02-004 – Application of multi-criteria analysis tools in smart cities: guidelines for use in project assessment models – Aplicación de herramientas de análisis multicriterio en ciudades inteligentes: directrices de utilización en modelos de evaluación de proyectos

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The concept of smart and sustainable cities has emerged as a key model for cities to address global challenges related to sustainability, resilience, cohesion, and the improvement of citizens' quality of life in the current context of urban transformation and development. The multidimensional nature of smart cities and the need to involve key urban stakeholders in their development, including citizens as the core of urban demand, are two widely accepted aspects in the scientific literature. As a logical consequence of these two characteristics, the most recent methods for evaluating smart cities incorporate the use of multi-criteria analysis. This paper examines how these tools have been used in various types of assessment models and their relationship to the main characteristics of smart cities. Based on this foundation, the application of multi-criteria analysis in evaluation models for smart city projects and initiatives is analyzed in different aspects, including the management of key urban decision-makers, city dimensions, indicators, priorities and project actions. Finally, practical guidelines are established for the specific use of the Analytic Hierarchy Process (AHP) method, applying them to a case study.

Keywords: *Project evaluation; Smart cities; Multi-criteria analysis*

El concepto de ciudad inteligente y sostenible ha emergido como un modelo clave para que las ciudades enfrenten los desafíos globales relacionados con la sostenibilidad, resiliencia, cohesión y mejora de la calidad de vida de los ciudadanos en el contexto actual de transformación y desarrollo urbano. El carácter multidimensional de la ciudad inteligente y la necesidad de involucrar a los principales actores urbanos en su desarrollo, son dos aspectos ampliamente aceptados en la literatura científica. Como consecuencia de estas dos características, los métodos más recientes de evaluación de la ciudad inteligente incluyen el uso de análisis multicriterio. En este trabajo se realiza un estudio de la forma en la que se han utilizado estas herramientas en las distintas tipologías de modelos de evaluación y su relación con las principales características de la ciudad inteligente. Partiendo de esta base, se analiza la aplicación del análisis multicriterio en modelos de evaluación de proyectos e iniciativas smart city en distintos aspectos: gestión de principales agentes urbanos de decisión, dimensiones de la ciudad, indicadores, prioridades y acciones de proyecto. Finalmente se establecen directrices prácticas de utilización para el caso concreto del método de análisis jerárquico de procesos (AHP), aplicándolas a un caso de estudio.

Palabras claves: *Evaluación de proyectos; Ciudades inteligentes; Análisis multicriterio*

1. Introduction

The urban development model implied by the Smart City concept and its evolution into the notion of a Smart and Sustainable City (Panagiotopoulou et al., 2020) has been established as a response to the global challenges urban areas face. Smart city assessment models serve as tools to evaluate the implementation of this transformative process in cities (Sharifi, 2019). Within these models, multi-criteria analysis methods emerge as one of the potential tools for assessing smart cities. (Gracias et al., 2023; Lacson et al., 2023). However, smart city projects serve as the vehicle through which these transformation processes are articulated (Angelidou, 2015) and translate the vision of the Smart City into reality (BSI PAS 184, 2017). For this reason, evaluation models for projects and initiatives in smart cities are essential tools for assessing their impact. (Hajek et al., 2022).

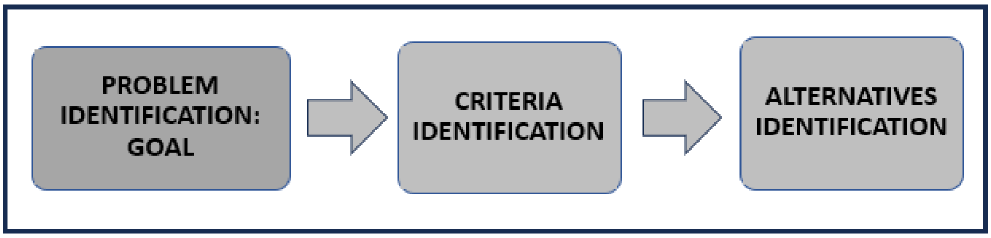
This study examines multi-criteria decision-making (MCDM) methods in smart city evaluation models within the current scientific literature. It aims to establish guidelines for their specific application to evaluation models for smart city projects and initiatives. The aim is to develop comprehensive action lines that consider the types of tools to be employed, their usage approaches, their roles within the models, and the elements that constitute these models.

The relevance of the study lies in addressing the identified gap in the application of MCDM methods to smart city project evaluation models despite their proven viability and effectiveness in other fields, research areas, and model types. The paper is structured as follows: a brief introduction to the theoretical foundations of MCDM methods, a description of the methodology used for selecting and analysing the models, and finally, sections 4 and 5 present the analysis results and the established guidelines. These include a practical application illustrated through a case study and conclusions.

