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Planning Smart cities: comparison of two quantitative multicriteria methods applied to real case studies

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Response to Reviewers:	

Response to the reviewers

Reviewer #1: The paper has significantly improved its quality. The general structure is now cleared and a most of the repeated/replicated information have been eliminated. Comparison between the method is clearer now too. Bibliography and the first sections have also been improved and the research framework is much clearer now. The ideas of the conclusions paragraph demonstrate now the interest of the comparison:

1. to demonstrate that the analysed methods do not produce significantly different results,
2. To question the weight of subjective opinions in measurement
3. To open new research paths for the inclusion or not of subjective methodologies.

Authors have made a significant effort and the paper have increased its quality. Still in my opinion the interest of the proposed methodology is relative. However, for the interest of the conclusions of the comparison In my opinion, it has reached the quality to be published in Sustainable Cities and Society

Authors would like to thank the reviewer for his/her effort. The paper was modified again in order to make it clearer and easier to read, taking into account more in deep all the suggestions of the reviewer.

Reviewer #2: The authors did not upload the revised manuscript with changes marked. Therefore, I am not able to review it in detail.
I can see that the authors tried to address the points that I raised in my prior comments. However, I must admit the fact that this manuscript is very difficult to follow. It is still too long and not well organized.
I really advise the authors to read the manuscript once again thoroughly and enhance the storytelling of it.

Authors would like to thank the reviewer for his/her effort and apologize for the inconvenience of the previous review phase: in the submission phase the wrong document was uploaded without changes marked.

Authors in this second round of review tried to address the suggestions of the reviewer the best they could. In particular, the manuscript was considerably cut and the storytelling was enhanced: the redundant part describing the Hybrid AHP method was deleted (info about it can be taken from the original paper of Giaccone et al. 2017) and more evidence was put to the description of the proposed new methodology, which is the core of the paper; furthermore in the results section the detailed application of all the methods to the case studies was synthesized: the description of the methods was provided for the Sicilian case study, while regarding Palazzo Baleani case study the final ranking were only shown. Finally, in the discussion section the main relevant aspects of the two methods were better highlighted comparing the final rankings. Furthermore, their potentialities and limits were evidenced.

Planning Smart cities: comparison of two quantitative multicriteria methods applied to real case studies

Abstract:

Today, cities are facing many challenges such as pollution, resource consumption, gas emissions and social inequality. Many future city views have been developed to solve these issues such as the Smart C~~c~~ity model. In literature several methods have been proposed to plan a Smart city, but, at the best of the authors' knowledge, only a few of them have been really applied to the urban context. Most of them are indeed theoretical~~ical~~ and qualitative approaches, providing scenarios that have not been ~~contextualized~~ applied to real cities/districts. Moreover, a comparison among the results of different quantitative planning models applied to real ~~urban contexts~~case studies is still missing. In this framework, the aim of the paper is to propose a new quantitative method based on a previous qualitative model developed by the same authors. The feasibility and validity of the method will be tested through the comparison with an existing AHP model and the application of both approaches on two real case studies, characterized by different territorial level~~dimension~~s. Results of the analysis show that both methods are consistent, reliable and do provide similar results despite the differences in the application process.

Keywords: Smart city; Planning Methodology; Multicriteria analysis; Smart ~~development goals~~District; Smart Building

1. Introduction

The ~~power of attraction of to~~attractiveness of living in cities has exponentially increased in the last decades. Nowadays, for the first time in the history of the world, more people are living in urban ~~contexts~~ than in rural areas (Marchetti Oliveira, & Figueira, 2019, World Urbanization Prospects 2018). This attractiveness is ~~due to the fact that~~because the economies in urban context reach their highest level of productivity, guaranteeing cultural, social and economic benefits to citizens (Fernandez-Anez, Fernández-Güell & Giffinger, 2018). On the other side, growing urbanization is also the cause of several problems, such as pollution, resource consumption, social inequality and others. Just to give a couple of figures, cities today is responsible for the 80% of greenhouse gas (GHG) emissions and the 80% of the world's resources consumption (Arbolino et al., 2017). Consequently, due to these emerging challenges, city planning deals no more to the design of buildings and infrastructure only, but also to the definition of a holistic vision where new issues as digitalization, integration, quality of life, citizen needs, and equality must be taken into account (Silva, Khan & Han 2018). The Smart city model emerged in the 1900s as an alternative and innovative concept for city planning. Till now the concept has evolved and got complex (Caragliu, Del Bo & Nijkamp 2009, Albino, Berardi, & D'angelico, 2015; Chourabi et al., 2012) including multidisciplinary aspects and assets (De Santis et al., 2014; Yigitcanlar et al., 2019) and aiming to find a balance between benefits and costs for the main stakeholders involved (people, institutions, industry, universities, and companies), (Nam & Pardo, 2011b). This complexity resulted in a lack of consensus about the Smart definition (Meijer & Bolivar, 2015; Caragliu & Del BO, 2019, Manville et al., 2014), and about the way to translate the ideal model into practical applications (Lee, Hancock & Hu, 2014; Nilssen, 2019; Camboim, Zawislak & Pufal 2019). ~~A~~ W~~w~~ide literature research is indeed available, proposing different definitions, conceptual models and approaches to the development of the Smart City concept (Sharifi, 2019; Ahvenniemi et al., 2017). Regarding the definitions, a group of literature research focuses on the use of ICT and modern technologies as the main driver to the smart city development (Angelidou, 2015; Kourtit & Nijkamp, 2018). Other studies underline the importance of human capital, city services and participation for improving economic, social and environmental aspects of a Smart C~~c~~ity (-Neirotti et al., 2014; Belanche, Casaló & Orús, 2016).

An ISO standard was proposed at the regulation level which proposes methodologies and indicators to measure the performance of the Smart cities (ISO 37122:2019). This standard defines the Smart cities as "*a city that increases the pace at which it provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life to those in the city (residents, businesses, visitors), now and for the foreseeable future, without the unfair disadvantage of others or degradation of the natural environment*". As noticeable, this definition is very general and inclusive.
Regarding the models and approaches, a considerable group of literature studies focuses~~d~~ on the development of evaluation frameworks for the smart city performance assessment, both from the qualitative and quantitative perspectives. Among them, the first one was proposed by (R. Giffinger et al., 2007) where the level of Smartness of 70 European medium-~~-~~sized cities is evaluated based on their performance in six main axes. More recently, in (Zygiaris, 2013) ~~developed~~ a ~~–~~measurement~~t–~~ tool was developed for assessing the smart performance, identifying six layers of a smart city. In (Lazaroiu & Roscia, 2012) a fuzzy procedure is applied for identifying the weights of different Smart indicators, which are used for the creation of a unique "S~~s~~mart city index". In this framework, a useful report was developed by (Manville et al., 2014), called "Mapping Smart Cities in the EU", ~~in order~~ which~~to~~ collects all the smart city projects and models in Europe, highlighting their performance~~s~~ ~~especially~~ with ~~the~~ respect to the Horizon 2020 objectives.

Moreover, interesting researches are available proposing qualitative planning methods. These studies are not aimed to evaluate the performance of a city but mainly to guide administrators in the identification of efficient Smart strategies to be applied in real case studies~~the real context~~. As an example, (Kumar, Kumar Singh & Gupta, 2019) a crowdsourcing approach was used to collect the most common smart services and to define ~~a~~ the Smart City Transformation Framework (SCTF) for the deploying of ~~smart~~ Smart interventions. In (Mattoni, Gugliermetti & Bisegna, 2015) an innovative and multidimensional methodology is provided, which is based on the analysis of the mutual impacts among strategies belonging to different smart axes by means of the "synergy" concept. Similarly, The "intelligenter method" (Marsal-Llacuna & Segal, 2016) is based on the creation of multi-subsystem interrelations~~collaborations~~ that provide better results in terms of efficiency in the use of natural and economic resources: this is called "Collaborative Sub-Systems" and it is based on the holistic and systemic approach of the urban context. Finally, in (Fernández-Güell et al., 2016) ~~proposed~~ a multilayer approach was proposed, based on the systems theory, which is~~and it was~~ used to envision how Spanish cities could evolve in the horizon 2030. Other researches applied the triple helix conceptual model to assess the role of different stakeholders in the planning phase of the Smart cities (Etzkowitz & Zhou, 2006; Lombardi et al., 2012). Stakeholders involvement has indeed recently begun a hot topic in literature: many studies evidenced the need of taking into account the stakeholders' opinion for an efficient urban transformation (Angelidou, 2017; Stratigea et al., 2015; Engelbert, Zoonen & Hirzalla, 2019, Bouzguenda, Alalouch & Fava, 2019).

