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Article

Fuzzy and Interval AHP Approaches in Sustainable Management for the Architectural Heritage in Smart Cities

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Abstract: For the past four decades, the methodology of fuzzy analytic hierarchy process based on fuzzy trapezoidal or triangular numbers with the linear type of membership functions has witnessed an expanding development with applicability to a wide variety of areas, such as industry, environment, education, government, economics, engineering, health, and smart city leadership. On the other hand, the interval gray analytic hierarchy process is a more practical method when a significant number of professionals have large variations in preferences and interests in complex decisions. The paper examines the management of architectural heritage in smart cities, using methods of multi-criteria decision making. Two appropriate methods generally recommended by the scientific literature have been applied: fuzzy and interval grey analytic hierarchy process. By using both techniques, there is an opportunity to analyze the consensual results from the aspect of two different stakeholder groups: architectural heritage experts and smart city development experts. Trapezoidal fuzzy analytical hierarchical process shows better stability than a triangular one. Both approaches assign priority to the strategy, but the interval approach gives a more significant rank to architectural heritage factors. The similarity of the proposed methods has been tested, and the similarity factor in the ranking indicates a high degree of similarity in comparing the reference rankings.

Keywords: MCDM; fuzzy analytic hierarchy process; interval grey analytic hierarchy process; architectural heritage; smart cities; sustainable management

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1. Introduction

In the 21st century, smart environments have become an integral part of people's everyday lives in urban areas. The smart city concept, based on the idea of an urban system that uses ICT—Information and Communications Technology in a sustainable, reversible, and rational way for self-improvement, is a strategic goal at the local and national levels of many countries around the world. There is a discourse in defining a smart city. On the one hand, a movement that promotes the concept of the smart city as a system full dependent on technological progress, caused by the fourth industrial revolution, has been developed. In this regard, the evolution of smart cities represents a direct product of the Internet of Things (IoT) platforms and the incorporation of technologies into every segment of urban space. On the other hand, studies focused on spatial planning and urban development define a smart city as a sustainable environment created by responsible citizens through sustainable mechanisms of action and management. Thus, innovative technologies can significantly improve people's quality of life, simplify production and construction processes, transport, waste, water, and energy management, and enhance health and education services, but are only one of the factors in creating healthy and living surroundings.

Cities are getting smarter, and moving to more sustainable and intelligent cities are helping to improve living standards in urban and suburban communities around the world. Energy savings, more efficient traffic flow, upgrade public safety, and a healthier environment are just some of the many benefits that smart cities can offer. A considerable range of possible solutions for smart cities can affect almost every aspect of urban life. In that sense, a large number of researches, scientific projects, and workshops have been conducted so far, the results of which provide qualitative guidelines for defining a smart city and transforming existing urban areas into more efficient entities. As part of the previous researches, the authors have viewed smart cities from different perspectives. Some authors have explored the smart city holistically, not going deeper into its segments and mechanisms of functioning but looking at the relationship of the concept to current urban theories and paradigms of sustainability [1–3]. Further, one group of authors dealt in published studies with the development, transformations, and characteristics of its urban subsystems—mobility, infrastructure, environmental management, livability, sustainable areas, planning, institutional frameworks, and citizenship. Many papers analyze the ecological dimension of a smart city, through the paradigm of a smart environment, focused on the recycling of abandoned brownfield areas [4,5], conservation of natural resources and water [6,7], waste management [8,9], use of renewable energy sources, and reducing CO2 [10,11], as well as building energy-efficient and smart facilities [12]. A certain number of studies discuss the use of modern technologies in different segments of social life, improving healthcare systems [13,14], education [15,16], housing [17], culture, and tourism sectors [18] while spreading the knowledge across the borders. Some researchers have addressed smart urban governance with a focus on the institutional framework in spatial planning, the cooperation of various stakeholders, and sustainable management models that combine centrally defined regulation with actions and citizen participation [19–21]. Smart economy including market growth, self-employment fostering, entrepreneurship, e-commerce, and strategic investment, is the subject of several pieces of research [22,23]. A large amount of scientific papers is dedicated to infrastructure development of urban areas through mobility systems [24,25] but also innovative improvement of energy systems [26].

Big data, crowdsourcing, IoT, 5G networks, and other smart technologies have reshaped the existing image of cities that was familiar to us. Adapting to the needs of people, global problems, and technological innovations, cities undergo numerous changes that transform their urban morphology on a macro and micro spatial level. All these challenges can be recognized in urban structure, disturbing existing urban identity and questioning its future preservation. The identity and integrity of an area depend on cultural heritage as an urban subsystem and a reflection of the social development throughout history. In addition to the cultural-sociological dimension, cultural heritage consists of individual or grouped buildings that are part of the architectural heritage of a place. Architectural heritage largely determines the environment in which people live, visually, formally, and spatially. It consists of various types of buildings as well as historic-cultural areas, that are protected as cultural assets or recognized as architectural and cultural valuable facilities from different epochs including contemporary movements [27,28].

To preserve the identity of urban areas and their existing values, sustainable urban development initiatives, including the smart city movement, are oriented towards architectural heritage management. The management of architectural heritage is multi-dimensional and can be seen from several perspectives. It is significant for recognizing, defining, and affirming cultural identity. Some organizations around the world are committed to the active protection of cultural heritage, including UNESCO, which pays special attention to the cultural and natural heritage of extraordinary characteristics. There are several international heritage charters, conventions, and recommendations regarding standards of heritage documentation, including the UNESCO World Heritage Convention from 1972, 2001, to 2003, the UNESCO recommendations concerning the protection from 1972, 1976, to 1978, Council of Europe Charter and Conventions from 2000, the ICOMOS principles for the recording of monuments, groups of buildings, and cities from 1996 [29,30]. Developing awareness of managing cultural and architectural heritage is an essential part of the concept of sustainability, which is confirmed by the directives 2030 Agenda for Sustainable Development and the New Urban Agenda [31,32].

Despite the existence of cultural heritage issues in strategies regarding smart city development, many studies on the positioning of cultural heritage in smart cities reveal fragmented approaches. Given that the process of protection and renewal of architectural heritage consists of several steps defined as determining a set of attributes that affect the construction and renewal of the human environment; collecting and analyzing information, modeling decisions, and selecting solutions to advance the state of the natural and built environment, applying effective decision-making in heritage reconstruction and protection with the support of multiple attribute assessment seems to be of great help [33]. In recent decades, there has been rapid development and popularity of methods of MCDM—multi-criteria decision-making and their application in various fields of scientific research. MCDM is increasingly used in cases where it is desirable to restructure a multi-criteria problem and break it down into separate subunits or when it is necessary to select the most optimal choice of an alternative. MCDM provides a formal framework for modeling multidimensional decision-making problems, especially those that require systems analysis, including analysis of decision complexity, the relevance of consequences, and the need for accountability of decisions made.

Regarding architectural heritage, many papers deal with abandoned historical, cultural, industrial, military, and other types of buildings and the problem of their redevelopment possibilities through reuse into new contents and purposes. In that sense, MCDM techniques rank previously defined redevelopment alternatives to choose the most sustainable and most optimal option [34]. Decision-making methodologies related to architectural heritage and the reuse of historic buildings are investigated in [35,36]. In terms of choosing alternatives, some papers used AHP—analytical hierarchical process to select the most optimal new purpose in the process of restoration and revitalization of historic buildings [37,38], while others used AHP for the most suitable historical buildings for protection [39]. On the other hand, AHP is often used to prioritize relevant risk issues or indicators regarding possible interventions and implementation of constructive measures [40,41]. Talking about the smart city framework, some authors have recognized AHP as a suitable MCDM technique for ranking criteria to provide qualitative guidelines for the development of smart cities or to identify the crucial barriers for smart strategies implementation [42–45].

The paper examines the issue of architectural heritage management in smart cities to identify the most crucial indicators that are a priority to ensure sustainable protection, preservation, and maintenance of architectural buildings. The research refers to all constructed buildings that possess values of built heritage, where they are or not placed under the protection regime. The management of architectural heritage in smart cities is considered in the paper from the aspect of multi-criteria decision making, applying different approaches of the AHP in the process of ranking priority indicators. The aim is to compare the final order of indicators, previously defined by experts in the field of management and protection of architectural heritage and experts in smart city development for different methods. The task of the paper is to compare the fuzzy AHP (based on trapezoidal and triangular fuzzy numbers) with interval grey AHP (based on interval grey numbers) to identify, assess and single out priority indicators for the architectural heritage in the smart city.

The paper is structured into five sections. After a brief research introduction, a theoretical background regarding an overview of previous researches in the field of management of architectural heritage from the aspect of the smart city paradigm and multi-criteria decision-making is provided. Additionally, the second section determines indicators (criteria) within six different groups that affect sustainable management of architectural heritage. The third section presents the research methodology defining applied algorithms of the fuzzy and interval grey AHP methods, while the fourth section gives obtained rankings, comparing results from different algorithms. Conclusion remarks and future research goals are presented in the fifth section.