2. Theoretical Foundations

Multi-criteria decision-making is the process of solving a problem that usually has several possible solutions or alternatives, involving multiple criteria of different natures. The basic and general framework for this approach (Yepes-Piqueras, 2018a) involves identifying the problem to be solved or the goal, identifying the different criteria involved, and identifying the alternatives presented as solutions (Figure 1). Multi-criteria decision-making methods (MCDM) are characterized by being a set of methods and analyses aimed at solving a problem, where the options are evaluated through multiple and often conflicting criteria (Vincke, 1992). They are a useful tool for making complex decisions because they provide a systematic approach to analyzing and ranking alternatives (Lacson et al., 2023).

Figure 1: Basic multi-criteria problem scheme. Own elaboration.



Multi-criteria analysis has been used as a tool for solving problems in various fields, such as sustainability and supply chain management (Aragonés-Beltrán et al., 2023), sustainability aspects in product design (Navarro Martínez et al., 2018), development of indicators in areas as diverse as tourism (Blancas et al., 2010) or corporative management (Garcia et al., 2016).

In the context of smart cities, it is a widely used tool as it facilitates communication between decision-makers in cities and, particularly, the involvement of citizens and key stakeholders (De Genaro Chiroli et al., 2022). The multi-criteria methods can be classified (Hwang & Yoon, 1981) into multi-attribute decision-making methods (MADM) to solve discrete problems with predetermined alternatives and multi-objective decision-making methods (MODM) for continuous problems with non-predetermined alternatives (Yepes-Piqueras, 2018). Within multi-attribute methods, various types are also based on the evaluation tools used (Table 1, Penadés-Plà et al., 2016).

Table 1: Multi-attribute decision-making methods. Own elaboration based on (Penadés-Plà et al., 2016)**.**

MADM group	MADM methods
Direct scoring methods	Simple additive weighting (SAW)
	Complex proportional assessment (COPRAS)
Distance-based methods	Technique for order of preference by similarity to ideal solution (TOPSIS)
	Multicriteria optimization and compromise solution (VIKOR)
Pairwise comparison methods	Analytic hierarchy process (AHP)
	Analytic network process (ANP)
	Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH)

Among them, pairwise comparison and distance-based methods in smart city evaluation models are the most commonly used methods. Among these, the most prominent are the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

2.1 Analytic Hierarchy Process (AHP)

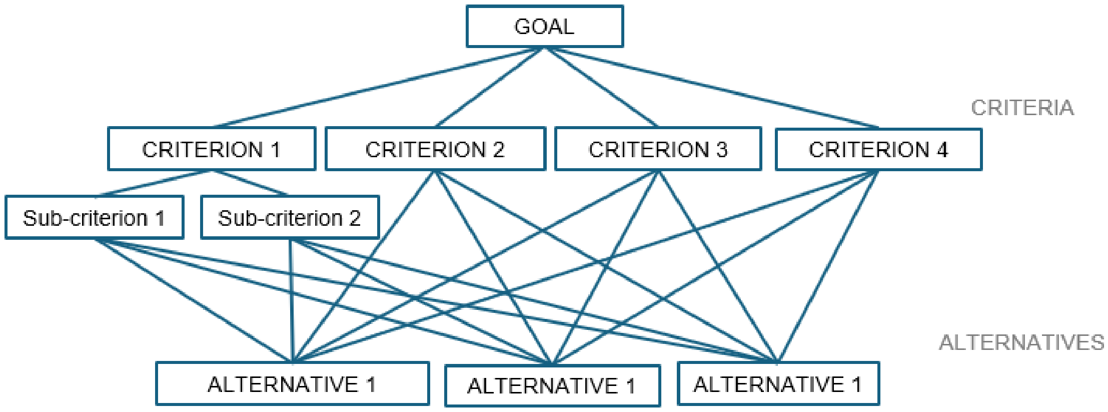
It is one of the most commonly used methods in multi-criteria analysis due to its simplicity and wide applicability (Shi et al., 2018). Proposed by Saaty (T. L. Saaty, 1980), provides a methodology with both psychological and mathematical components: pairwise comparison and linear algebra, respectively. It is based on three basic principles: decomposition, comparative judgments, and hierarchical composition of priorities (T. L. Saaty, 2001a). Decomposition structures the problem into groups of different hierarchies: criteria, sub-criteria, etc. The final objective is at the top level, and the alternatives are at the bottom level (Figure 2). The criteria must be well-defined, relevant, and independent of each other.

Once this structure is defined, a comparison is made between criteria of the same hierarchical level and alternatives according to each criterion. The human brain is well-suited to compare two criteria or alternatives with each other, but less so for joint comparisons (Yepes-Piqueras, 2018c). For this reason, pairwise comparisons are made using a fundamental scale from 1 to 9 (Table 2).