This brief overview of the Smart city vision highlights that, besides the variety of proposals~~approaches~~, there is still the need for the development of quantitative ~~approaches~~ models able to put the smart city theory into practice and to apply a global and holistic view in the planning phase. ~~According to this~~As a matter of fact, scientists propose ~~models as much as possible~~ integrated, comprehensive and multifaceted models; practitioners on the other side have to face with the limitations of implementing visionary projects in ~~the real context~~cities, preferring therefore to work on sector-based interventions instead of integrated strategies (Fernandez-Anez, Fernández-Güell & Giffinger, 2018, Angelidou 2017, Caragliu & Del Bo, 2019).

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The presence of those two opposite approaches, highlighted by (Fernandez- Anez, Fernández-Güell & Giffinger 2018), is still a concrete limitation for a holistic and integrated smart city realization. Current Smart applications frequently use~~s~~ top-down approaches~~-~~, as it can be noticed for the 15 major cities described by (Angelidou 2017): those smart planning projects are mainly focused on the ICT aspect and this is considered as the principal driver for pushing improvements in the urban systems. This is clearly in contrast with the Smart City concept, that aims to promote the application of both top~~-~~-down and bottom-up approaches, starting from a global view of the urban context (Caragliu & Del Bo, 2019).

There is, ~~-~~therefore, the need to fill the gap between theory and practice proposing "practical planning methodologies" which can help in choosing, prioritiz~~ing~~e and control~~ling~~ ~~-~~the performance of the implemented Smart strategies ~~implemented in the urban contexts~~ (Mattoni, Gugliermetti & Bisegna, 2015; Pompei et al., 2018; Mattoni, Nardecchia & Bisegna, 2019) from a~~n~~ holistic perspective, as scientist suggest (Bibri & Krogstie, 2017).

An important example of planning methodologies is the work of (Fernandez-Anez et al., 2018), that proposes a tool called Smart City Projects Assessment Matrix. It is a holistic framework for developing smart city projects and assessing urban challenges. ~~-in each region~~ Moreover, this methodology was applied ~~on~~ to the South and East Mediterranean Region at both the regional and project levels. Another example is the ASEAN Smart City Network (ASCN) project that ~~has the aim~~aims to transform 26 cities into smart ~~contexts~~cities. This project provides a digital platform in which designers and policies can disseminate and promote initiatives (ASEAN Smart Cities Network 2018). Finally, the Institute of Technology, Bandung (ITB) developed the Garuda Smart City Framework (GSCF), a methodology that consists in different steps, including ~~:~~ city measurement models, ~~smart~~ smart city Architecture, standard and services (Tay et al., 2018). In this case, the technological aspect is recognized as one of the main ~~driver~~drivers for the smart city. This planning method aims to highlight the importance of innovative, technology and integrated solutions for improving the quality of life.

Starting from this point, the present work is in line with the targets of the aforementioned ~~ose~~ projects, since the aim is to reduce the gap between theory and practice of Smart City, providing quantitative and integrated methodologies for the transformation of real case studies.

This paper, ~~-~~therefore, proposes a new quantitative method based on a previous qualitative model developed by the same authors (Mattoni, Gugliermetti & Bisegna, 2015). The feasibility and validity of the method will be tested through the comparison with an existing AHP model and the application of both approaches on two real case studies, characterized by different territorial dimensions. Both the new and the AHP methods belong to the group of the MADM models; these models can be very suitable for the assessment of the best smart strategy among a set of different proposals, thanks to their capability of prioritization and scoring.

Quite ~~-~~a few studies in literature applied the MADM models for city ~~planning~~evaluation, either for the development and evaluation of ~~the~~ Smart cities (Escolar et al., 2019; Lombardi et al., 2012) or for the assessment of urban sustainability level (Mohammed Ameen & Mourshed, 2019). ~~An exception is the work of (Lombardi et al., 2012), in which authors decide to use the Analytic Network Process (ANP), an advanced version of the Analytic Hierarchy Process. As highlighted by (Lombardi et al., 2012), the network nature of the city should be described through a realistic model based on a network system, which allows to guide the interactions and to provide feedback within all the elements.~~ A more detailed description of the MADM models and their potentialities is provided in the following section.

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Moreover,
~~A~~at the best of our knowledge, there are no~~t~~ studies in the literature comparing two quantitative planning models.

Therefore, in this work, the comparison of the two methods allows to:

- Validate the methodological approach developed by authors, through the comparison with an existing AHP method and the application of both the models on two real case studies, characterized by different territorial scales.
- Highlight the differences and similarities between the two methods
- Compare the final rankings and assess the impacts of the modelling process on the identification of the most performing strategies
- Identify limits, strengths and potentials of the proposed methodology.

After the Introduction section, explaining the state of the art of the Smart C~~c~~ity concept and models, the next section (Section 2) presents the evolution and modification of the two approaches used in the paper, showing their entire processes in detail and the two case studies are described. Section 3 contains the results of the application of the two models, while in section 4 the results are compared and discussed. Finally, the conclusions and future developments are drawn.

2. Methodology

Multicriteria analysis is a decision-making tool based on the quantitative analysis of the strengths and weaknesses among ~~heterogenous~~heterogeneous criteria of a certain proposed strategy. Following the classification made by (Hwang and Yoon, 1981), MADM is one of the two branches of Multiple - Criteria Decision Making (MCDM), which transforms the real-world problems into continuous or discrete systems. MADM allows ~~to~~ reproducing~~e~~ discrete problems, considering a limited number of alternatives not measurable in a single dimension. More in detail, MADM consists of a group of operations for ranking and scoring multiple alternative solutions usually characterized by contrasting attributes (Figueira, Greco & Ehrgott, 2005) MADM is composed by a matrix, called decision matrix, which describes the contribution of each alternative against each attribute. Two operations are generally required to calculate this matrix: scoring and weighting. The first one involves assigning a numerical value to each attribute contributions, within a preference scale. The weighting, instead, consists in identifying a weight for each attribute. Consequently, a MADM method provides an explicit weighting system for the different criteria in order to estimate the correct weight.

The new methodology proposed in this paper is called Quantitative Incidence Matrix Method (QIMM), which is an evolution of a matrix method (IMM) firstly elaborated in a previous paper of the same authors (Mattoni, Gugliermetti & Bisegna, 2015). The QIMM can be included in the MADM methods, due to its typical structure of matrix weighting process.

The QIMM ~~is~~ has validated ~~-~~through~~trough~~ the comparison with another MADM approach: a modified version of the Analytic Hierarchy Process (AHP) (Saaty, 1980), called Hybrid AHP, which was developed by the University of Palermo in (Giaccone et al., 2017).

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One of the most important aspects of those two methods is their flexibility: the number of smart city fields, actions and indicators can be changed from time to time, depending on the characteristics of the case study. The core of the two methods lays in the capability of putting the different actions in relation to each other to understand the mutual impacts and establish the priorities of the actions in an integrated way: this is ~~actually~~ one of the main target of a Smart city.

Those two methods will be applied to two different case studies, ~~in order~~ to verify if and to what extent the results are similar and how this would change the strategy decision making.