2. Theoretical Background

2.1. Architectural Heritage in Smart Cities: Defining Indicators for Sustainable Management

Many global problems and challenges, including an increased urban population, societal needs, political and economic change, and technological innovation, significantly impede the preservation of existing architectural heritage and identity. In addition to human, technological, organizational, and natural resources, architectural heritage represents an urban reflection of civilization development. Looking for new patterns for architectural heritage management, the concept of smart city has developed as a framework for the integration of sustainable solutions that could meet global challenges.

Architectural heritage determines the landscapes in urban areas, reflecting their past and shaping unique silhouettes and urban structures. As physical evidence of historical and cultural development, architectural heritage obtains various architectural facilities which often indicate specific principles of construction of the historical period, as well as forms and features of authentic styles and architectural movements. It represents evidence of the past, an urban resource of the present for the foundation of future activities. Managing architectural heritage can be a significant driver of social and economic development in urban areas. Given that architecture resources are part of the cultural pillar of sustainability [46], protecting, preserving, and managing architectural heritage is one segment of sustainable urban redevelopment. Management of architectural heritage encompasses a wide range of activities and measures covered by many pieces of research. Some of the scientific studies have been so far related to the different technical procedures regarding the refurbishment of existing construction of facilities [47,48] as well as various treatments for the restoration of aesthetic values of the buildings, archeological ruins, and historical monument in term of applied materials and plastics [49,50]. There are different types of principles for the preservation of architectural heritage. Many papers analyze the various aspects of revitalization, which in addition to the protection of original forms and materials, often involves the adaptive re-use of existing abandoned facilities and upgrading spatial capacities [51–53]. One group of authors dealt with vernacular architecture, examining traditional materials, traditional culture, patterns, and habits of construction [54,55]. A certain number of studies is dedicated to the formation of new cultural routes or inclusion of a facility in defined ones [56] while promoting facilities and culture through tourism development [57,58]. Some researchers have addressed the improvement of architectural heritage in terms of energy retrofitting [59,60]. In a large number of researches concerning the management of architectural heritage, the authors have dealt with concrete case studies of historically significant units, city centers, or buildings of cultural significance [61–63].

As sustainability is one of the crucial preconditions for the formation of smart cities, management of architectural heritage in smart environments include various urban operations and tools related to the main aspects of current spatial sustainable development strategies. All instruments for the management of architectural heritage can be classified through the system of appropriate groups of indicators refer to the conceivable aspects of the sustainability paradigm [64–66]—economic, environmental, social (three primary dimensions), institutional [67], and cultural [68,69] (included later), with the introduction of the technological framework that corresponds to smart development [70,71]. Given that architectural heritage is one type of cultural heritage and the focus of this paper, the cultural dimension of sustainable smart management is recognized as an architectural aspect of influencing factors. The economic aspect includes investment and its financial analysis in the restoration and management of architectural heritage as well as financial returns. For this research, they are divided into three sub-criteria groups—the rate of income, investment costs, and external funding support. The second dimension of sustainability, the social aspect, means the social influence on the architectural heritage perception as well as preferences towards its protection and preservation. The most significant social side is the creation of job opportunities for citizens through heritage management and heritage tourism development, which has become the crucial sector in the economic policies of many countries [72,73]. The environmental aspect concerns if existing architectural heritage harms the environment and pollution degree control during its restoration. In that sense, urban recycling has become part of sustainable urban redevelopment plans and, is closely related to adaptive reuse and conversion of different types of architectural heritage. It enhances the reduction in new material use in construction, direct influences the reduction of energy use, and decreases the emission of harmful gases [74]. The institutional aspect means management of architectural heritage at different levels of hierarchy, including various stakeholders, and legislative, legal, and planning frameworks for the implementation of management procedures. In that sense, the smart city concept often promotes community participation in decision making and the development of a participatory approach as support to urban governance [75]. Current architectural heritage management practice shows the importance of community involvement and shifts from a centralized governing process to a more holistic approach that meets the preferences of the residents [76,77]. The architectural indicators include the possibilities for the protection and restoration of existing architectural heritage facilities. They cover all specificities regarding the unique character of the building, its aesthetic significance, state of conservation, but also capacities regarding space, functional layout, and construction stability and durability.

With the development of the smart city, the notion of architectural heritage management is increasingly moving towards the application of innovative technologies in the process of its renewal, protection, and promotion. Technological aspect obtains mobile and internet communications that enabled the digital connection of architectural heritage with different actors and institutions. ICT allows the valorization of urban heritage resources of historical areas and architectural elements of built heritage. Using augmented reality (AR) is possible to examine the characteristics of architectural monuments that have long been demolished, destroyed, and whose ruins are hard to search the past and authentic construction processes [78,79]. ICTs have been integrated on various scales to improve the tourist experience of cultural and architectural heritage. With the heritage digitalization, it is possible to virtually walk through all known world museums and other public buildings, which proved to be extremely attractive, but also useful during the COVID pandemic when free walking is disabled or restricted. It also increases the awareness of citizens about architectural heritage and new opportunities for active participation at a distance, by expressing views within the survey, giving proposals for the reconstruction of buildings by participating in numerous international calls. The use of IoT platforms and services opens up opportunities for the application of smart cities in the architectural heritage sector [80,81]. Some of the techniques used to preserve the architectural heritage are GIS (geographic information system) platforms for the formation of different spatial databases related to updating analysis properties [82], digital photogrammetry techniques, BIM (building information modeling) software that enables the classification of built heritage through modeling systems facilities, automation of documents related to heritage management, application of materials and interventions, as well as numerous software and methods for diagnosing the state of structures and detecting problems.

Denotation and description of the main groups of criteria and corresponding subcriteria have represented in Table 1. The table points to the most significant researches which examines different perspectives of architectural heritage management, from which the classification criteria system has arisen.

Table 1. The overview of adopted indicators for the management of architectural heritage.

Criteria Group	Sub-Criteria	Description of Sub-Criteria
Institutional (A)	A_1—Legislative framework	Adoption and implementation of strategies, urban and spatial plans, laws and regulations, recommendations and guidelines, and other relevant national and local documents regarding protection and preservation of architectural heritage and their harmonization with international standards;
	A_2—Public-private stakeholder partnership	Collaboration and cooperation between stakeholders at different hierarchical levels [83,84] including local authorities, institutions for heritage protection, non-government organizations, ministries, private investors, scientific bodies, cultural institutions, universities, architects and urban planners, etc. while creating interactions patterns;
	A_3—Heritage database	Documenting of architectural heritage and creating unique national databases on heritage, accessible to the public, in written and digitalized forms of information and documents;
	A_4—Public participation	Support of local communities in terms of making opportunities for citizens active participation in heritage management strategies to express their knowledge and experience [76,85] through volunteer programs and different workshops
Economic (B)	B_1—The rate of income	Providing growth in the annual income generated for municipality and city [86], especially from the heritage tourism sector and its activities;
	B_2—Investment costs	Includes investment costs on heritage restoration process during the field studies, state analysis, development and realization of reconstruction and refurbishment as well as investments costs on heritage promotion in terms of organization of the workshops, exhibitions, marketing, tourism offers, etc. [28];
	B_3—External funding	External funding support [86] for the architecture heritage promotion, protection, and preservation from foreign direct investments, private investors, and individual donation
Social (C)	C_1—Local employment	Making job opportunities for the residents through activation of the heritage tourism sector and employment within heritage redevelopment programs;
	C_2—Education on heritage	Spreading knowledge on architectural heritage through education and promotion programs while connecting citizens and visitors (tourists) with the importance and values of historical monuments and sites [87];
	C_3—Cultural identity	Creating a sense of place and collective memory as the urban identity of the local community [88]
Environmental (D)	D_1—Urban recycling	Includes adaptive reuse and revitalization of the architectural heritage while preserving urban landscapes [51–53,89];
	D_2—Pollution degree	Degree of environmental pollution that comes with the abandoned architectural heritage (industrial, military, etc.) and endangers the environment as well as the amount of waste generated during the restoration process [28];
	D_3—Green energy support	Implementation of renewable energy sources [90] and energy-efficiency tools during the restoration and refurbishment of architectural heritage [59,60]

Table 1. *Cont.*

Criteria Group	Sub-Criteria	Description of Sub-Criteria
Technological (E)	E_1—Mapping and documenting	Use of advanced technologies as GIS and BIM systems for urban mapping of architectural heritage and its classification through modeling systems as a precondition for making local and national database on heritage [82,91];
	E_2—Heritage digitalization	Development of infrastructure for continuous interoperable digitalization of architectural heritage and networking [92];
	E_3—A virtual presentation	Use of various applications, platforms, and other multimedia solutions for education, as well as part of heritage tourism experience, often using AR concept [78,79,93];
	E_4—Diagnosis, and monitoring	Implementation of smart applications for architectural heritage diagnosis [94] in terms of structural integrity and degree of preservation, stability, and safety of facility as well as smart monitoring of the effects of interventions and its conservation state, often using photogrammetry tools
Architectural (F)	F_1—Existing state	Includes structural integrity, degree of material and construction conservation, facade plastic conservation, and previous interventions;
	F_2—Spatial reuse	The ability of internal layout, spatial capacities, and infrastructure of abandoned architectural heritage for the new purpose;
	F_3—Lifespan	Duration of the building after restoration [28];
	F_4—Architectural integrity	Includes authenticity, originality, rarity, and architectural-compositional values of the heritage and its regime of protection;
	F_5—Refurbishment works	The scope and the character of rehabilitation and restoration construction works [28]

