scenarios, DMs can gain insight into the most efficient urban development methods. The case study provides more proof that the SWARA-WASPAS paradigm works well in addressing problems that arise in real-world situations. The model not only gives DMs a thorough and systematic way to assess possible opportunities for urban development, but it also makes it possible to carry out more informed and sustainable urban planning. Urban planning has benefited greatly from the study's presentation of a complex decision-making framework that combines SFSs with the SWARA-WASPAS model. It is possible to create more sustainable and informed urban development practices by addressing the model's emphasis on the difficulties involved in integrating autonomous sensors into urban planning processes.

5. Limitations

1. The strength of the conclusions depends on some assumptions and data inputs which vary in alternative assessment.
2. Despite the SWARA-WASPAS approach, it still has some limitations, including criteria bias and weighting issues.
3. The linguistic terms assigned to stakeholder roles are only subjective to the assessor values and can vary.
4. The choice of alternatives in the study may limit its applicability to various urban settings. The instability of urban settings is dictated by outside factors over time.

Managerial Implications

Policymakers, urban planners, and everyone else with a stake in the creation of sustainable urban living environments should take into account the results of these research. We describe the SWARA-WASPAS model with respect to SFSs, thus providing a comprehensive framework to assess different city planning strategies. Our work provides this foundation. DMs will be able to assess the benefits and drawbacks of each option more precisely if they follow the thorough methodology of the study, which will eventually lead to better and more informed decisions. One of the important managerial implications of our research is the importance of considering several factors and the inherent uncertainties when making decisions regarding urban development. The SWARA-WASPAS paradigm may be used to include stakeholder, environmental, and economic issues into decision-making. It is an

effective tool when combined with SFSs. Because of this, policymakers and urban planners may utilize this paradigm to establish goals for initiatives meant to improve the equality, resiliency, and ecological sustainability of cities. This covers initiatives aimed at improving the environmental sustainability of cities. The findings of our study highlight the necessity to create creative and flexible municipal development strategies. Strategies must be adaptable enough to take into account shifts in the social, economic, and environmental spheres, since urban environments are dynamic. Adopting innovative models, like the SWARA-WASPAS framework, might help cities better manage the difficulties that arise with urban development and expansion. Cities would be able to ensure the population's long-term sustainability and prosperity in this way.

6. Conclusions

Applying the SWARA-WASPAS model within the SFS framework has proven to be a reliable and effective replacement for complex decision-making circumstances. It is evident that $AAlt_2$ is always the best option when doing sensitivity analysis, especially when calculating λ^F for different values. It is important to note that this stresses both the model's adaptability to diverse contexts and its consistency. Combining the WASPAS model with the approach makes it more beneficial in supporting DMs in navigating complex selection scenarios. The SWARA-WASPAS concept has been applied and proven useful in real-world circumstances by incorporating autonomous sensors into urban planning methodologies. The model's consistent preference for $AAlt_2$ across many conditions enhances its ability to smoothly transition between distinct dynamics, thus making it more relevant and useful. Future research should focus on developing the SWARA-WASPAS model to make it acceptable for a variety of decision-making scenarios, as well as investigating its applicability in real-world settings. Furthermore, there is the prospect of investigating the model's scalability in larger option landscapes and improving its ability to solve a broader range of decision-making difficulties. In conclusion, the SWARA-WASPAS model provides a reliable and versatile instrument for dealing with complex option situations inside the SFS framework, thus considerably assisting research and development in decision making. This has proven to be a significant development in the sector.

Future Research Directions

Building on the findings of this study, several avenues for future research emerge that warrant exploration:

1. **Refinement of the SWARA-WASPAS Model:** Future study may improve SWARA-WASPAS to manage urban development decision-making complexity and uncertainty. We may add criteria, improve weighting, or test various decision-making frameworks.
2. **Integration of Stakeholder Engagement:** Researchers could improve stakeholder engagement in decision making. Participatory decision-making frameworks may empower communities and integrate their opinions in urban development.
3. **Longitudinal Studies:** Longitudinal studies may demonstrate urban development initiatives' success and durability. This may entail evaluating the social, economic, and environmental repercussions of past initiatives to shape future ones.
4. **Incorporation of Emerging Technologies:** Future research may analyze how AI, blockchain, and the IoT affect urban development. This may involve investigating how these technologies might boost urban efficiency, justice, and sustainability.

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