The first case study is~~-~~ the Sicilian residential building sector's EEMP (Energy and Environmental Master Plan developed by the Sicilian Region) and ~~the Sicilian residential building sector's EEMP (Energy and Environmental Master Plan developed by the Sicilian Region) and~~ the second one is the Palazzo Baleani, a building in the city centre of Rome, that is owned by Sapienza University.

~~the Palazzo Baleani, a building in the city centre of Rome, that is owned by Sapienza University.~~

~~The application of the Hybrid AHP method to the Sicilian case district was originally developed by (Giaccone et al.,2017): in the current work, authors therefore limit to describe and reproduce what was originally done in that paper. Conversely the application of the Hybrid AHP method to Palazzo Baleani, the application of the QIMM to both the Sicilian district and Palazzo Baleani~~case studies and~~, the comparison among all the results is an~~are ~~original work~~ elaborations ~~of the authors.~~

~~Those two cases study represent two different configurations, on one hand the entire Sicilian building sectors and on the other hand a single historical building. The flexibility of those methods is demonstrated due to the different case studies scale application: macro scale as district and micro scale as the single building.~~

2.1 Methods description

Quantitave Incidence Matrix (QIMM) Method

The flowchart of the original method IMM includes different steps: data collection, performance indicators analysis, actions strategies elaboration and their mutual impact on the smart fields (Mattoni, Gugliermetti & Bisegna, 2015). The phase involving the identification of the best fitting strategy is represented by the Incidence Matrix, that establishes in a qualitative way, the influence of each action~~s~~ on the smart aspects. According to this, it is possible to obtain the best action for each smart field. The last step is to simulate the winner actions and implement them i~~o~~n the urban context.

Starting from this methodology, some important modifications are carried out ~~in order~~ to transform this qualitative method into a quantitative one: the QIMM method. Moreover, those modifications allow users to ~~applicate~~ apply this new methodology for both planning and ex-post analysis.

Three main difference can be noticed in the modified method:

1) All the strategies are simulated in the first phase. It allows to obtain quantitative results in different fields (Mobility, Community, Environment, Energy and Economy) represented by specific Smart Indicators, belonging to the various Smart fields.
2) The assessment of the impact of each strategy in the incidence matrix is developed by means of quantitative Smart performance indicators (in substitution of the qualitative Synergy scores) and

quantitative additional weights. The standardisation of those indicators is based on a common process, which uses standard normalization criteria.

3) In the transformation of the method from qualitative to quantitative, the Users score was no more taken into consideration due to the complexity in collecting and quantifying stakeholders' opinions.

This variation in the method allows ~~to fill~~to fill the gaps highlighted in the previous approach proposed by the authors (Mattoni, Nardecchia & Bisegna, 2019).

Figure 1 shows the flowcharts of both methods and their differences. Following, authors provide a deep explanation of each step of the presented method.

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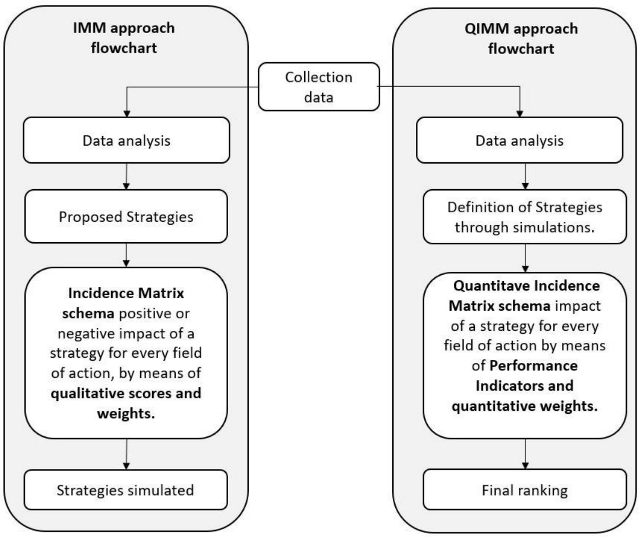

Figure 1. Elaboration of QIMM procedure

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~~Following, authors provide a deep explanation of each step of the presented method.~~

- **Generate matrix**

In the QIMM method, a single matrix is used, which contains all the indicators that need to be measured for every intervention. A segmentation is recommended ~~in order~~ to make it easier to read, but it will not affect the results. An example can be seen below:

Table 1: Sample of Incidence matrix

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Field of action	Index	Action 1	Action 2	Action3
Energy	Gross primary energy consumed (ktoe/year)	$En1_1$	$En1_2$	$En1_3$
	Energy produced by renewable resources (%)	$En2_1$	$En2_2$	$En2_3$
Environment	Tons of CO2 produced	$Env1_1$	$Env1_2$	$Env1_3$
Economy	Total investment cost (€)	$Ec1_1$	$Ec1_2$	$Ec1_3$
	Rate of return (%)	$Ec2_1$	$Ec2_2$	$Ec2_3$

Mobility	Time saved to arrive to office (min)	$Mob1_1$	$Mob1_2$	$Mob1_3$
Community	Thermal comfort index (%)	$Com1_1$	$Com1_2$	$Com1_3$

The magnitudes corresponding to the effect of the actions against the proposed indicators will be determined through simulations, which will evaluate how the proposed actions perform under the examined conditions. ~~—~~It is important to verify the capacity of the simulation software and the data availability at this point as if the results cannot be trustfully measured by the indexes, these should be adjusted accordingly.

- **Distance to mean normalization**

For the normalization and scaling method, the "distance to mean" method has been chosen. A similar method to those proposed in the OECD (Handbook on Constructing Composite Indicators, 2008) and in the work of (Pompei et al., 2018). Firstly, the mean for every indicator has to be calculated.

$$M_i = \frac{\sum_{j=1}^{n} x_{ij}}{n}; for\ i = ind1, ind2, ind3 \ldots m \qquad [1]$$

Where, *i* will be the indicators and *j* will be each of the actions, *m* will be the total indicators and *n* stands for the total amount of actions suggested. Now, the distance to the mean is calculated for every indicator, using the following equation:

$$a_{ij} = \frac{x_{ij} - M_i}{M_i} \qquad [2]$$

- **Scaling**

After using Equation 2 for all the actions, a scaling factor needs to be added in order to be able to effectively compare all indicators. The scale will be set by using the maximum and minimum magnitudes for every action. The spaces between the limits will be divided into 10 ranges, which will be assigned a score from -5 to 5. The score ranges will be set in such a way that if the action magnitudes are less than 0, they will be set with a score of 0 or below. This means that for negative scores there will be 6 ranges, while for positive ranges only 4. This distribution was made ~~in order~~ to benefit the alternatives that have a higher performance in the indicators. Two different equations will be needed in order to set the limit value for every range:

$$\begin{cases} x_{s+1} + \left|\frac{x_{min}}{5}\right|; for\ s > -4 \\ x_{s-1} + \left|\frac{x_{max}}{4}\right|; for\ s > 0 \end{cases} \qquad [3]$$

Where *s* refers to the score, and x_{min} refers to the minimum and x_{max} refers to the maximum magnitude of the actions. This procedure has to be repeated for all indicators of interest until the matrix is completely normalized and scaled.