2.2. MCDM and Architectural Heritage Management

In the last few decades, the application of MCDM methods has increased, as well as the number of techniques for evaluating alternatives and selecting the best of them. Multi-criteria decision making is widely used in solving many of today's problems. These methods can divide into two categories: The ordinal, in which the information about criteria has a qualitative nature and require decision-makers to assign grades to each alternative, and the cardinal, where information on choices is quantitative and can be used directly in the decision-making process [95]. The MCDM is an efficient method used to address complex choice issues, including multiple criteria and options, especially for qualitative variables. Recent literature notes many typical applications of different MCDM methods. The MCDM method quantifies qualitative criteria and helps decision-makers have a robust and more accurate basis on which to make decisions. The growing complexity of the decision-making context and the ever-present uncertainty about the consequences of the decision-making process have conditioned the appropriate changes in the observation, modeling, and solving real problems. Models become multi-complex in the mathematical sense, and to overcome this for some categories are developed and formalized methods of solving problems. Scientists agreed that the ranks of the alternatives differ when various MCDM methods are used for their determination [96]. Decision-making in complex problems, including business and real-life decisions, implies an appropriate and relevant decision support system. Everyday problems include multiple data sets, some of them are accurate or objective, while others are uncertain or subjective. The theory of fuzzy sets laid the foundation for significant modeling uncertainty, imprecision, and vagueness.

The methodology of fuzzy sets has made significant progress in both theoretical and practical studies.

Decision-making in the field of cultural heritage is facilitated by applying multi-criteria decision-making. For example, Turkis et al. discuss the significance and nature of cultural heritage and the existing methods for its valuation from the perspective of sustainable development in cities [97]. As new methods and numerous modifications of existing ones are continuously developing that include various techniques and mathematical tools, MCDM is a universal means of support in decision-making processes in urban planning, construction, and architecture [98–100].

In the field of architectural heritage with application MCDM, a review of the literature was presented by Morkūnaitė et al. [101]. Special attention is pay to the consideration of various indicators related to selected social, economic, spatial, cultural, ecological, and historical-architectural aspects in the secondary use of historic buildings [33]. In the process of carrying out construction works or building maintenance works, questions of evaluation of alternatives using even contradictory criteria regularly arise. Restoration and preservation of architectural buildings as being a part of cultural and historical heritage, adapting them to contemporary demands require a large-scale effort reflecting economic significance and developing the city, making a smart city more recommendable, appealing, and imposing. There is a considerable number of papers dealing with MCDM in architecture and civil engineering, among which papers Zavadskas et al. [102–105] stand out.

The decision-maker often faces many challenges of MCDM in the process of solving the accurate response selection problem for planning in the field of construction or architectural management, when sustainable environment requirements are crucial [106,107]. The MCDM is applied in various fields and disciplines. These methods can solve the issues related to decision-making for a particular everyday problem with several conflicting criteria. Some of the recently developed researches have raised the issue of selecting appropriate methods and attempt to perform benchmarking of various MCDM approaches. For this purpose, it is necessary to single out a set of feasible methods that should support the decision-makers to find the best solution following the given. In addition to different individual approaches and modifications, the whole MCDM schools have been developed.

Methods developed within American schools have based on a functional approach. They use two types of relationships between alternatives—indifference and preference while excluding the incompatibility of variances. The most used methods from this group are AHP—Analytical Hierarchy Process, introduced by Saaty [108,109], ANP—Analytical Network Process [110], UTA—Utility Theory Additive [111], TOPSIS—a Technique for Order Preference by Similarity to the Ideal Solution [112–114], SMART—Simple Multi-Attribute Rating Technique [115]. The American school is also recognizable by VIKOR—VIseKriterijumska Optimizacija i kompromisno Resenje [116] and COPRAS—The COmplex PRoportional ASsessment [117] methods. Nevertheless, as the main disadvantage, the American school methods do not take into account the variability and uncertainty of expert opinion. This shortcoming can be overcome using European school methods based on a relational model. Namely, they use the outranking relation in the preference aggregation process. ELECTRE—ELimination Et Choice Translating REality [118,119] and PROMETHEE—Preference Ranking Organization METHod for Enrichment of Evaluations [120] belong to the European school. A mixed approach to decision-making, which combines elements of the American and European schools, is advocated by members of the third group of researchers [121–123]. This approach gives methods from the PCCA group—Pairwise Criterion Comparison Approach which it belongs IDRA—Intercriteria Decision Rule Approach. The most used method from the IDRA group is COMET—Characteristic Object METhod [124] uses fuzzy sets theory, and the DRSA—Dominance-based Rough Set Approach method [125,126] uses the rough set theory. The COMET is useful in problem-solving because it allows the decision-maker to organize the structure of the problem, and analyze, compare, and rank alternatives when the complexity of the algorithm is entirely independent of the number of alternatives.

In their research, Salabun et al. pointed out that when choosing the MCDM method, it is significant to take care of the selected method and the method of normalization. Nearly any combination of methods and their parameters can bring different results that they confirmed by comparing TOPSIS, VIKOR, COPRAS, and PROMETHEE II methods [127].

When solving a particular decision-making problem [128], it is difficult to determine which method is the most appropriate to use. Most of the authors agree there is no perfect method suitable for application in different decision-making fields [129]. When various MCDM methods give contradictory results, the correctness of the method choice arises [130,131]. If the selection is made following the decision-makers' priority, a satisfactory answer can be obtained [132]. On the other side, many MCDM methods meet the formal requirements of a particular decision-making problem and can be chosen regardless of the problem specificity [133]. Various approaches can provide different solutions to the same problem [134]. Differences in results, originating from various calculation methodologies, can be influenced by several factors, and the assessment of the accuracy and reliability of the results is current in many pieces of research. Some of the authors deal with the assessment benchmarking of MCDM comparison of methods, Zanakis et al. [128], Chang et al. [125].

Apart from deterministic, stochastic methods are used in the process of optimization in decision making. Deterministic methods use mathematical formulas, and unlike them, stochastic methods use random processes [135]. The stochasticity of the criteria is considered using stochastic dominance, perspective theory, and regret theory.

The lack of MCDM methods of the American school to disregard data uncertainty can be remedied using granular mathematics, for example, fuzzy sets theory or interval mathematics [136]. In this paper, improvements in American school AHP methods regarding the failure to take into account the uncertainty of expert opinion by introducing granular mathematics, specifically by applying fuzzy AHP methods with triangular and trapezoidal membership function and applying interval grey methods, are considered.

The process of selecting new uses for buildings needs to consider several criteria to preserve its value. Ranking of the alternatives, recognized by a different type of purpose for future use, is done according to defined criteria related to spatial capacities of the existing building(s), their historical and architectural values, protection regime, urban context, and different external social and economic factors. Sometimes the value of heritage buildings is examined to determine the level of protection to be implemented [137]. Further, MCDM is used in combination with other methodological tools such as BIM—Building Information Modeling, and GIS—Geographic Information System [138,139]. In some papers, one can see the concept of integrated analysis of the built and renewed human environment as a whole, as well as multiple criteria assessment of alternatives to the projects of restoration of heritage with SAW—Simple Additive Weighting, TOPSIS, COPRAS, and ARAS—Additive Ratio ASsessment [140].

3. Materials and Methods

It seems that there is a gap between the integration of comprehensive smart city solutions and applications for the preservation and promotion of architectural heritage. Research at the intersection of smart cities and architectural heritage could be more useful if it focuses on different types of cases and methods. This paper is an attempt to approach the research with several methods.

AHP (fuzzy or interval approach) is suitable for MCDM problems where it is not possible to accurately quantify the impact of criteria on decision problems. The introduction and implementation of AHP are to minimize the subjective factors that prevail in the decision-making process and increase the transparency of the prioritization process.

3.1. Trapezoidal and Triangular Fuzzy Numbers

A fuzzy number is a fuzzy set $F = \{(x, \mu_F(x)), x \in R\}$, where $x \in R$, and $\mu_F(x)$: $R \to [0,1]$ is a continuous function. In this paper, trapezoidal and triangular fuzzy numbers are used.

A trapezoidal fuzzy number can be denoted as $\bar{a} = \left(l, m^l, m^u, u\right)$ and the membership function is [141].

$$\mu_F(x) = \begin{cases} \frac{x-l}{m^l-l}, & x \in \left(l, m^l\right) \\ 1, & x \in \left(m^l, m^u\right) \\ \frac{u-x}{u-m^u}, & x \in (m^u, u) \\ 0, & otherwise. \end{cases} \tag{1}$$

For an arbitrary two trapezoidal fuzzy numbers $\bar{a}_1 = \left(l_1, m_1^l, m_1^u, u_1\right)$ and $\bar{a}_2 = \left(l_2, m_2^l, m_2^u, u_2\right)$ addition, subtraction, multiplication, and division are defined in Table 2 [142].

Table 2. Arithmetical operations for trapezoidal (left) and triangular fuzzy numbers (right).