Table 2: Saaty's fundamental scale. Own elaboration based in (T. L. Saaty, 1980)**.**

Numerical Value	Definition
1	Equal importance of both elements.
3	Moderate importance of one element over another.
5	Strong importance of one element over another.
7	Very strong importance of one element over another.
9	Extreme importance of one element over another.

Figure 2: AHP hierarchy scheme. Own elaboration based on (Yepes-Piqueras, 2018c)**.**



The comparison between criteria of the same level and between alternatives according to each criterion results in square matrices:

$$A = \begin{bmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \cdots & 1 \end{bmatrix} \qquad (1)$$

where a_{ij} are the values of the comparison between the pairs of criteria i and j (value 1 in the case of a criterion against itself and a_{ij}= 1/a_{ji} in case of reciprocal comparisons), and n is the number of criteria. Therefore, the matrices must satisfy the properties of reciprocity and homogeneity. Additionally, they must be consistent, meaning there should be no significant contradictions in the comparisons made. For this purpose, consistency must be checked by calculating *CI* (consistency index) and *CR* (consistency ratio) according to the following expressions:

$$CI = \frac{\lambda_{max} - \mathrm{n}}{\mathrm{n} - 1} \qquad (2)$$

$$CR = \frac{CI}{RI} \qquad (3)$$

where λ_{max} is the maximum eigenvalue, n is the size of the matrix and *RI* is the consistency index of a random matrix of the same size. *CR* must be less than 0.1 for an adequate degree of consistency in the pairwise comparison process.

Once the consistency of the matrix is verified, the weights of each criterion are obtained from the criteria comparison matrix using the eigenvalue method, according to the equation:

$$A\ w_c = \lambda_{max}\, w_c \qquad (4)$$

where *A* represents the comparison matrix (1) and w_c is its eigenvector or preference criterion vector. The eigenvector of this matrix includes the value of the weights for each criterion.

For each alternative matrix, its eigenvector is also obtained, and a matrix with these eigenvectors is constructed. The multiplication of this matrix with *n* rows (number of alternatives) and *m* columns (number of criteria) by the eigenvector of criterion weights (*m* rows and 1 column) gives the evaluation of each alternative considering all criteria.

The use of the AHP method is widespread in smart city evaluation models, especially for maturity and performance assessments, as well as the construction of indices based on indicators. It is a method that provides simplicity in its application and can detect and manage the inconsistency of human decision-makers. (Harker & Vargas, 1987) and considers the hierarchy of criteria. (Vargas, 1990), unlike some methods that require global comparisons of the alternatives (De Genaro Chiroli et al., 2022).

2.2 Analytic Network Process (ANP)

Also proposed by Saaty (T. L. Saaty, 2001b), it is an advanced version of the AHP method, generalizing it. In this case, the elements of the problem to be solved (criteria and alternatives) are not independent of each other but rather have influences and interrelationships among them. (Aragonés-Beltrán et al., 2017). The ANP model captures groups of homogeneous elements of the problem (clusters), the network nodes or elements (criteria and alternatives), and the interrelationships between clusters and elements. It allows interactions and feedback within and between clusters, providing a process to derive priorities from relationship scales based on the elements (Lombardi et al., 2012). The design of this network is the most important step in finding the appropriate solution and requires the decision-maker to conduct a thorough analysis of the situation (Aragonés-Beltrán et al., 2017). The main steps are (T. Saaty & Vargas, 2006):

- Structuring the decision-making model: The elements that make up the problem and the relationships between them are identified. There are two types of interdependencies: between elements of different clusters (external connections) and within the same cluster (internal relationships, known as "loops").
- Pairwise comparisons of elements and clusters: Participants (such as experts, managers, or citizen representatives) make pairwise comparisons to determine the relative importance of elements in the network. The same numerical scale from 1 to 9 used in the AHP method (Saaty’s fundamental scale) is applied. The results create matrices that are used to calculate weighted priority vectors.
- Obtaining final priorities: A global priority vector is calculated using "super-matrices," which are matrices composed of submatrices of priority vectors. In the end, a final super matrix is generated that contains the global priority vector for all elements, including the alternatives.

It is a much more complex model to use and develop, requiring a significant preliminary analysis. Its main advantage lies in its ability to represent interrelated criteria and alternatives. This allows for representing more complex systems with strong relationships between their components. ANP is, therefore, more complex than AHP, with fewer model assumptions but more considerations regarding the interactions among the factors of the network system (He, 2023). It is also widely used in smart city models, especially in those conceptual models that consider it essential to consider the interrelationships between components. (Lombardi et al., 2012).