- **Correction Factor**

A ~~correction~~ Correction ~~factor~~ Factor has been included to balance the positive and negative magnitudes of the indicators. In some cases, the indicators will measure changes that the higher they get, the higher the project will get benefits. The opposite situation can also happen, where the higher magnitude of the indicator would affect the project negatively. According to this, a correction factor of -1 or 1 was introduced in order to establish the correct interpretation of the indicators. This correction factor is given by the interpretation of the designers and could be avoided if the indicators are properly selected. An example will be given assuming 2 different indicators~~from an energy efficiency project~~:

Table 2: Example of correction factor

Indicator	Correction factor
Gross Energy Consumption (ktoe/year)	-1
Economic savings (€/year)	1

In the example shown in Table 2, it can be seen how correction factor is applied. When Gross Energy Consumption indicator increases, it ~~-~~means that more energy will be consumed per year, which will be an undesirable behaviour for the aims of a project that aims to increase energy efficiency. On the other side, when the Economic Savings indicator increases, it will represent a benefit as it means less money will be spent.~~, which is the objective of energy efficiency projects.~~

- **Economic and time feasibility**

Two additional scores are going to be considered and summed separately from the previously calculated indicators. The assignment of the scores will be determined between 0 and 1 depending on the amount of time and money spent for every intervention. The most expensive interventions got the lowest score of 0, while those most cheap were assigned a score of 1. A similar approach was used for time, where the actions that needed more time to be completed were assigned a value of 0, while those that were installed the quickest had a score of 1. The values in between were given a score according to their value respect to 1. Equation 14 shows the process for assigning the scores to all the intermediate interventions which are neither the cheapest nor the most expensive.

$$x_i = 1 - \left(\frac{c_i}{max[c_i, c_n]}\right) for\ i = 1, n \qquad [4]$$

An example can be seen below in Table 3:

Table 3: Example of time score

Action	Time to install (h)	Score
Action 1	30	0.33
Action 2	15	0.67
Action 3	3	1
Action 4	45	0

The magnitude of the score (between 0 and 1), was assigned targeting to avoid a big change in the final ranking. The use of these weights is intended to show the contribution of aspects that are considered important for any project to be developed, independently from which indicators are being measured.

Hybrid AHP method

A specific modification of the AHP method ~~will be studied in this paper, called by the authors~~was proposed in (Giaccone et al., 2017), called ~~as~~ “Hybrid AHP””. The main difference with the AHP method is the way the data is aggregated from the base level of “action” to the intermediate and higher levels. The scheme, shown in figure 2, ~~will~~ describes the ~~4~~ four levels used in this method and their significance. This hybrid

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scheme has been also applied in literature in the works of (Chen and Wang 2010) and (Fahrul Hassan et al., 2012); it allows to give high relevance to the judgments of the stakeholders related to the selected indicators during the evaluation process. The addition of the stakeholders' opinion is relevant and in line with the latest literature studies, which go in the direction of including all the users and actors in the planning process. Nevertheless, it could imply the addition of a certain subjectivity in the model that should be carefully managed. The comparison of the two methods is a useful way to assess how much this subjectivity influence the final results. This aspect will be further discussed in the conclusion section.

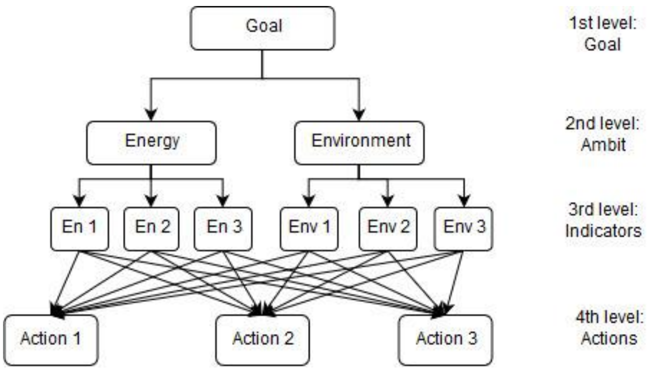

Figure 2. Hybrid AHP scheme

As shown in Figure 2,~~A brief explanation of the Hybrid AHP method is exposed, instead, deep information can be found in the paper of Giaccone et at., 2017.~~ ~~Tt~~t~~T~~he 1^{st} level is the Goal, which is the target that must be reached. The 2^{nd} level ~~,~~ refers to each ambit, which means to the main topic the indicators can be grouped on, ~~. In case of figure 2, the example was given using~~ only energy and environment were given in the example. ~~(Figure 2).~~ However, this model is flexible since the number of main topics and indicators can be changed as needed, including other smart axes such as People & Living, Economy, and Mobility. The weight used for the aggregating data at the 2^{nd} level is given by the number of indicators measured for each ambit divided by the total amount of indicators. Referring to figure 2, the weight for the "Energy" ambit is 0.5 as it is composed ~~by~~ of 3 indicators while the total number of indicators is 6. The 3^{rd} level weight is given by the stakeholders. It refers to how favourable would they be to one indicator of respect to the others in the same ambit. People were, therefore, asked to select which indicator was the most important for each ambit; from the votes, the percentage influence of each indicator ~~in relation to~~concerning its ~~ow~~ambit was assessed. Finally, in the 4^{th} level, the pairwise comparison among actions is made by using eigenvalues. More detailed information regarding the Hybrid AHP method can be found in the paper of (Giaccone et al., 2017).

Finally, i~~I~~n order to properly compare the two methods, authors made a single modification in the Hybrid AHP process proposed by (Giaccone et al., 2017)~~, the original Hybrid AHP model was modified~~ adding the correction factor ~~to~~ ~~inside~~ at the Goal level calculation (1^{st} level of the method).

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Formatted: Justified, Don't keep with next the equation number (Equation 9). This correction factor, as aforementioned before, is a relevant part of the QIMM method since it allows to measure if the impact of indicators is beneficial or unfavourable depending on their correct interpretation. The new equation 9 therefore becomes:

n ambit was assessed. A hypothetical voting process can be seen below, assuming 30 people voting for the energy indicators:

Table 4: Hypothetical voting of indicators

Indicator	EN 1	EN 2	EN 3
Votes	20	2	8
Percentage %	66	7	27

The weight for each indicator is given by the percentage respect to the total voters. In the 4th level the pairwise comparison among actions is made by using eigenvalues. Firstly, a square matrix for every indicator is needed, where the size is determined by the amount of actions to be analysed (3 in this example). Which means, a total of 6 matrices sized 3x3. Taking for example the indicator En1, using magnitudes of each action represented as a variable (A_x), the generated matrix has the following shape:

Table 5: Ratio matrix for EN 1

	Action 1	Action 2	Action 3
Action 1	1	A_1/A_2	A_1/A_3
Action 2	A_2/A_1	1	A_2/A_3
Action 3	A_3/A_1	A_3/A_2	1

Then, local values are calculated, by using the equation:

$$v_n = \sqrt[m]{a_{n1} * a_{n2} * \ldots * a_{nm}} \qquad [5]$$

Where n = m as they represent the number of criteria that will be evaluated. Looking at , the following eigenvector component values, v_i can be obtained:

$$v_1 = \sqrt[3]{A_{11} * A_{12} * A_{13}};\ v_2 = \sqrt[3]{A_{21} * A_{22} * A_{23}};\ v_3 = \sqrt[3]{A_{31} * A_{23} * A_{33}} \qquad [6]$$

where the values A_{nm} refer to each element of the matrix, n referring to the row number, and m to the column number. Now, each eigenvector component is divided by the sum of all of them, as stated by those normalization equations:

$$S = \sum_1^n v_i \quad ; \quad x_n = \frac{v_n}{S} \qquad [7]$$

Equations below show the solution for this example:

$$S = v_1 + v_2 + v_3$$

$$x_1 = \frac{v_1}{S};\ x_2 = \frac{v_2}{S};\ x_3 = \frac{v_3}{S} \qquad [8]$$

In this way, the normalized values for the EN 1 for every action can be obtained. This is used as the local weight $L_{4,EN1}$, to be aggregated with the other weights in order to obtain a score, as it can be seen below:

$$G_{Action1,EN1} = L_{4,EN1} * L_3 * L_2 \qquad [9]$$

Where, the L_3 and L_2 values stand for the 3rd level weight and 2nd level weight. Checking at it can be found L_3 = 0.67 and L_2 = 0.5 as previously stated. The process must be repeated for every indicator, which leads to the equation:

$$G_{Action1} = \sum_{i=EN1 \div ENV3}^{6} G_{Action1,i} \quad [10]$$

Equation 10 must then be repeated for every action. When all the final scores of all actions are calculated, a ranking is created by which an optimal action can be selected for the required goal.