$\bar{a}_1 \oplus \bar{a}_2 = \left(l_1 + l_2, m_1^l + m_2^l, m_1^u + m_2^u, u_1 + u_2\right)$	$\tilde{a}_1 \oplus \tilde{a}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$
$\bar{a}_1 \ominus \bar{a}_2 = \left(l_1 - u_2, m_1^l - m_2^u, m_1^u - m_2^l, u_1 - l_2\right)$	$\tilde{a}_1 \ominus \tilde{a}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2)$
$\bar{a}_1 \odot \bar{a}_2 = \left(l_1 \cdot l_2, m_1^l \cdot m_2^l, m_1^u \cdot m_2^u, u_1 \cdot u_2\right)$	$\tilde{a}_1 \odot \tilde{a}_2 = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2)$
$\bar{a}_1 \oslash \bar{a}_2 = \left(l_1 / u_2, m_1^l / m_2^u, m_1^u / m_2^l, u_1 / l_2\right)$	$\tilde{a}_1 \oslash \tilde{a}_2 = (l_1 / u_2, m_1 / m_2, u_1 / l_2)$
$k\bar{a}_1 = \left(kl_1, km_1^l, km_1^u, ku_1\right)$	$k\tilde{a}_1 = (kl_1, km_1, ku_1)$

In the case when $m^l = m^u = m$ trapezoidal fuzzy number becomes triangular one $\tilde{a} = (l, m, u)$. The corresponding membership function is now

$$\mu_F(x) = \begin{cases} \frac{x-l}{m-l}, & x \in \{l, m\} \\ \frac{u-x}{u-m}, & x \in \{m, u\} \\ 0, & otherwise. \end{cases} \tag{2}$$

The corresponding arithmetical operations for two triangular fuzzy numbers $\tilde{a}_1 = (l_1, m_1, u_1)$ and $\tilde{a}_2 = (l_2, m_2, u_2)$ and $k \in R$ are also present in Table 2.

3.2. Trapezoidal and Triangular Fuzzy AHP Algorithm

Analytical hierarchical process, as a methodology of multi-criteria decision-making, since its inception, has experienced resounding development in theoretical and practical terms. The fuzzy AHP method is an extension of the crisp AHP method, where estimates are presented with fuzzy values [143]. Many researchers express a lot of methods and applications of the fuzzy AHP method [144–146]. These methods are used to find the preference weightings of indicators by subjective assessment [147,148]. Trapezoidal fuzzy AHP has multiple application possibilities [149]. The meaning of triangular and trapezoidal fuzzy numbers is given in Table 3.

Table 3. The meaning of trapezoidal and triangular fuzzy numbers according to Saaty's scale.

Meaning of Fuzzy Numbers	Trapezoidal Fuzzy Numbers	Inverse Trapezoidal Fuzzy Numbers	Triangular Fuzzy Numbers	Inverse Triangular Fuzzy Numbers
Equal importance	(1, 1, 1, 2)	(1/2, 1, 1, 1)	(1, 1, 3)	(1/3, 1, 1)
Intermediate values	(1, 1, 3, 4)	(1/4, 1/3, 1, 1)	(1, 2, 3)	(1/3, 1/2, 1)
Weak dominance	(1, 2, 4, 5)	(1/5, 1/4, 1/2, 1)	(1, 3, 5)	(1/5, 1/3, 1)
Intermediate values	(2, 3, 5, 6)	(1/6, 1/5, 1/3, 1/2)	(3, 4, 5)	(1/5, 1/4, 1/3)
Strong dominance	(3, 4, 6, 7)	(1/7, 1/6, 1/4, 1/3)	(3, 5, 7)	(1/7, 1/5, 1/3)
Intermediate values	(4, 5, 7, 8)	(1/8, 1/7, 1/5, 1/4)	(5, 6, 7)	(1/7, 1/6, 1/5)
Demonstrated domination	(5, 6, 8, 9)	(1/9, 1/8, 1/6, 1/5)	(5, 7, 9)	(1/9, 1/7, 1/5)
Intermediate values	(6, 7, 9, 9)	(1/9, 1/9, 1/7, 1/6)	(7, 8, 9)	(1/9, 1/8, 1/7)
Absolute domination	(8, 9, 9, 9)	(1/9, 1/9, 1/9, 1/8)	(7, 9, 9)	(1/9, 1/9, 1/7)

3.2.1. Trapezoidal Fuzzy AHP Algorithm

Step 1. Defining the goal.

Step 2. Formation of a hierarchical structure of criteria and sub-criteria.

Step 3. Construction of a comparison matrix $\overline{A} = \left(\overline{a}_{ij}\right)_{n\times \mathrm{n}}$ with trapezoidal fuzzy numbers, where $\overline{a}_{ij}$ is the fuzzy number that represents the relative importance of one indicator to another. The fuzzy number $\overline{a}_{ij} = (1,\ 1,\ 1,\ 1)$, if $i = j$ and $\overline{a}_{ij} = 1/\overline{a}_{ji}$ for $i \neq j$.

Step 4. Calculation values $CI = \frac{(\lambda_{max} - n)}{(n-1)}$, and $CR = CI/RI$ of the crisp matrix $A = \left(a_{ij}\right)_{n\times \mathrm{n}}$, where $a_{ij} = \left(m_{ij}^{l} + m_{ij}^{u}\right)/2$, λ_{max} is the maximum eigenvalue of a matrix A and RI is a random index. The consistency of the comparison matrix $\overline{A}$ is conditioned by the consistency of the crisp matrix A ($CR < 0.1$) [150].

Step 5. The trapezoidal fuzzy weighting vectors for the comparison matrix $\overline{A}$ are evaluated using the geometric mean technique

$$\overline{M}_i = \left(\prod_{j=1}^{n} \overline{a}_{ij}\right)^{\frac{1}{n}},\ \ i = 1,\ 2, \ldots, n. \tag{3}$$

Based on these values, by normalization, we obtain normalized trapezoidal fuzzy weighting vectors

$$\overline{M}_i^{*} = \overline{M}_i / \sum_{i=1}^{n} \sum_{j=1}^{n} \overline{a}_{ij},\ \ i = 1,\ 2, \ldots, n. \tag{4}$$

Step 6. For the obtained normalized trapezoidal fuzzy weighting vectors $\overline{M}_i^{*} = \left(l_i, m_i^{l}, m_i^{u}, u_i\right)$, $i = 1, \ldots, n$, the total integral value has calculated as follows [151]:

$$w_i^{\lambda} = I_T^{\lambda}\left(\overline{M}_i^{*}\right) = 0.5\left(\lambda\left(m_i^{u} + u_i\right) + (1-\lambda)\left(l_i + m_i^{l}\right)\right),\ \ \lambda \in [0,\ 1]. \tag{5}$$

The number λ is an optimism index. The higher values represent the smaller degree of risk. To present the pessimistic, moderate, and optimistic views, we have used values 0, 0.5, and 1, respectively.

Step 7. The ranking of sub-criteria is obtained by sorting the final weights calculated by multiplying the corresponding weights of the criteria and sub-criteria.

3.2.2. Triangular Fuzzy AHP Algorithm

If in the trapezoidal fuzzy number $\overline{a} = \left(l, m^{l}, m^{u}, u\right)$ holds equality $m^{l} = m^{u} = m$, then the trapezoidal fuzzy number becomes a triangular fuzzy number $\widetilde{a} = (l, m, u)$. In the corresponding algorithm, all calculations are performed with a triangular fuzzy number instead of a trapezoidal one. The steps in the algorithm are the same as in the trapezoidal case except for some differences.

Step 1 and Step 2 are the same as in the algorithm in Section 3.2.1.

Step 3. Using triangular fuzzy numbers, a comparison matrix, similar to in the trapezoidal method, has formed.

Step 4. In the crisp matrix $A = (a_{ij})_{n\times n}$, $a_{ij} = m_{ij}$.

Step 5. Is similar to the algorithm in Section 3.2.1.

Step 6. The total integral value of the obtained normalized triangular fuzzy weighting vectors $\widetilde{M}_i^* = (l_i, m_i, u_i)$, $i = 1, \ldots, n$ is calculated by the formula

$$w_i^\lambda = I_T^\lambda\left(\widetilde{M}_i^*\right) = 0.5(\lambda u_i + m_i + (1 - \lambda)l_i),\ \ \lambda \in [0,\ 1]. \tag{6}$$

Step 7. is the same as in the algorithm in Section 3.2.1.

3.3. Interval Grey Numbers

To overcome the disparity between the natural and social sciences, as well as the incompleteness and uncertainty of amiss information, Deng introduced an effective mathematical method, the Grey system theory [152,153], applying partially known data and supporting decision-makers. Nowadays, this theory is widespread and is applied in many disciplines: economics, management, industry, military issues, environment, agriculture [154,155].

An interval grey number $x_\otimes$ is a number that belongs to the interval [156]:

$$x_\otimes = \left[x^l, x^u\right] = \left\{x \middle| x^l \le x \le x^u\right\}. \tag{7}$$

For such numbers, one can define the degree of greyness by the value $x^u - x^l$. When the degree of greyness tends to infinity, interval grey numbers become interval black numbers. In the opposite case, when the degree of greyness tends to zero (when $x^l = x^u$), the interval grey number becomes a crisp number. More about the interval grey number is present in the papers [157–159].