2.3 Technique for order of preference by similarity to ideal solution (TOPSIS)

As proposed by Hwang y Yoon (Hwang & Yoon, 1981), its function is based on finding the farthest alternative from the negative ideal solution and closest to the positive ideal solution. The preferable alternative should have the shortest geometric distance to the best solution, which is the one that achieves the highest possible scores on each criterion (Tzeng & Huang, 2011). The method allows for compensation of criteria, where good or positive results in another can balance poor or negative results in one criterion. The functioning of the method can be summarized in the following steps (Shen et al., 2018):

- Preparation of the decision matrix: Information about the alternatives and criteria is organized into a matrix, where each entry reflects how an alternative meets a criterion. The values are then normalized for homogeneous comparison.

- Criterion weighting: A weight is applied to each criterion based on its relative importance, resulting in a weighted matrix that combines the normalized values with the assigned priorities.
- Identification of ideal solutions: Two reference points are determined: the positive ideal solution, which represents the most desirable values for each criterion, and the negative ideal solution, which represents the least desirable values.
- Distance measurement: The distances from each alternative to the positive and negative ideal solutions are calculated.
- Calculation of the proximity coefficient (Ci): Using both distances, a coefficient is determined that reflects the proximity of each alternative to the positive ideal solution.
- Final ranking: This proximity coefficient ranks alternatives from highest to lowest.

It is also a widely used method in smart city evaluation models, particularly oriented towards developing city rankings based on their performance. (Stanković et al., 2017). It is relatively simple to apply, although somewhat more complex than AHP.

3. Methodology and Materials

The initial objective of this research is to analyse the application of multi-criteria decision-making methods in smart city evaluation models. To achieve this, the first step is to conduct a systematic review of the scientific literature to identify, collect, analyse, and critically assess the state of the art in the research area (Liberati et al., 2009). The systematic review also aligns with a working philosophy of collecting and analyzing results from a qualitative perspective (Snyder, 2019).

The following databases have been selected for the search: Scopus (https://www.scopus.com/) and Web of Science ((https://apps.webofknowledge.com/). They were chosen for their widespread use in this scientific literature search. The keywords used were a combination of "Multi-criteria Decision Making" in its various acronym forms, such as "MCDM" or "MCDA" (analysis), combined with the terms "smart cities assessment," "smart city evaluation," or "smart city model." The following search criteria were applied:

- Articles that have been peer-reviewed, including scientific journal articles or conference proceedings.
- Publications from 2010 to the present (March 2025).

In an initial analysis of the abstracts of the works found, those based on reviews of existing literature, those that do not propose a smart city evaluation model as such, or those that do not use multi-criteria tools as an integral part of the model were excluded. Finally, eight models were selected, which utilize different multi-criteria analysis methods, either alone or in combination with other tools. The selected models are listed in Table 3. It should be clarified that this work aims not to analyze the statistical presence of the different multi-criteria decision-making tools but rather to conduct a qualitative analysis of their use in smart city models. Therefore, a sample like the one obtained is considered sufficient.

In each of the selected models, the following aspects are analyzed:

- Purpose of the model: creation of city rankings, evaluation of smart city performance, project evaluation, etc.
- Multi-criteria tools or combinations of tools used.
- The specific role of multi-criteria methods within the model.
- Elements identified in each model as criteria, sub-criteria, and alternatives.

Subsequently, a critical analysis of the studied models is conducted as a whole, focusing on the types of multi-criteria methods used, common patterns, usage trends, and the suitability of one tool over another in each case.

Based on this analysis, a multi-criteria tool is finally applied to a project evaluation model in the case study of the city of Alcoy in Spain.

Table 3: Selected models. Own elaboration.

Reference	Description	MCDM method
(Shen et al., 2018)	Assessment model for smart cities in China.	TOPSIS
(Lombardi et al., 2012)	Evaluation model for smart cities.	ANP
(Stanković et al., 2017)	Ranking of smart cities in East and central Europe.	AHP+TOPSIS
(Shi et al., 2018)	Comprehensive evaluation of smart cities based in PSF model.	AHP
(Aragão et al., 2023)	Maturity evaluation model for smart cities.	TOPSIS
(De Genaro Chiroli et al., 2022)	Evaluation of smart cities in Brazil.	AHP+MACBAC
(Esteban-Narro et al., 2025)	Stakeholders identification framework for smart cities	AHP
(Ghaemi Rad et al., 2018)	Assessment of ubiquitous cities.	ANP+DEMATEL

4. Results and Discussion

The field of knowledge that smart city evaluation models represent, whether for measuring the performance of smart city policies, assessing the level of maturity reached, creating city rankings, or evaluating projects within the smart city paradigm, is relatively new (Sharifi, 2019). Despite the significant increase in recent years, the number of models remains limited (Lacson et al., 2023), even more so when focusing on the specific case of models using multi-criteria tools. However, by analyzing the sample resulting from the systematic literature review, several clear guidelines and lessons for applying these tools in models to be developed can be observed. On the one hand, the most commonly used methods are those mentioned in Section 2 of the theoretical foundations, namely AHP, ANP, and TOPSIS, occasionally combined with other tools with complementary functions within the model. On the other hand, analyzing issues related to the functioning of the model, the effective use of multi-criteria methods, and identifying its elements allows us to differentiate a series of common approaches.