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2.2 Case study

Sicilian residential district case study

This case study comes from the work of (Giaccone et al., 2017), whose objective was to analyse the strategies implemented by a Residential Sector Master Plan using the Hybrid AHP method. The Residential Sector Master Plan aimed to optimally distribute the available economic resources of the region for the development of sustainable interventions supported by building owners. However, the opinion of the stakeholders in the definition of the indicators that would measure the effectivity of the interventions was originally missing. The indicators used for selecting the interventions were mostly referred to as economic issues: €/toe and €/t_{CO2}. The authors of the paper (Giaccone et al., 2017), decided, therefore, to study how the priority of the interventions would have changed if the indicators would have been weighted considering the opinion of the stakeholders. The votes from the stakeholders are presented in the work of (Giaccone et al., 2017). In Tables 4 and 5, the interventions and their respective indicators are shown. Input data referred to these interventions are available in the original paper of (Giaccone et al., 2017).

Table 4: Indicators for the Sicilian District (modified from Giaccone et al., 2017)

Indicators/ Actions		**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**K**
EN1	**Final uses gross energy consumption (ktoe/year)**	1311	1297	1312	1294	1305	1306	1305	1311	1276	1298
EN2	**Energy intensity of the residential sector (toe/M€)**	26.4	26.10	26.40	26.10	26.30	26.30	26.30	26.40	25.70	26.10
EN3	**Saved energy during the life span of proposed action (toe)**	58460	98353	122442	555399	289993	54495	59915	60314	820000	94000
ENV1	**CO2 emission avoided through lifespan of proposed action (tCO2)**	135627	228181	397937	1805047	922980	177110	476331	196022	2665000	305500
ENV2	**Emission intensity (tCO2/M€)**	0.092	0.091	0.092	0.091	0.091	0.091	0.09	0.092	0.09	0.091
EC1	**Average cost of one saved toe (€/toe)**	0.0023	0.0063	0.0015	0.0074	0.0055	0.0028	0.0178	0.0016	0.0292	0.0094
EC2	**Average cost of one tCO2 (€/t CO2)**	0.0053	0.0146	0.0048	0.024	0.018	0.009	0.1418	0.0054	0.0689	0.0209
EC3	**Average cost of one toe saved during the lifespan of the action (€/toe)**	0.0004	0.0008	0.0007	0.0035	0.0026	0.0003	0.0022	0.0003	0.01	0.0012
EC4	**Increase in number of working hours**	192343	312234	564441	5315291	3237806	0	111992	274157	3760000	480000

Table 5: Reference letters and interventions

Reference	Interventions
A	Replacing electric boilers with natural gas boilers
B	Replacing gas fired water heater with open chamber and pilot flame with sealed chamber and electronic ignition
C	Replacing single-window glasses with double - window glasses
D	Building envelope insulation
E	Roof insulation
F	Replacement of electric and electronic household appliances
H	Replacing electric water heaters with methane water heater
I	Installation of high efficiency air conditioning systems
J	Solar thermal collectors
K	PV panels

Palazzo Baleani case study

In order to verify the applicability of the proposed Quantitative Incidence Matrix (QIMM) method, a real case study located in Rome was chosen. It is a typical historical building, called Palazzo Baleani, which was built in the sixteenth century. Currently, the biggest part of the building is owned by the Sapienza University of Rome and the spaces are mainly used as classrooms and offices. The study started with the an analysis of the present state of the art of the building. The main Data data about the building, such as dimensions, construction materials, electrical and thermal loads was were gathered or simulated using engineering software. As expected for an old building, the inefficient outer structureenvelope and and windows greatly reduce impact on the cooling and heating efficiency of the installed systemsconsumption. However, the age and relevance of the building limits the possibilities of refurbishment and the addition of technical and technological devices, especially on the façade, according to the current Standard (Ragni et al., 2018; Legislative Decree, 2004). A similar situationSiImilarly, the installation limits the placement area of PV panels is forbidden, because they can affect the outer appearance of the building. Considering these restrictions, the improvement due to the implementation of selected interventions was calculated. Performing the simulations, the biggest issues to be resolved were identified. TheFew indicators were defined in order to measurefor measuring the impact of the interventions would have on many several Smart fields of action (Energy, Economy, Environment, Community). The final list of interventions can be seen in Tables 46 and 57. Information provided by the simulations and available data is enough to calculate the indicators in a proper way. In Ttable 46, The results from the simulations can be seen in the incidence matrix shown in Table 84. the cells highlighted in grey show that in a few cases the results are negative. These values were substituted with zero by the authors to properly apply both QIMM and AHP methods to this case study, since the AHP cannot process negative values. Some cells are highlighted in grey, as the significance of the measuring opposes the indicator EC 2, Com1 and Com2 (they have negative values) becoming an invalid magnitude. In order to properly compare both methods, the negative values were substituted with zero. The list of interventions can be seen in Tables 8 4 and 95.

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Moreover, ~~In Ttable 84,~~ four of the strategies are alternative. The method can be indeed used to assess if it would be preferable to install a traditional photovoltaic system (PV A) or the photovoltaic roof tiles (PV B). Similarly, it can also be used for choosing between COOL 1 and COOL 2:

- COOL 1: The installation of four heat pumps at Variable Refrigerant Flow which supply indoor air conditioning units in offices, school rooms and conference rooms
- COOL 2: The installation of an air handling unit and an inverter heat pump for conditioning the entire building, taking advantage of the existing air ducts and an absorption chiller.

Intervention on windows regards the addition of a supplementary internal glass to the existing windows in order to create an air gap of 20 mm and reduce the thermal transmittance; the Energy Management System (EMS) allows to monitor and manage ~~the~~ loads of the building ~~in order~~ to reduce consumption and optimize electricity peaks; intervention on the solar heating system (SHS) consists in the substitution of the broken collectors already placed on the roof of the building and to reactivate the entire system; regarding the lighting systems, the two mono-lamp fluorescent tubes installed in the ceiling fixtures are replaced with LED tubes. The other strategies (T, E, T-E, T-D, E-D, T-E-D) are ~~basically~~ combinations of the aforementioned strategies. By applying the two methods it will be therefore interesting to assess if it is more efficient to develop single or combined strategies from a holistic perspective.

Table ~~8~~6: List of indicators and strategies

		Strategies													
Indicators		Windows	Cool 1	Cool 2	PV A	PV B	EMS	SHS	Light	T	E	T-E	T-D	E-D	T-E-D
En1	Gross Energy Consumption (toe/year)	20.8	25.9	24.8	42.1	41.3	43.4	44.9	43.7	32.8	37.0	23.1	30.9	36.6	21.6
En2	Energy Consumption on lifespan (toe)	417	648	621	842	826	1301	1123	1310	656	924	461	618	914	431
En3	Primary Energy Index (%)	0.16	0.19	0.24	0.09	0.11	0.08	0.03	0.07	0.29	0.20	0.50	0.33	0.20	0.53
Env 1	Annual CO2 emissions (tCO2)	97	106	101	95	93	98	106	98	94	82	61	93	81	57
Env 2	Local pollution index (%)	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	1.00
Ec1	Average cost of toe saving (€/toe*year)	51	138	109	309	256	309	1323	339	216	52	83	114	149	31
Ec2	Average cost of CO2 saving (€/tCO2)	3491	-24	-24	866	896	4950	30296	5428	1661	691	745	658	-2412	211
Com 1	Thermal comfort index (%)	1.29	0.82	0.82	0	0	0	0	-0.01	0.88	-0.01	0.88	0.88	-0.04	0.88
Com 2	Thermal dissatisfaction index (%)	0.53	0.63	0.63	0	0	0	0	-0.03	0.67	-0.03	0.66	0.66	-0.03	0.66