Let $a_\otimes = \left[a^l, a^u\right]$ and $b_\otimes = \left[b^l, b^u\right]$ be two interval grey numbers and $k \in R$. Then the basic operations of interval grey numbers $a_\otimes$ and $b_\otimes$ are defined as follows (Table 4).

Table 4. Arithmetical operations for interval grey numbers.

$a_\otimes \oplus b_\otimes = \left[a^l + b^l,\ a^u + b^u\right]$
$a_\otimes \ominus b_\otimes = \left[a^l - b^u,\ a^u - b^l\right]$
$a_\otimes \odot b_\otimes = \left[a^l b^l,\ a^u b^u\right]$
$a_\otimes \oslash b_\otimes = \left[a^l / b^u,\ a^u / b^l\right]$
$ka_\otimes = \left[ka^l, ka^u\right]$

An overview of some interval mathematics algorithms is in papers [160–162].

3.4. Interval Grey AHP Algorithm

The interval grey matrices for pairwise comparisons, with numerical intervals, in the AHP method are used to overcome the uncertainty that arises from the degree of subjectivity [163].

Step 1 and Step 2 are the same as in algorithms in Section 3.2.

Step 3. An interval grey pairwise comparison matrix is constructed.

$$A_\otimes = \begin{bmatrix} 1 & [a_{12}, b_{12}] & \cdots & [a_{1n}, b_{1n}] \\ [a_{21}, b_{21}] & 1 & \cdots & [a_{2n}, b_{2n}] \\ \vdots & \vdots & \ddots & \vdots \\ [a_{n1}, b_{n1}] & [a_{n2}, b_{n2}] & \cdots & 1 \end{bmatrix}. \tag{8}$$

In the matrix $A_{\otimes}$ for all $i, j = 1, 2, \ldots, n$, inequalities $a_{ij} \leq b_{ij}$, $a_{ij} \geq 0$, $b_{ij} \geq 0$, $a_{ij} = 1/\ b_{ij}$ and $b_{ij} = 1/\ a_{ji}$ hold, and the matrix $A_{\otimes}$ is a reciprocal.

Step 4. Matrices $P = (p_{ij})_{n\times n}$, $Q = (q_{ij})_{n\times n}$ and $R = (r_{ij})_{n\times n}$ are constructed, based on the matrix $A_{\otimes}$:

$$p_{ij} = \begin{cases} b_{ij}, & i < j \\ 1, & i = j \\ a_{ij}, & i > j \end{cases}, \quad q_{ij} = \begin{cases} a_{ij}, & i < j \\ 1, & i = j \\ b_{ij}, & i > j \end{cases}, \quad r_{ij} = p_{ij}^{\alpha} q_{ij}^{1-\alpha},\ i, j = 1, 2, \ldots, n, \tag{9}$$

where $0 \leq \alpha \leq 1$.

The consistency of non-interval matrices P and Q $(CR < 0.1)$ provide the consistency of the interval matrix $A_{\otimes}$.

Step 5. Using the method of the convex combination one can obtain the interval weights of an interval grey matrix $A_{\otimes}$. Let $w(R)$ be a weighting vector of a matrix R, where $w_i(R) = \left(\prod_{j=1}^{n} r_{ij}\right)^{1/n}$, for all $i = 1, 2, \ldots, n$ and all $0 \leq \alpha \leq 1$.

If $\prod_{i=1}^{n} w_i = 1$, then

$$w_i(R) = \left(\prod_{j=1}^{n} r_{ij}\right)^{\frac{1}{n}} = \left(\prod_{j=1}^{n} p_{ij}{}^{\alpha} q_{ij}{}^{1-\alpha}\right)^{\frac{1}{n}} = w_i{}^{\alpha}(P) w_i{}^{1-\alpha}(Q). \tag{10}$$

Weighting vectors for matrices P and Q are $w(P)$ and $w(Q)$, respectively. Using the weighting vector w of the matrix R interval weight $w(A_{\otimes})$ for a matrix $A_{\otimes}$ is

$$w_i(A_{\otimes}) = [\min\{w_i(R)|\alpha \in [0,\ 1]\}, \max\{w_i(R)|\alpha \in [0,\ 1]\}] = [\min\{w_i(P), w_i(Q)\}, \max\{w_i(P), w_i(Q)\}]. \tag{11}$$

Step 6. The probability that one interval weight is bigger than the other is calculated [164]. Interval weight $w_i = [w_i^L, w_i^U]$ is bigger than the interval weight $w_j = \left[w_j^L, w_j^U\right]$ if

$$P(w_i \geq w_j) > P(w_j \geq w_i), \tag{12}$$

with probability

$$p_{ij}^{*} = P(w_i \geq w_j) = \frac{max\left(0, w_i^U - w_j^L\right) - max\left(0, w_i^L - w_j^U\right)}{(w_i^U - w_i^L) + (w_j^U - w_j^L)}, \tag{13}$$

for all $i, j = 1, 2, \ldots, n$, $i \neq j$. When $w_i = w_j$, then $p_{ij}^{*} = 0.5$. Specially $p_{ii}^{*} = 0.5$, for all $i = 1, \ldots, n$. Using probabilities from (13) for all intervals, one can form a probability matrix of preferences $P_p^{*} = \left(p_{ij}^{*}\right)_{n\times n}$.

Step 7. The final rank is obtained by the row-column elimination method applied to the probability matrix P_p^{*} [165].

These algorithms are schematically presented uniquely in Figure 1.

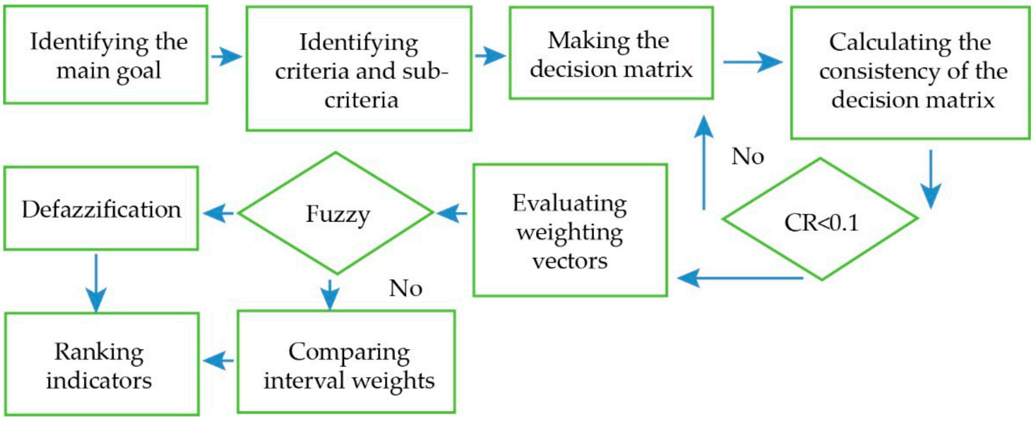

Figure 1. Block diagram of algorithms.

4. Results and Discussion

In this section, the algorithms outlined in Sections 3.2 and 3.4 have been applied. The pairwise comparison matrices are made respecting the opinions of the experts. The appropriate fuzzy comparison matrices are created using the meaning in Table 3.

For adopted criteria and sub-criteria, defined in Section 2.1, the problem hierarchy is formed. The matrix of criteria comparison, given by experts, is in Table 5. According to the obtained value $CR < 0.1$, it can be concluded that the comparison matrix is consistent.

Table 5. Fuzzy comparison matrix and weights for the criteria in the trapezoidal fuzzy AHP method (CI = 0.024, CR = 0.019).

	A	**F**	**B**	**E**	**D**	**C**	w^1	$w^{0.5}$	w^0
A	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	(3, 4, 6, 7)	(4, 5, 7, 8)	0.348	0.354	0.384
F	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	(3, 4, 6, 7)	0.248	0.247	0.243
B	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	0.173	0.170	0.154
E	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.113	0.110	0.099
D	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.071	0.071	0.068
C	$(\frac{1}{8}, \frac{1}{7}, \frac{1}{5}, \frac{1}{4})$	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.045	0.045	0.048

Pairwise comparison matrices of main criteria and sub-criteria in the fuzzy trapezoidal AHP method are given in Tables 5–11, and the final ranking of the indicators has done in Table 12.

Table 6. Fuzzy comparison matrix and weights for the sub-criteria A in the trapezoidal fuzzy AHP method (CI = 0.017, CR = 0.018).

	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_4}$	$\mathbf{A_3}$	w^1	$w^{0.5}$	w^0
A_1	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(3, 4, 6, 7)	0.443	0.446	0.460
A_2	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(2, 3, 5, 6)	0.291	0.289	0.281
A_4	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 2, 4, 5)	0.188	0.185	0.171
A_3	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	(1, 1, 1, 1)	0.076	0.078	0.086

Table 7. Fuzzy comparison matrix and weights for the sub-criteria B in the trapezoidal fuzzy AHP method (CI = 0.004, CR = 0.007).

	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$	w^1	$w^{0.5}$	w^0
B_1	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.509	0.510	0.516
B_2	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.307	0.306	0.300
B_3	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.183	0.183	0.183

Table 8. Fuzzy comparison matrix and weights for the sub-criteria C in the trapezoidal fuzzy AHP method (CI = 0.004, CR = 0.007).