4.1 Approach Focused on Smart City Evaluation through Dimensions and Indicators

The most common approach, which is shared to varying degrees and with certain variations by six of the eight models analysed, is evaluating city performance as smart cities. This approach is presented by Aragão et al., 2023; De Genaro Chiroli et al., 2022; Ghaemi Rad et al., 2018; Shen et al., 2018; Shi et al., 2018; Stanković et al., 2017. These are models that aim to evaluate the performance of the city or its level of maturity using collections of indicators. Multi-criteria tools are employed to weigh the importance of these indicators (criteria or sub-criteria) in the city evaluation, which are generally presented as alternatives. The final objective varies between creating city rankings within a specific context (country, region) or developing synthetic valuation indices.

The evaluation of smart cities based on collections of indicators is very common. It is used in most evaluation models, starting with Giffinger et al., 2007, to the standardized collection represented by the standards ISO 37120:18, 2018 and ISO 37122:19, 2019. It is true that original collections of indicators are less common, which is why many of these models rely on collections, primarily the aforementioned ISO standards (Lacson et al., 2023; Sharifi, 2019). Moreover, the holistic nature of the Smart City as a widely accepted characteristic by the scientific community, (Cohen, 2014; Giffinger et al., 2007; Manville et al., 2014; Mattoni et al., 2015; Naguib & Ragheb, 2022) means that these indicators are organized based on city dimensions. Therefore, another aspect to address is the weighting of these indicators.

The aspect of weighting the importance of dimensions and indicators is addressed in many models by assigning equal weights to all dimensions (De Genaro Chiroli et al., 2022) and even to indicators within each dimension (Giffinger et al., 2007). However, it is logical to consider the problem of assigning different weights to the indicators based on their nature. MCDM methods are presented as tools for assigning weights to both dimensions and indicators, taking expert opinions into account in this process (He, 2023).

The model of Shen et al., 2018 uses the TOPSIS method, combined with the Entropy method, to evaluate the performance of Chinese cities, considering 18 smart city indicators grouped into five dimensions as criteria and the 44 cities to be assessed as alternatives. Another model in this region is that of Shi et al., 2018. In this case, the AHP method is used to construct a synthetic evaluation index, and then, using a neural network model, an integrated evaluation model for smart urban development is built and tested on 151 cities in China. It is a much more complex model, but essentially, six smart city dimensions are considered as criteria, and a collection of 16 indicators is used as sub-criteria, with weights assigned to each of them through AHP, following a structure very similar to that of Shen et al. in this regard.

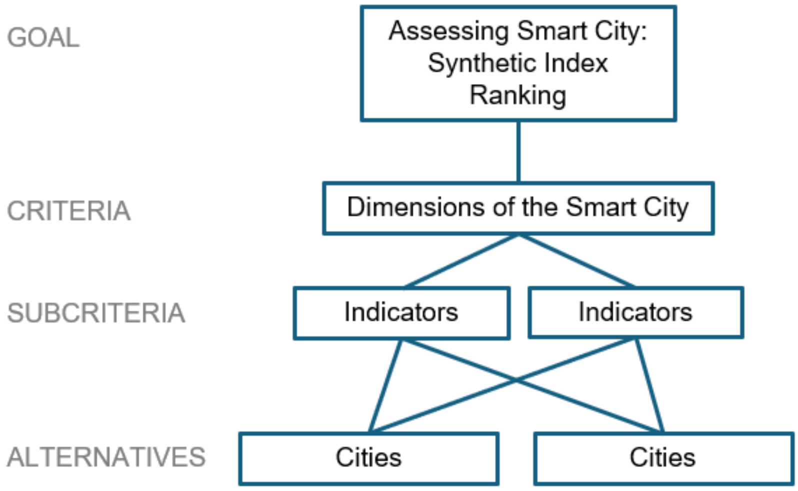
The use of AHP for weighting, considering the smart city dimensions as criteria and indicators or groups of them as sub criteria, is repeated in the models of Stanković et al., 2017 y Genaro Chiroli et al., 2022, both of which consider the cities to be evaluated (European and Brazilian cities, respectively) as alternatives. In these models, other methods are used as complementary tools: TOPSIS for ranking in the case of Stankovic and MACBAC (Multi-Attributive Border Approximation Area Comparison) in the case of Chiroli et al.