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Table 97: Reference abbreviation of interventions

actions	Alternative
A	Windows refurbishment
B	Improvement of the cooling system (type A)
C	Improvement of the cooling system (type B)
D	Photovoltaic System
E	Roof tiles Photovoltaic System
F	Energy management system
G	Solar Heating System
H	Light fixtures replacement
I	Thermal (COOL2 +Windows)
J	Electric (PV A + Management system+ Light)
K	Thermal + Electric
L	Thermal + Solar Heating System
M	Electric + Solar Heating System
N	Thermal + Electric + Sanitary hot water

Sicilian residential district case study

This case study comes from the work of (Giaccone et al., 2017), whose objective was to analyse the strategies implemented by a Residential Sector Master plan by means of the Hybrid AHP method. The Residential Sector Master Plan This plan aimed to optimally distribute the available economic resources of the region for the development of sustainable interventions supported by building owners. However, the opinion of the stakeholders in the definition of the indicators that would measure the effectivity of the interventions was originally missing. The indicators used for selecting the interventions were mostly referred to economic issues: €/toe and €/t_{CO2}. The authors of the paper (Giaccone et al., 2017), decided therefore to study how the priority of the interventions would have changed if the indicators would have been weighted considering the opinion of the stakeholders.presented(Giaccone et al., 2017) The data for the indicators was obtained from simulations for each intervention, throughout the years of 2004 to 2012. In Tables 6 and 7, the interventions and their respective indicators are shown. Input data referred to these interventions are available in the original paper of (Giaccone et al., 2017).

Table 6: Indicators for Sicilian District (see table 3 in the work of Giaccone et al., 2017 for the numerical results).

Actions								
EN1	EN2	EN3	ENV1	ENV2	EC1	EC2	EC3	EC4
Final uses gross energy consumption (ktoe/year)	Energy intensity of the residential sector (toe/M€)	Saved energy during the life span of proposed action (toe)	CO2 emission avoided through lifespan of proposed action (tCO2)	Emission intensity (tCO2/M€)	Average cost of one saved toe (€/toe)	Average cost of one tCO2 (€/t CO2)	Average cost of one toe saved during the lifespan of the action (€/toe)	Increase in number of working hours

Table 7: Reference letters and interventions

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Reference	Interventions
A	Replacing electric boilers with natural gas boilers
B	Replacing gas fired water heater with open chamber and pilot flame with sealed chamber and electronic ignition
C	Replacing single-window glasses with double - window glasses
D	Building envelope insulation
E	Roof insulation
F	Replacement of electric and electronic household appliances
H	Replacing electric water heaters with methane water heater
I	Installation of high efficiency air conditioning systems
J	Solar thermal collectors
K	PV panels

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3. Results

3.1. Sicilian residential district case study: QIMM method application Application of QIMM method

Sicilian residential district case study

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In this section, the QIMM model is applied to the Sicilian district. The entire process using Action A as an example is shown in Table 10.

Table 10. Example of QIMM process for Action A

		Action A								
		Indicators								
		EN 1	EN 2	EN 3	ENV1	ENV2	EC1	EC2	EC3	EC4
L3	Distance to mean	0.72	0,72	-73,59	-81,45	-0,99	-72,55	-83,05	-81,82	-86,5
	Score	4	5	-4	-5	-5	-4	-4	-4	-4
	CF	-1	1	1	1	1	-1	-1	-1	1
	Sum	-5								
L2	Time feasibility	0.83								
	Economic feasibility	0.30								
L1	TOTAL	-3.87								

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As noticeable in table 10, the level L3 includes the “distance to mean” normalization; the level L2 regards the weighting process with the addition of the scores “Economic feasibility” and “time feasibility”; the level L1 finally allows to get the score of each action. As aforementioned in the QIMM scaling process for the score assignation, the scale can be adjusted to the magnitudes that are being worked with. In this work authors propose a score range between -5 and 5 and the exemplificative results are shown in Table 11. Since the distance to mean for EN1 is 0.72, which is comprised between 0.60-0.80 according to this scaling, the score assigned is 4.

Table 11. Example of scaling factor of EN1 indicator

EN1		
score scaling	min	max
-5	-2.0	
-4	-1.98	-1,58
-3	-1.58	-1,19
-2	-1.19	-0,79
-1	-0.79	-0,40
0	-0.40	0,00
1	0.00	0,20
2	0.20	0,40
3	0.40	0,60
4	0.60	0,80
5	0.80	

A "standard house" was chosen as base case example to assess the time required for intervention, used in the calculation of the "Time feasibility score". An example of timing for a few actions is shown in Table 12 with the relative bibliographic sources.

Table 12: Estimated time for interventions

Intervention	Time required	Source
A	3 days/ floor	[1]
B	about 10 week	[2]
C	15 windows per day	[3]
D	25 days	[4]
E	1 week	[5]
F	5 days	[6]
H	3 hours/ house	[7]
I	4 days	[8]
J	2 days	[9]
K	2 days	[9]

Regarding the economic feasibility, the investment costs of each intervention were available in the paper of (Giaccone et al., 2017). Using therefore the data on time and costs, the respective scores have been calculated, as shown in Table 13. The final ranking is shown in Table 14.

Table 13: Time and cost feasibility scores for the Sicilian residential district

Costs feasibility	Time feasibility

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Intervention	Total cost (M€)	Score	Hours	Score
A	192.3	0.30	288	0.83
B	156.1	0.44	1728	0.00
C	276.5	0.00	384	0.78
D	250.7	0.09	600	0.65
E	171	0.38	168	0.90
F	196.4	0.29	120	0.93
H	33.9	1.00	1728	0.00
I	274.1	0.01	96	0.94
J	117	0.58	3	1.00
K	100	0.64	48	0.97

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Table 14: Final Ranking for the Sicilian residential district applying the QIMM method

Ranking	QIMM Actions	QIMM Score
1	D	6.74
2	E	3.28
3	C	1.78
4	I	-2.05
5	J	-2.42
6	A	-3.87
7	F	-4.78
8	B	-8.56
9	K	-11.39
10	H	-22

With this method, high relevance was attributed to the interventions on the building envelope (D, E and C actions), which occupy the first three positions. Conversely, the last positions are occupied by the installation of PV panels (K) and the replacement of electric water heaters with methane water heaters (H).

Palazzo Baleani case study

In this sub-section, the QIMM is applied to the Sicilian residential districtPalazzo Baleani. In order to To explain clearly each step of the method, steps, the authors decided to describe the entire process for a single action, knowing that it is repeated for all the strategies exposedshown in Table 5. MoreoveIn this caser, the Correction Factor has been defined based on the indicator's interpretation given in (Giaccone et al., 2017). More in detail, EN1 is negative since it represents the total energy consumption per year and so the best is the lowest; EN2 is positive since it is the efficiency used for a country to convert the Gross Domestic Product into energy commodities; EN3 is positive since it represents the total energy saved in one year; both the environment indicators (ENV1 and ENV2) are positive and represent savings in CO_2 emissions; EC1, EC2 and EC3 are considered negative since they quantify the average expenses per toe and

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CO_2 and finally EC4 is positive since, as said in (Giaccone et al., 2017), it represents the number of new jobs created by the realization of each intervention. A~~. The process is the same as for the Sicilian district: performing normalization procedure; defining the scale factors; assigning the additional weights. An~~n example of the QIMM application is shown for action A (~~ for action A is shown in~~ Table ~~15~~8):

Table ~~15~~8: Example of QIMM process for Action A

		Action A								
		Indicators								
		EN 1	EN 2	EN 3	ENV1	ENV2	EC1	EC2	EC3	EC4
L3	Distance to mean	0.72	0.72	-73.59	-81.45	-0.99	-72.55	-83.05	-81.82	-86.5
	Score	4	5	-4	-5	-5	-4	-4	-4	-4
	CF	-1	1	1	1	1	-1	-1	-1	1
	Sum	-5								
L2	Time feasibility	0.83								
	Economic feasibility	0.30								
L1	TOTAL	-3.87								

As noticeable in Table 8, the level L3 includes the “distance to mean” normalization and the CF assignment; the level L2 regards the weighting process with the addition of the scores “Economic feasibility” and “time feasibility”; the level L1 finally allows to get the score of each action. As aforementioned in this method, the scaling process for score assignation can be adjusted to the magnitudes that are being worked with. In this work, authors propose a score range between -5 and 5 and the exemplificative results are shown in Table 9. As an example for EN1, since the distance to mean for EN1 is 0.72, which is comprised between 0.60-0.80 according to this scaling, the score assigned is 4.