	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_1}$	w^1	$w^{0.5}$	w^0
C_2	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.509	0.510	0.516
C_3	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.307	0.306	0.300
C_1	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.183	0.183	0.183

Table 9. Fuzzy comparison matrix and weights for the sub-criteria D in the trapezoidal fuzzy AHP method (CI = 0.004, CR = 0.007).

	$\mathbf{D_3}$	$\mathbf{D_2}$	$\mathbf{D_1}$	w^1	$w^{0.5}$	w^0
D_3	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.509	0.510	0.516
D_2	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.307	0.306	0.300
D_1	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.183	0.183	0.183

Table 10. Fuzzy comparison matrix and weights for the sub-criteria E in the trapezoidal fuzzy AHP method (CI = 0.010, CR = 0.011).

	$\mathbf{E_2}$	$\mathbf{E_1}$	$\mathbf{E_3}$	$\mathbf{E_4}$	w^1	$w^{0.5}$	w^0
E_2	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	0.432	0.436	0.457
E_1	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.281	0.279	0.266
E_3	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.179	0.177	0.166
E_4	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.105	0.106	0.109

Table 11. Fuzzy comparison matrix and weights for the sub-criteria F in the trapezoidal fuzzy AHP method (CI = 0.017, CR = 0.015).

	$\mathbf{F_4}$	$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{F_3}$	$\mathbf{F_5}$	w^1	$w^{0.5}$	w^0
F_4	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	(3, 4, 6, 7)	0.383	0.388	0.416
F_1	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	(2, 3, 5, 6)	0.263	0.261	0.253
F_2	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	(1, 2, 4, 5)	0.176	0.173	0.156
F_3	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	(1, 1, 3, 4)	0.109	0.108	0.102
F_5	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{6}, \frac{1}{5}, \frac{1}{3}, \frac{1}{2})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{2}, 1)$	$(\frac{1}{4}, \frac{1}{3}, 1, 1)$	(1, 1, 1, 1)	0.066	0.067	0.070

In Figure 2, we observe that the trapezoidal fuzzy AHP is stable. Namely, the first ten indicators have the same rank for all levels of optimism.

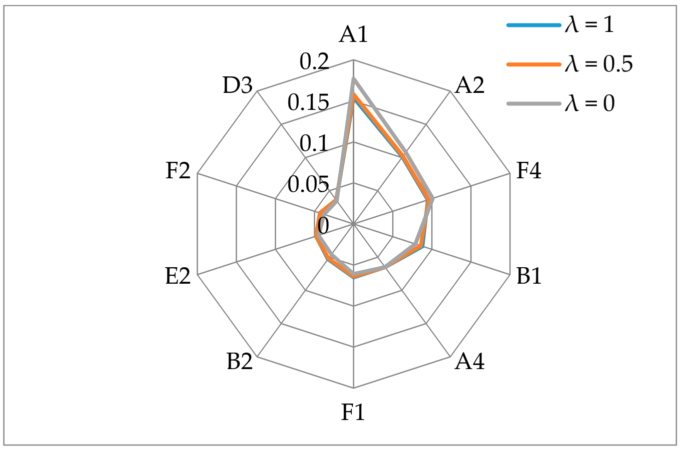

Figure 2. The final ranking of indicators by the trapezoidal fuzzy AHP.

Table 12. Ranking of indicators with final weights by the trapezoidal fuzzy AHP method.

	w^1		$w^{0.5}$		w^0
A_1	0.154	A_1	0.158	A_1	0.177
A_2	0.101	A_2	0.102	A_2	0.108
F_4	0.095	F_4	0.096	F_4	0.101
B_1	0.088	B_1	0.086	B_1	0.079
A_4	0.065	A_4	0.065	A_4	0.065
F_1	0.065	F_1	0.064	F_1	0.061
B_2	0.053	B_2	0.052	B_2	0.046
E_2	0.048	E_2	0.048	E_2	0.045
F_2	0.043	F_2	0.043	F_2	0.038
D_3	0.036	D_3	0.036	D_3	0.035
E_1	0.031	B_3	0.031	A_3	0.033
B_3	0.031	E_1	0.031	B_3	0.028
F_3	0.027	A_3	0.027	E_1	0.026
A_3	0.026	F_3	0.027	C_2	0.025
C_2	0.023	C_2	0.023	F_3	0.025
D_2	0.022	D_2	0.021	D_2	0.020
E_3	0.020	E_3	0.019	F_5	0.017
F_5	0.016	F_5	0.016	E_3	0.016
C_3	0.013	C_3	0.014	C_3	0.014
D_1	0.013	D_1	0.013	D_1	0.012
E_4	0.011	E_4	0.011	E_4	0.010
C_1	0.008	C_1	0.008	C_1	0.009

Pairwise comparison matrices of main criteria and sub-criteria in the triangular fuzzy AHP method are given in Tables 13–19, and the final ranking of the indicators is in Table 20. Sub-criteria are ranked using the triangular fuzzy AHP method with different index λ.

Table 13. Fuzzy comparison matrix and weights for the criteria in the triangular fuzzy AHP method (CI = 0.024, CR = 0.019).

	A	**F**	**B**	**E**	**D**	**C**	w^1	$w^{0.5}$	w^0
A	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	(3, 4, 5)	(3, 5, 7)	(5, 6, 7)	0.326	0.333	0.349
F	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	(3, 4, 5)	(3, 5, 7)	0.251	0.250	0.250
B	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	(3, 4, 5)	0.180	0.178	0.174
E	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	0.124	0.120	0.110
D	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	0.074	0.073	0.071
C	$(\frac{1}{7}, \frac{1}{6}, \frac{1}{5})$	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	0.043	0.043	0.043

Table 14. Fuzzy comparison matrix and weights for the sub-criteria A in the triangular fuzzy AHP method (CI = 0.017, CR = 0.018).

	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_4}$	$\mathbf{A_3}$	w^1	$w^{0.5}$	w^0
A_1	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	(3, 5, 7)	0.436	0.432	0.423
A_2	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	0.280	0.289	0.312
A_4	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 3, 5)	0.210	0.202	0.184
A_3	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	(1, 1, 1)	0.072	0.074	0.079

Table 15. Fuzzy comparison matrix and weights for the sub-criteria B in the triangular fuzzy AHP method (CI = 0.004, CR = 0.007).

	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$	w^1	$w^{0.5}$	w^0
B_1	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	0.529	0.521	0.502
B_2	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	0.298	0.303	0.317
B_3	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	0.172	0.174	0.179

Table 16. Fuzzy comparison matrix and weights for the sub-criteria C in the triangular fuzzy AHP method (CI = 0.004, CR = 0.007).

	C_2	C_3	C_1	w^1	$w^{0.5}$	w^0
C_2	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	0.529	0.521	0.502
C_3	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	0.298	0.303	0.317
C_1	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	0.172	0.174	0.179

Table 17. Fuzzy comparison matrix and weights for the sub-criteria D in the triangular fuzzy AHP method (CI = 0.004, CR = 0.007).

	D_3	D_2	D_1	w^1	$w^{0.5}$	w^0
D_3	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	0.529	0.521	0.502
D_2	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	0.298	0.303	0.317
D_1	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	0.172	0.174	0.179

Table 18. Fuzzy comparison matrix and weights for the sub-criteria E in the triangular fuzzy AHP method (CI = 0.010, CR = 0.011).

	E_2	E_1	E_3	E_4	w^1	$w^{0.5}$	w^0
E_2	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	(3, 4, 5)	0.427	0.432	0.444
E_1	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	(1, 3, 5)	0.297	0.291	0.276
E_3	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	(1, 2, 3)	0.177	0.176	0.175
E_4	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	(1, 1, 1)	0.097	0.099	0.102

When applying the triangular fuzzy AHP, we notice that there is a difference in the ranking for the second indicator for different degrees of optimism (Figure 3).

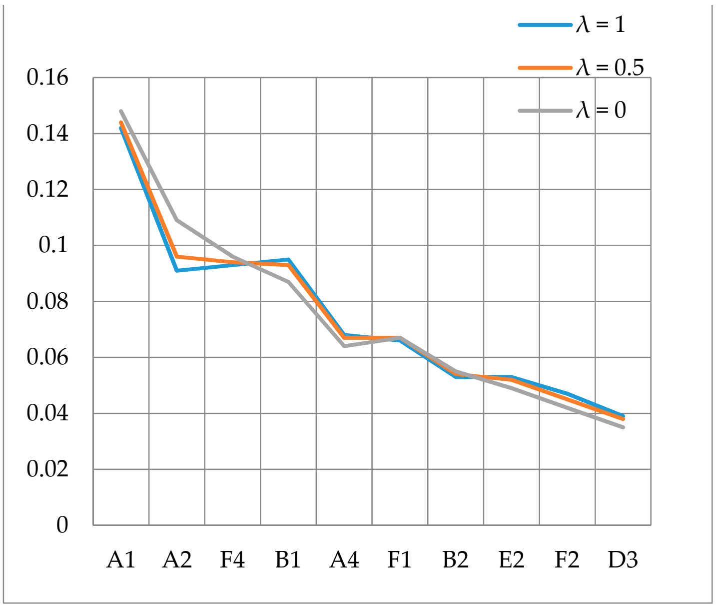

Figure 3. The final ranking of indicators by the triangular fuzzy AHP.