Similar to the model of. Shi et al., 2018, the use of AHP for the development of synthetic indices is widespread in institutional models, such as those of the Intelligent Community Forum or IBM, as well as in government models at the national, regional, and local levels, making it the most used method in this regard (He, 2023). However, in Aragão et al., 2023 model, a synthetic index is constructed for evaluating the maturity level of smart cities using TOPSIS. The criteria scheme as indicators (in this case, 40 indicators obtained from ISO 37120:18) and the alternatives as cities are repeated.

Ghaemi Rad et al., 2018 also aim to construct a synthetic index. In this case, the ANP method is used, presenting methodological and conceptual differences but with a similar foundational approach. The model is based on the Ubiquitous City, an evolution of the Smart City concept, developing an index to evaluate a city's preparedness level. It starts with 11 city components (clusters in ANP terminology, such as citizenship, transportation network, economy, education, etc.) and develops adaptability criteria for the ubiquitous city model. The tool for selecting the criteria is the DEMATEL method (Decision-Making Trial and Evaluation Laboratory), and the criteria weights are subsequently calculated using ANP. In the end, the criteria function as indicators, in this case, 34, and the multi-criteria approach is used to assign weights to the indicators.

Therefore, the models that follow the common approach of evaluating cities through synthetic indices or ranking development differ in the multi-criteria method used and additional tools, but they share a common framework (figure 3) with slight variations across them.

Figure 3: Common outline of models with approach 1. Own elaboration.



4.2 Other Approaches: Urban Stakeholders

In the previous approach, the elements considered when applying multi-criteria analysis methods are the dimensions of the Smart City and the indicators. These reflect the previously mentioned holistic nature of the smart city and another key attribute of it: being measurable (BSI PAS 184, 2017). However, another widely accepted characteristic of the Smart City by the scientific community is the importance of stakeholder engagement (Fernandez-Anez et al., 2018; Fernández-Güell et al., 2016; Gracias et al., 2023; Sharifi, 2019). In the previous models, the establishment of criteria is influenced by consultations with experts and various urban stakeholders, so this characteristic is also implicit in the models. However, other approaches consider stakeholders to be an additional element in the application of MCDM.

Lombardi et al., 2012 use the ANP method to analyse the interrelationships between the components and stakeholders of the smart city to verify whether the evaluated cities are smart and if they are moving in the right direction (Lombardi et al., 2012). Stakeholders are an intrinsic part of the model as criteria. The four stakeholder groups from the extended triple helix model are used (Lombardi et al., 2011). The alternatives are the different visions or paradigms of a smart city (Connected City, Entrepreneurial City, Liveable, and Pioneer City), and the clusters are formed by the dimensions of the smart city, with indicators within each of them. It is a conceptually complex model but very comprehensive and innovative in this field (2012).

In Esteban-Narro et al., 2025, a recent work by the authors, the AHP method is specifically applied to a framework for identifying and managing stakeholders in smart cities, to manage and process data from consultations with different categories of urban stakeholders, depending on their relationship with the dimension of the smart city and their nature. In this case, the objective is to determine the weight assigned to each identified stakeholder category in processing data collected during consultations. The criteria are the different thematic areas in which the opinions of the stakeholders will be considered, and the alternatives are the different categories of stakeholders.

Therefore, these two works represent a different application scheme than the previous approach in terms of the design and components of the multi-criteria decision-making tools, considering stakeholder groups as such and establishing distinct functions.

4.3 Use of MCDM in Project Evaluation Models

The models analysed are based on the evaluation of cities as a whole from various perspectives, but they are not specific project evaluation models. This is not surprising, as most smart city evaluation models focus on analysing the city. Models or sets of indicators specifically focused on projects are much less numerous (ASCIMER, 2017; Bosch et al., 2017). It should come as no surprise that this scarcity also applies to models using multi-criteria tools. However, in other fields, there are examples of their use, such as in investment studies related to sustainability criteria (Aragonés-Beltrán et al., 2023) or civil engineering (Navarro Martínez et al., 2018).