Table 9. Example of scaling factor of EN1 indicator

EN1		
score scaling	min	max
-5	-2.0	
-4	-1.98	-1.58
-3	-1.58	-1.19
-2	-1.19	-0.79
-1	-0.79	-0.40
0	-0.40	0.00
1	0.00	0.20
2	0.20	0.40
3	0.40	0.60
4	0.60	0.80
5	0.80	

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Then, a "standard house" was reference case studies were chosen as a base case examples to assess the time required for intervention, used in the calculation of the "Time feasibility score". An example of timing for a few actions is shown in Table 10 with the relative bibliographic sources.

Table 10: Estimated time for interventions

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Intervention	Time required	Source
A	3 days/ floor	[1]
B	about 10 week	[2]
C	15 windows per day	[3]
D	25 days	[4]
E	1 week	[5]
F	5 days	[6]
H	3 hours/ house	[7]
I	4 days	[8]
J	2 days	[9]
K	2 days	[9]

Regarding the economic feasibility, the investment costs of each intervention were available in the paper of (Giaccone et al., 2017). Using, therefore, these data on time and costs, the respective scoresscores have been calculated, as shown in Table 11. The final ranking is reportedshown in Table 12.

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Table 11: Time and cost feasibility scores for the Sicilian residential district

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	Costs feasibility		Time feasibility	
Intervention	Total cost (M€)	Score	Hours	Score
A	192.3	0.30	288	0.83
B	156.1	0.44	1728	0.00
C	276.5	0.00	384	0.78
D	250.7	0.09	600	0.65
E	171	0.38	168	0.90
F	196.4	0.29	120	0.93
H	33.9	1.00	1728	0.00
I	274.1	0.01	96	0.94
J	117	0.58	3	1.00
K	100	0.64	48	0.97

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Table 12: Final Ranking for the Sicilian residential district applying the QIMM method

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	QIMM	
Ranking	Actions	Score
1	D	6.74
2	E	3.28
3	C	1.78
4	I	-2.05

5		J	-2.42
6		A	-3.87
7		F	-4.78
8		B	-8.56
9		K	-11.39
10		H	-22

Using this method, high relevance was attributed to the interventions on the building envelope actions D, E and C, which respectively regard: Building Envelope Insulation (D), Roof insulation (E), Replacing single-window glasses with double ones (C). These results underline that very high importance is given to those interventions regarding the refurbishment of the building envelope, which guarantees good energy and environmental performance with moderate economic expenses. Conversely, the last positions are occupied by the installation of PV panels (K) and the replacement of electric water heaters with methane water heaters (H).

Regarding the of the indicatorsthe Correction Factor is assigned as follows: also COM1 and COM2 is method, the can As an example for EN1, sAs table 15 shows, the entire process of normalization is applied to each indicator, using the distance to mean methods. Therefore, the scores range between -5 and 5, as in the previous case study. In Table 16 an example of scaling factor for EN1 is shown.

Table 16: Example of scaling factor of EN1 indicator

EN1		
score scaling	min	max
-5	-37.8	
-4	-37.8	-30.2
-3	-30.2	-22.7
-2	-22.7	-15.1
-1	-15.1	-7.6
0	-7.6	0.0
1	0.0	8.5
2	8.5	17.1
3	17.1	25.6
4	25.6	34.1
5	34.1	

Time data for calculating the additional weight were taken from literature studies, where similar interventions to the planned ones have been performed. Data collected are shown in table 17 along with the relative bibliographic sources. Assumptions have been made for adjusting these data. As an example, in our case study air ducts for HVAC and pipes for DHW are already installed in the building and works properly. Accordingly, the original data about the installation timing were proportionally reduced.

Table 17: Estimated time for interventions

Intervention	Time required	Source
D-E	2 days	[9]

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A	15	windows per day	[10]
B-C	4	days	[11]
G	3	hours	[12]
H	1	hour / room	[13]
F	1	hour / room	[14]

Assumptions have been made for adjusting these data. As an example, in our case study air ducts for HVAC and pipes for DHW are already installed in the building and works properly. Accordingly, the original data about the installation timing were proportionally reduced. Regarding the costs, information was taken either from literature or from market price. Data, sources and relative scores are shown for each intervention in Tables 18 and 19.

Table 18: Time estimations scores

Intervention	Hours	Score
D-E	48	0.68
A	149	0.00
B-C	96	0.35
G	3	1.00
H	132	0.11
F	132	0.11
I	149	0.00
J	132	0.11
K	149	0.00
L	149	0.00
M	132	0.11
N	149	0.00

Table 19: Cost estimations scores

	Cost (€)	Source	Score
A	32865	[15], [16]	0.87
B	250337	[15]	0.00
C	74629	[15]	0.70
D	38400	[17], [18]	0.85
E	70900	[18], [19]	0.72
F	29645	[20]	0.88
G	4200	[21], [22]	1.00
H	8715	[23], [24]	0.97
I	107494	Sum of COOL 2+Windows	0.57
J	76760	Sum of PV A+ EMS+Light	0.69
K	184254	Sum of T+E	0.26

L	111694	Sum of T+SHS	0.55
M	80960	Sum of E+SHS	0.68
N	188454	Sum of T+E+SHS	0.25

Table 20 shows the final ranking of the proposed QIMM approach.The best scenario is the combination of thermal, electric and the renovation of the Solar heating system (N) as in the Hybrid AHP ranking and the second position (K) is occupied by the thermal + electric scenario (PV, Management system and Lighting systems). The third position is occupied by the thermal + solar heating system (L). These three ranks show the importance of the thermal interventions combined with all the others. Regarding the single interventions, the best one is still the improvement of the cooling system type B (C). The last positions are occupied also in this case by the refurbishment of the lighting system (H) and the Solar heating system (G).

Table 20: Final Ranking for Palazzo Baleani applying the QIMM method

Ranking	QIMM Actions	QIMM Score
1	N	39.25
2	K	34.26
3	L	23.55
4	C	23.06
5	I	16.57
6	B	16.35
7	A	14.87
8	J	-9.19
9	M	-9.21
10	E	-18.61
11	D	-21.48
12	F	-29.01
13	H	-29.92
14	G	-41.02

3.2 Sicilian residential district case study: Hybrid AHP -method application

The best scenario is the combination of thermal, electric and the renovation of the Solar heating system (N) as in the Hybrid AHP ranking and the second position is occupied by the thermal + electric scenario (PV, Management system and Lighting systems). The third position is occupied by the thermal + solar heating system (L). These three ranks show the importance of the thermal interventions combined with all the others. Regarding the single interventions, the best one is still the improvement of the cooling system type B (C). The last positions are occupied also in this case by the refurbishment of the lighting system (H) and the Solar heating system (G). *Palazzo Baleani case study*

The steps of the application of Hybrid AHP method to Palazzo Baleani are shown in table 25 for Action A.As aforementioned, idevelopthe two methodsThis section describes the application of the Hybrid AHP method to the Sicilian district. Table 13 shows the results at each level of the method related to Action A. As aforementioned, in order to develop a correct comparison of the two methods, the Correction Factor (highlighted in grey in Table 13) was added in the Hybrid AHP procedure by the authors.

Table 13: Example of Local-global final table of each action.

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	Action A						
Indicators	Eigenvalues	Stakeholders preferences %	Evaluation Ambits	Goal level		Final score	
	L4	L3	L2	L1	Sum	CF	G
EN1	0.1	22			0.74	-1	
EN2	0.1	30	0.33	1	1.01	1	
EN3	0.03	48			0.42	1	
ENV1	0.02	67	0.22	1	0.28	1	
ENV2	0.1	33			0.74	1	1.72
EC1	0.03	15			0.18	-1	
EC2	0.02	15	0.44	1	0.11	-1	
EC3	0.02	15			0.12	-1	
EC4	0.02	55			0.43	1	

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Table 25. Example of Local-global final table of each actions.