Table 19. Fuzzy comparison matrix and weights for the sub-criteria F in the triangular fuzzy AHP method (CI = 0.0170201, CR = 0.0151965).

	F_4	F_1	F_2	F_3	F_5	w^1	$w^{0.5}$	w^0
F_4	$(1, 1, 1)$	$(1, 2, 3)$	$(1, 3, 5)$	$(3, 4, 5)$	$(3, 5, 7)$	0.374	0.377	0.386
F_1	$(\frac{1}{3}, \frac{1}{2}, 1)$	$(1, 1, 1)$	$(1, 2, 3)$	$(1, 3, 5)$	$(3, 4, 5)$	0.265	0.267	0.270
F_2	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	$(1, 1, 1)$	$(1, 2, 3)$	$(1, 3, 5)$	0.188	0.182	0.168
F_3	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	$(1, 1, 1)$	$(1, 2, 3)$	0.109	0.109	0.108
F_5	$(\frac{1}{7}, \frac{1}{5}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{4}, \frac{1}{3})$	$(\frac{1}{5}, \frac{1}{3}, 1)$	$(\frac{1}{3}, \frac{1}{2}, 1)$	$(1, 1, 3)$	0.062	0.063	0.065

Table 20. Ranking of indicators with final weights by triangular fuzzy AHP method.

	w^1		$w^{0.5}$		w^0
A_1	0.142	A_1	0.144	A_1	0.148
B_1	0.095	A_2	0.096	A_2	0.109
F_4	0.093	F_4	0.094	F_4	0.096
A_2	0.091	B_1	0.093	B_1	0.087
A_4	0.068	A_4	0.067	F_1	0.067
F_1	0.066	F_1	0.067	A_4	0.064
B_2	0.053	B_2	0.054	B_2	0.055
E_2	0.053	E_2	0.052	E_2	0.049
F_2	0.047	F_2	0.045	F_2	0.042
D_3	0.039	D_3	0.038	D_3	0.035
E_1	0.037	E_1	0.035	B_3	0.031
B_3	0.031	B_3	0.031	E_1	0.030
F_3	0.027	F_3	0.027	A_3	0.027
A_3	0.023	A_3	0.024	F_3	0.027
C_2	0.022	C_2	0.022	D_2	0.022
E_3	0.022	D_2	0.022	C_2	0.022
D_2	0.022	E_3	0.021	E_3	0.019
F_5	0.015	F_5	0.015	F_5	0.016
C_3	0.012	C_3	0.013	C_3	0.013
D_1	0.012	D_1	0.012	D_1	0.012
E_4	0.012	E_4	0.012	E_4	0.011
C_1	0.007	C_1	0.007	C_1	0.007

The following results are obtained using the interval grey AHP method and they are presented in Tables 21–28. The interval matrix $A_{\otimes}$ proposed by experts, is consistent because the matrices P and Q are consistent.

Table 21. Interval comparison matrix and weights of criteria in the interval grey AHP method (CIQ = 0.014, CRQ = 0.011, CIP = 0.037, CRP = 0.029).

	A	F	B	E	D	C	w_c
A	$[1, 1]$	$[1, 2]$	$[3, 3]$	$[3, 4]$	$[4, 4]$	$[5, 5]$	$[2.372, 2.814]$
F	$\left[\frac{1}{2}, 1\right]$	$[1, 1]$	$[2, 3]$	$[3, 3]$	$[3, 4]$	$[4, 5]$	$[2.031, 2.116]$
B	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{2}\right]$	$[1, 1]$	$[1, 2]$	$[2, 2]$	$[3, 3]$	$[1.007, 1.047]$
E	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, 1\right]$	$[1, 1]$	$[1, 2]$	$[2, 3]$	$[0.776, 0.796]$
D	$\left[\frac{1}{4}, \frac{1}{4}\right]$	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, 1\right]$	$[1, 1]$	$[2, 2]$	$[0.660, 0.555]$
C	$\left[\frac{1}{5}, \frac{1}{5}\right]$	$\left[\frac{1}{5}, \frac{1}{4}\right]$	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	$[1, 1]$	$[0.401, 0.362]$

Table 22. Interval comparison matrix and weights of criteria A in the interval grey AHP method (CIQ = 0.010, CRQ = 0.011, CIP = 0.017, CRP = 0.018).

	$\mathbf{A_1}$	$\mathbf{A_2}$	$\mathbf{A_4}$	$\mathbf{A_3}$	w_{sc}
A_1	[1, 1]	[2, 2]	[3, 3]	[4, 5]	[2.215, 2.341]
A_2	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[2, 2]	[3, 4]	[1.314, 1.407]
A_4	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[2, 3]	[0.759, 0.841]
A_3	$\left[\frac{1}{5}, \frac{1}{4}\right]$	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{2}\right]$	[1, 1]	[0.452, 0.360]

Table 23. Interval comparison matrix and weights of criteria B in the interval grey AHP method (CIQ = 0, CRQ = 0, CIP = 0.004, CRP = 0.007).

	$\mathbf{B_1}$	$\mathbf{B_2}$	$\mathbf{B_3}$	w_{sc}
B_1	[1, 1]	[1, 2]	[2, 3]	[1.259, 1.817]
B_2	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[2, 2]	[1.259, 1]
B_3	$\left[\frac{1}{3}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[0.629, 0.550]

Table 24. Interval comparison matrix and weights of criteria C in the interval grey AHP method. (CIQ = 0.0046, CRQ = 0.007, CIP = 0.004, CRP = 0.007).

	$\mathbf{C_2}$	$\mathbf{C_3}$	$\mathbf{C_1}$	w_{sc}
C_2	[1, 1]	[2, 2]	[3, 3]	[1.817, 1.817]
C_3	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[2, 2]	[1, 1]
C_1	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[0.550, 0.550]

Table 25. Interval comparison matrix and weights of criteria D in the interval grey AHP method. (CIQ = 0.004, CRQ = 0.007, CIP = 0.004, CRP = 0.007).

	$\mathbf{D_3}$	$\mathbf{D_2}$	$\mathbf{D_1}$	w_{sc}
D_3	[1, 1]	[1, 2]	[2, 3]	[1.259, 1.817]
D_2	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[2, 2]	[1.259, 1]
D_1	$\left[\frac{1}{3}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[0.629, 0.550]

Table 26. Interval comparison matrix and weights of criteria E in the interval grey AHP method (CIQ = 0.0068734, CRQ = 0.00763711, CIP = 0.0068734, CRP = 0.00763711).

	$\mathbf{E_2}$	$\mathbf{E_1}$	$\mathbf{E_3}$	$\mathbf{E_4}$	w_{sc}
E_2	[1, 1]	[1, 2]	[3, 4]	[4, 4]	[1.863, 2.385]
E_1	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[3, 3]	[3, 4]	[1.729, 1.556]
E_3	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{3}\right]$	[1, 1]	[1, 2]	[0.576, 0.636]
E_4	$\left[\frac{1}{4}, \frac{1}{4}\right]$	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[0.537, 0.423]

Table 27. Interval comparison matrix and weights of criteria F in the interval grey AHP method (CIQ = 0.009, CRQ = 0.008, CIP = 0.008, CRP = 0.007).

	F_4	F_1	F_2	F_3	F_5	w_{sc}
F_4	[1, 1]	[1, 2]	[2, 2]	[3, 3]	[4, 4]	[1.901, 2.193]
F_1	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[1, 2]	[2, 3]	[3, 4]	[1.433, 1.653]
F_2	$\left[\frac{1}{2}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, 1\right]$	[1, 1]	[2, 2]	[3, 3]	[1.245, 1.075]
F_3	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{2}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[2, 2]	[0.695, 0640]
F_5	$\left[\frac{1}{4}, \frac{1}{4}\right]$	$\left[\frac{1}{4}, \frac{1}{3}\right]$	$\left[\frac{1}{3}, \frac{1}{3}\right]$	$\left[\frac{1}{2}, \frac{1}{2}\right]$	[1, 1]	[0.423, 0.400]

Table 28. Ranking of indicators with final interval weights in the interval grey AHP method.