Project evaluation models share many aspects with city evaluation models:

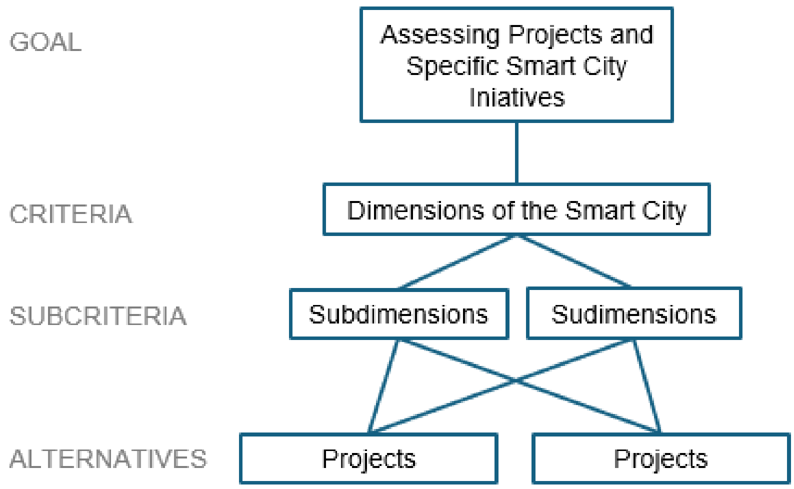
- A multidimensional structure to reflect the holistic nature, containing dimensions and subdimensions that include indicators for each thematic area. (ASCIMER, 2017).
- Including the main urban stakeholders as an integral part of the model (ASCIMER, 2017; Esteban-Narro et al., 2022).
- Indicators capable of measuring the impact of the projects, although these are specifically developed for the object of measurement, which are concrete smart city projects and initiatives (Bosch et al., 2017).

Therefore, using MCDM methods in such models is not only perfectly feasible but can become a very useful tool based on the guidelines obtained from their application in smart city evaluation models, while also considering their particularities. The basic structure shown in Figure 3 should be adapted and completed to reflect the characteristics of a model that focuses on project evaluation:

- Weighting of Dimensions: Without losing sight of the multidimensional nature of smart city initiatives, the importance of the projects' impact on each dimension can be weighted based on the city's situation at the time, ensuring the necessary adaptation of the model. (Hajek et al., 2022; Sharifi, 2019).
- Weighting of Subdimensions: Similarly to the dimensions, within each one, the thematic areas represented by the subdimensions should be weighted. Projects will have unequal impacts depending on their nature, so prioritizing certain thematic areas over others based on the city's specific needs is absolutely necessary.
- Weighting of Priorities in Project Actions: The weighting of subdimensions addresses this aspect, as creating a model with as many components as possible project actions would make the number of criteria unmanageable.
- Weighting of Indicators: The project impact indicators are more specific and less general than those used for city-wide evaluation. In a city evaluation model, many aspects are measured, and therefore, numerous indicators exist. However, project evaluation is more focused, and the indicators are typically specific to each thematic area.
- Management of Stakeholder Information: The weighting of data gathered from consultations with urban stakeholders, depending on their nature, when establishing project priorities or smart city master plans is a complementary but crucial component in evaluation models.

The adaptation of the basic framework to project evaluation is shown in Figure 4.

Figure 4: Outline of application of MCDM tools to project assessment models. Own elaboration.



The basic function of MCDM methods in project evaluation will be the weighting of criteria and sub-criteria, so AHP and ANP emerge as the most suitable tools due to their ability to produce this type of result quickly. Their use is predominant in this aspect in the models studied (De Genaro Chiroli et al., 2022; Esteban-Narro et al., 2025; Ghaemi Rad et al., 2018; Shen et al., 2018; Shi et al., 2018; Stanković et al., 2017). The choice of one tool over the other depends on the level of complexity desired for the model (greater simplicity and replicability with AHP) or the importance of reflecting interdependencies between dimensions and subdimensions (ANP).

4.4 Practical Guidelines for Use: Case Study

As a practical example of application, a case study is presented on using an MCDM tool in a smart city project evaluation model in the city of Alcoy (Spain). This city, located in the interior of the province of Alicante, has a population of 60,000 inhabitants, categorizing it as a small city according to the European Commission (Dijkstra & Poelman, 2012).

In this case, the weighting of dimensions and subdimensions in the model structure will be established using AHP. This method has been chosen to prioritize simplicity in the development of the tool, as it is considered necessary for it to be easily replicable and adaptable over time based on the evolving situation of the city with the development of new projects. The model structure developed by the authors in a previous work is used to achieve this. (Esteban-Narro et al., 2022), As shown in Table 5, along with the results from the case study application.

Following the scheme in Figure 4, in this case, the criteria will be the dimensions, and the sub-criteria are subdimensions. The weighting of dimensions is initially set with an equal coefficient for all of them. This reflects that the difference in the project's impact according to the dimension is irrelevant, and all dimensions are given the same importance as a starting point. With six dimensions, the weighting coefficient value will be 1/6.