	$w_c \odot w_{sc}$	p^*
A_1	[5.255, 6.588]	1
F_4	[3.862, 4.640]	0.992
A_2	[3.117, 3.962]	0.853
F_1	[2.911, 3.498]	1
F_2	[2.276, 2.529]	0.841
E_2	[1.877, 2.500]	0.659
A_4	[1.800, 2.367]	1
E_1	[1.630, 1.742]	1
F_3	[1.354, 1.413]	0.864
B_1	[0.978, 1.447]	0.859
A_3	[1.015, 1.073]	1
D_3	[0.832, 1.009]	0.669
B_2	[0.796, 0.978]	0.684
F_5	[0.847, 0.860]	1
D_2	[0.555, 0.832]	0.500
C_2	[0.658, 0.729]	0.993
E_3	[0.580, 0.667]	1
E_4	[0.443, 0.541]	0.790
B_3	[0.438, 0.489]	1
C_3	[0.362, 0.401]	0.688
D_1	[0.305, 0.416]	1
C_1	[0.199, 0.220]	

Comparing the finally ranked indicators using trapezoidal fuzzy AHP, triangular fuzzy AHP, and interval grey AHP, all applied methods favor as the most crucial factor the strategic and legislative framework for the management of the architectural heritage because it is a prerequisite for further activities and measures. For moderate views of decision-makers for both trapezoidal and triangular fuzzy AHP algorithms, the first ten indicators have the same rank. The key indicators are a public-private stakeholder partnership, architectural integrity, and the rate of economic income after the heritage restoration and activation. Further, the significant indicators are also the active public participation of the citizens in heritage management, the existing state of the architectural heritage, and investment costs on heritage restoration and heritage digitalization. In terms of optimistic and pessimistic attitudes, there are slight differences in ranking indicators using trapezoidal and triangular fuzzy AHP. According to the optimistic view, the triangular fuzzy AHP gives priority to economic aspects and economic profitability of investments in heritage renewal projects, while trapezoidal favors institutional indicators concerning factors related to the stakeholders' collaboration.

The ranking results for the interval grey AHP method besides the legislative framework for heritage management, favor the architectural integrity of architectural heritage, the existing state of the architectural heritage, public-private stakeholders collaboration, and the possibility for the adaptive reuse of existing spatial capacities. Besides, the application of interval grey AHP gives more attention to the development of infrastructure for continuous interoperable digitalization of architectural heritage and networking as one of the technological factors in smart cities.

The experts chose how to compare the criteria and sub-criteria. A group of experts in the field of architectural heritage management agreed on the interval approach. The fuzzy approach in the evaluation has been used by experts from various scientific fields dealing with Smart City in different sectors of urban areas. The differences in the final ranks between the interval grey AHP and the fuzzy AHP methods are a consequence of the various evaluations of experts. In the interval assessment, all values from the selected interval, by the expert, have the same weight, while in the fuzzy methods, the central values have a higher weight. Comparing the final results is noticed that the interval approach gives priority to indicators which, in addition to institutional, refer to the architectural aspect of heritage and its characteristics.

Ranked indicators in the interval grey AHP method are presented in Figure 4.

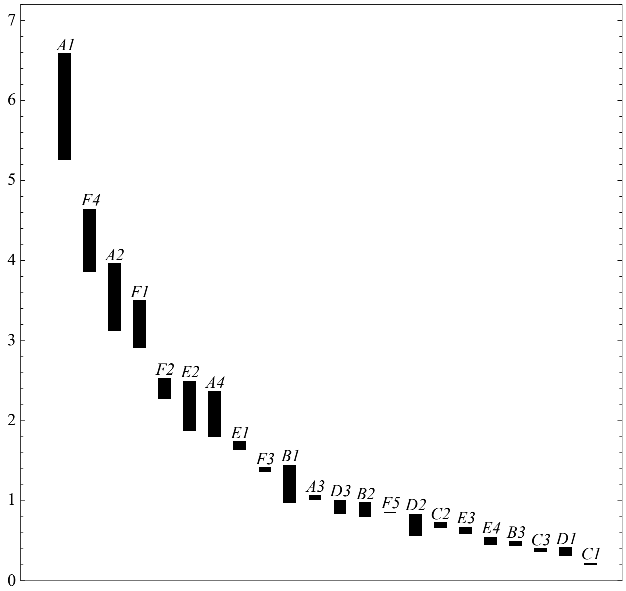

Figure 4. The final ranking of indicators by interval grey AHP.

In this paper, seven different rankings have been obtained. In assessing and analyzing ranking similarities, the authors most often use Spearman's rank correlation coefficient [166]

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}, \quad d_i = R_{x_i} - R_{y_i}, \tag{14}$$

but the application of different solving techniques can lead to inconsistencies even though the problem is the same. Salabun and Urbaniuk recently introduced a new *WS* coefficient suitable for comparing rankings in the field of decision making, where changes of the ranks on the top of ranking have more influence on coefficient [167]

$$WS = 1 - \sum_{i=1}^{n}\left(2^{-R_{x_i}} \frac{|R_{x_i} - R_{y_i}|}{\max\{|1 - R_{x_i}|, |n - R_{x_i}|\}}\right). \tag{15}$$

In Formulas (14) and (15), n represents the number of elements in the ranking, while R_{x_i} and R_{y_i} are ranks of the element i in rankings that are compared.

Using Formulas (14) and (15), the ranking obtained by trapezoidal and triangular fuzzy AHP algorithms for different coefficient values was first compared with each other λ. In the trapezoidal fuzzy AHP algorithm comparison rankings for $\lambda = 1$ and $\lambda = 0.5$ gives coefficients $r_s = 0.998$ and $WS = 0.999$, while the results in the case of comparing ranking for λ = 1 and λ = 0 are $r_s = 0.989$ and $WS = 0.999$. The corresponding coefficients for triangular fuzzy AHP algorithm are $r_s = 0.994$ and $WS = 0.968$, for λ = 1 and λ = 0.5 and $r_s = 0.989$ and $WS = 0.965$, for λ = 1 and λ = 0.

Second, the ranking obtained by trapezoidal and triangular fuzzy AHP algorithms for the same values of the coefficient λ was compared. For λ = 1 the coefficients are $r_s = 0.994$ and $WS = 0.968$, for λ = 0.5, $r_s = 0.998$ and $WS = 0.999$, while in the case when λ = 0, $r_s = 0.991$ and $WS = 0.997$. Finally, the interval grey AHP method was compared with the fuzzy AHP methods. For the trapezoidal fuzzy AHP coefficients are $r_s = 0.877$ and $WS = 0.950$, for λ = 1, $r_s = 0.862$ and $WS = 0.950$, for λ = 0.5, and $r_s = 0.863$ and $WS = 0.950$, for λ = 0. Similarly, for triangular fuzzy AHP coefficients $r_s = 0.859$ and $WS = 0.880$, for λ = 1, $r_s = 0.877$ and $WS = 0.950$, for λ = 0.5, and $r_s = 0.867$ and $WS = 0.952$, for λ = 0 were obtained.

According to all comparisons, one can conclude that all rankings have high similarity since $\min\{WS\} = 0.880$.

5. Conclusions

Architectural heritage management is an imperative of modern society that develops on the principles of sustainable development. Although there are many indications of the application and approach of the management architectural heritage, it currently represents an unexploited asset, even if there are more opportunities for integration in the context of smart cities. Smart cities have a huge potential to improve the quality of life as a complex system based on the heterogeneity of urban resources and interconnectivity between people, devices, platforms, and infrastructures. The integration of comprehensive solutions for smart cities and opportunities for the preservation and promotion of architectural heritage is currently entering a phase of maturity. Using advanced technologies urban sectors are successfully enhanced in cities across the world. Thus, IoT platforms and services enable the use of the smart application in the architectural heritage sector and facilitate the organization of management steps. More importantly, sustainable principles established and improved through the concept of a smart city can significantly preserve the integrity of architectural heritage for future generations, while permanently protecting recognizable landscapes and silhouettes of cities, but also to offer new ways of using dilapidated and devastating urban resources in an economically sustainable way and use them in educating the local and wider community about the cultural, social and architectural past. The paper has examined the issue of managing architectural heritage in the sustainable urban environments of a smart city. Indicators related to the management of the architectural heritage have been divided into six groups institutional, economic, social, environmental, technological, and architectural aspects. The approach in assessing the indicators, with fuzzy numbers, and intervals, impacts the concluding ranking results. Using trapezoidal and triangular fuzzy AHP and interval grey AHP, 22 different criteria were rank to identify priority ones in the decision on protection and preservation of architectural heritage.

Trapezoidal fuzzy AHP shows better stability, and for different degrees of optimism, there is no difference in the ranking of the first ten indicators, unlike triangular fuzzy AHP. Both approaches assign priority to the strategy, and legal framework for architectural heritage management, although the interval approach gives a more significant rank to architectural heritage factors. The similarity of the proposed methods has been tested, and the similarity factor in the ranking indicates a high degree of similarity in comparing the reference rankings.

The obtained results and conclusions opened up the possibilities for further research in the field of architectural heritage management using MCDM. Future studies regarding fuzzy and interval grey AHP approaches will be applied in the field of architectural heritage management under the protection regime in terms of rehabilitation techniques concerning different levels of preservation of the heritage. Given the importance of the energy sector and energy efficiency in smart cities, some of the future papers will try to identify optimal measures to enhance energy efficiency according to the level of protection of the architectural heritage buildings. Multi-criteria analysis has evidential a convenient theoretical and methodological toolkit in solving many decision problems in heritage praxis. The results of the ranking of indicators contribute to a field of architectural heritage protection and management and its support using the concept of the smart city, which is to position the goals strategies and legislative framework for heritage management, favor the authenticity and integrity of the architectural heritage, its existing state in terms of the degree of conservation and stability, public-private stakeholder partnership and the flexibility of existing spatial capacities for a different purpose. Guided by significance indicators, policymaker management for the architectural heritage in smart cities has the opportunity to prepare documented, targeted, and informed strategies and measures to incorporate architectural heritage goals into technology-driven urban development.

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