However, it is considered necessary to establish an unequal weighting for each of the subdimensions within each dimension. To do this, a panel of experts is established, with three members for each dimension, and they are given a questionnaire for each dimension based on Saaty's fundamental scale (Table 2), where the sub criteria (subdimensions) are compared to each other. This results in the construction of six matrices, one for each dimension, according to (1), which are checked for consistency using equations (2) and (3), and the eigenvector is obtained through iteration according to equation (4).

As an example, the values for matrix *A* for the "Economy and Competitiveness" dimension and the resulting eigenvector are shown in Table 4.

Table 4: Decision matrix *A* for the Economy and Competitiveness dimension. Own elaboration.

	Business and labor innovation.	Entrepreneurship	Productivity.	Local-global interconnectedness	Eigenvector
Business and labor innovation.	1	3,667	0,556	2,111	0,308
Entrepreneurship.	0,273	1	0,289	0,2889	0,083
Productivity.	1,8	3,462	1	2,111	0,407
Local-global interconnectedness	0,474	3,462	0,474	1	0,202

Finally, the weights for each subdimension are obtained, as shown in Table 5. These weights are presented in relative terms (the weighting of each subdimension within the dimension) and absolute terms (adjusted by the weighting coefficient of 1/6 for each dimension).

Table 5: Results of weighting coefficients by subdimensions. Own elaboration.

Dimensions	Subdimensions	% Relative	% Absolute
ECONOMY AND COMPETITIVENESS (ECO)	Business and labor innovation.	30,8%	5,1%
	Entrepreneurship.	8,3%	1,4%
	Productivity.	40,7%	6,8%
	Local-global interconnectedness.	20,2%	3,4%
HUMAN AND INTELLECTUAL CAPITAL (HIC)	Academic and digital training.	24,4%	4,1%
	Creativity.	25,6%	4,3%
	Management and promotion of urban life.	16,4%	2,7%
	Work flexibility and work-life balance.	33,7%	5,6%
GOVERNANCE (GOV)	Transparency and citizen communication channels.	8,3%	1,4%
	E-government and online services.	13,7%	2,3%
	Participation in decision making.	32,8%	5,5%
	Innovation and efficiency in municipal management.	45,2%	7,5%
INFRASTRUCTURE AND MOBILITY (INF)	Public transport and multimodal network.	17,6%	2,9%
	ICT infrastructures.	13,3%	2,2%
	Urban logistics.	44,3%	7,4%
	Sustainable mobility.	24,8%	4,1%
ENVIRONMENT AND	Energy efficiency.	29,0%	4,8%

Dimensions	Subdimensions	% Relative	% Absolute
ENERGY (ENV)	Resource and waste management.	23,8%	4,0%
	Environmental monitoring.	24,3%	4,0%
	Renewable energy and social awareness.	22,9%	3,8%
SOCIAL WELFARE AND SERVICES (SOW)	Public, social and security services.	32,8%	5,5%
	Tourism, culture and leisure.	21,6%	3,6%
	Social cohesion and inclusion.	29,0%	4,8%
	Health and welfare.	16,6%	2,8%

The influence of this weighting on the values obtained when evaluating projects according to the model is significant. For example, it means that a project impacting the dimension of urban logistics or innovation and efficiency in municipal management will be valued more than five times higher than another project with the same impact on the subdimension of transparency and citizen communication channels. These values depend on the situation of the municipality when the consultation with the expert panel is conducted. Therefore, the model must be adaptable and applied based on the status of previously developed municipal projects.

5. Conclusions

Multi-criteria decision-making (MCDM) methods are increasingly used in smart city evaluation models. These methods not only align with but also strengthen the two most accepted characteristics of smart cities in the scientific community: their holistic nature and the importance of considering key stakeholders.

This paper analyses how MCDM methods are employed in existing models in the scientific literature, identifying several patterns in their application. The most common basic structure used in smart city evaluation models considers the city's dimensions as criteria, state measurement indicators as sub-criteria, and the cities being evaluated as alternatives.

Based on this analysis, an application framework is established for using multi-criteria tools in smart city project evaluation models, considering the specific characteristics of such models and offering guidelines for their use. The application line for these models involves weighting dimensions and subdimensions, leaving indicators aside due to the nature of the object being evaluated (projects), using AHP or ANP depending on the context and needs. Using stakeholder consultation data as complementary to the main model structure is also recommended.

The research identifies key weaknesses, such as the scarcity of evaluation models that use MCDM tools and the complete absence of their application in project evaluation models. Complementing the use of MCDM methods with other tools that involve stakeholder participation (such as mass consultations, Delphi method, or DEMATEL) to determine criteria, sub-criteria, and project action priorities, as well as establishing a system for defining indicators by project type, are proposed as future research lines.

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Use of generative artificial intelligence

Generative artificial intelligence has not been used in this work.

Communication aligned with the Sustainable Development Goals