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-	Action A						
Indicators	Eigenvalues	Stakeholders preferences %	Evaluation Ambits	Goal level		Final score	
	L4	L3	L2	L1	Sum	CF	G
EN1	0.0444	1	0.33		0.014652	-1	
EN2	0.0376	1	0.33	1	0.012408	-1	
EN3	0.053	1	0.33		0.01749	1	
ENV1	0.0769	1	0.5	1	0.03845	-1	
ENV2	0	1	0.5		0	1	0.05078
EC1	0.0148	1	0.5	1	0.0074	-1	
EC2	0.0878	1	0.5		0.0439	-1	
Com1	0.1695	1	0.5	1	0.08475	1	
Com2	0.1307	1	0.5		0.06535	1	

In this case the interpretation of correction factor (CF) has been developed by the authors. Regarding the energy indicators (EN1 and EN2) the value is negative since they respectively represent the annual consumption in toe of each intervention and the total consumption of each intervention in its lifespan, while EN3 is positive since it is the savings in primary energy before and after the interventions. The ENVI1 environmental indicator is negative since it counts the amount of global emissions while ENV2 is positive since it represents the reduction; similarly, also the economic indicators are negative, quantifying the expenses for savings one toe and one tonne of CO_2 per year. Finally, both the community indicators express a positive impact, representing the improvements in thermal comfort and level of dissatisfaction before and after the intervention.

In the 4th level (L4), eigenvalues pairwise comparison is applied to the proposed interventions. Each indicator has a corresponding ratio matrix (as Table 14), with a total of 9 matrices.

The pairwise comparison among the interventions is performed using the same procedure as in the previous case study. In table 26 there is an example of EN1 matrix while in Table 27 the Eigenvectors calculation is shown.

Table 2614. Example of Ratio matrix of each indicators

	A	B	C	D	E	F	H	I	J	K
	1	1.011	0.999	1.013	1.004	1.004	1.005	1.000	1.028	1.010
	0.989	1	0.989	1.002	0.994	0.993	0.994	0.990	1.017	0.999
	1.001	1.011	1	1.013	1.005	1.005	1.005	1.001	1.028	1.011
	0.988	0.998	0.987	1	0.992	0.991	0.992	0.988	1.015	0.997
EN1	0.996	1.006	0.995	1.008	1	1.000	1.001	0.996	1.023	1.006
	0.996	1.007	0.995	1.009	1.000	1	1.001	0.996	1.024	1.006
	0.995	1.006	0.995	1.008	0.999	0.999	1	0.995	1.023	1.005
	1.000	1.011	0.999	1.013	1.004	1.004	1.005	1	1.027	1.010
	0.973	0.984	0.972	0.985	0.977	0.977	0.978	0.973	1	0.983
	0.990	1.001	0.989	1.003	0.994	0.994	0.995	0.990	1.017	1

-	Windows	COOL 1	COOL 2	PV A	PV B	EMS	DWH	Light	T	E	T-E	T-D	E-D	T-E-D
	1	0.803	0.838	0.495	0.504	0.480	0.464	0.477	0.635	0.564	0.904	0.674	0.569	0.966
	1.245	1	1.043	0.616	0.628	0.598	0.577	0.594	0.791	0.702	1.125	0.839	0.709	1.202
	1.193	0.959	1	0.590	0.602	0.573	0.553	0.569	0.758	0.672	1.078	0.804	0.679	1.152
	2.021	1.623	1.694	1	1.019	0.970	0.937	0.964	1.284	1.139	1.826	1.362	1.151	1.952
	1.983	1.593	1.662	0.981	1	0.952	0.920	0.946	1.260	1.118	1.791	1.337	1.129	1.915
	2.083	1.674	1.746	1.031	1.050	1	0.966	0.994	1.323	1.174	1.882	1.404	1.186	2.012
	2.156	1.732	1.807	1.067	1.087	1.035	1	1.028	1.370	1.215	1.948	1.454	1.228	2.083
EN1	2.096	1.684	1.757	1.038	1.057	1.007	0.972	1	1.332	1.182	1.894	1.413	1.194	2.025
	1.574	1.265	1.319	0.779	0.794	0.756	0.730	0.751	1	0.887	1.422	1.061	0.896	1.520
	1.774	1.425	1.487	0.878	0.895	0.852	0.823	0.846	1.127	1	1.603	1.196	1.010	1.714
	1.107	0.889	0.928	0.548	0.558	0.531	0.513	0.528	0.703	0.624	1	0.746	0.630	1.069
	1.483	1.192	1.243	0.734	0.748	0.712	0.688	0.707	0.942	0.836	1.340	1	0.845	1.433
	1.756	1.411	1.472	0.869	0.886	0.843	0.814	0.838	1.116	0.990	1.587	1.184	1	1.696
	1.035	0.832	0.868	0.512	0.522	0.497	0.480	0.494	0.658	0.583	0.935	0.698	0.590	1

Then, the eigenvectors are elaboratedelaborated and it is possible to obtain the normalized values of EN1 for every action, as shown in Table 15. Once the eigenvalues for each indicator are calculated, they are multiplied by both the weights of the stakeholders and the weights of each ambit to get athe final score for a determined alternative.

Table 2715. Example of eigenvectors calculation as local values.

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Indicator	Eigenvectors		Eigenvectors (divided by the Sum)	Actions
EN1	v1	0.644	0.0444	A
	v2	0.802	0.0553	B
	v3	0.769	0.0530	C
	v4	1.302	0.0898	D
	v5	1.278	0.0881	E
	v6	1.342	0.0925	F
	v7	1.390	0.0958	G
	v8	1.351	0.0932	H
	v9	1.014	0.0699	I
	v10	1.143	0.0788	J
	v11	0.713	0.0492	K
	v12	0.956	0.0659	L
	v13	1.1320	0.0780	M
	v14	0.6674	0.0460	N
	Sum	14.5093		

Indicator	Eigenvectors		Eigenvectors (divided by the Sum)	Actions
EN1	v1	1.007	0.1007	A
	v2	1.00	0.100	B
	v3	1.01	0.101	C
	v4	0.99	0.099	D
	v5	1.00	0.100	E
	v6	1.00	0.100	F
	v7	1.00	0.100	H
	v8	1.01	0.101	I
	v9	0.980	0.098	J
	v10	0.997	0.100	K
	Sum	10		

The votes from the stakeholders are reported in the work of Giaccone et al 2017 in Table 6. The total votes for each indicator are divided by the 67 voters of the ambit and multiplied by 100 to obtain the percentage weight. The number of indicators for each ambit is divided by the total number of indicators. According to this, the weights of the ambits are respectively: 0.33 for Energy, 0.22 for Environment, 0.44 for Economy. Final results are provided in Table 16.

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Table 16: Final ranking for the Sicilian district applying the Hybrid AHP method

	Hybrid AHP	
Ranking	Actions	Score
1	D	15.12
2	J	11.82
3	E	8.86
4	C	3.40
5	I	2.09
6	B	1.79
7	A	1.72
8	K	1.71
9	F	1.25
10	H	-2.44

The rank shows that the most efficient solutions, occupying the first four positions, are the following: Building Envelope Insulation (D), Solar Thermal collectors (J), Roof insulation (E), Replacing single-window glasses with double ones (C). Intervention D got the same rank with both methods, instead; conversely,, intervention J achieved a better position, compared to the ranking of the QIMM method (see Table 12). ConverselTy, the last positions are occupied by the replacement of electric and electronic household appliances (F) and the replacement of electric water heaters with methane water heaters (H).

~~The weights of the ambits (2nd level) are assigned for every indicator. In this case, the weights are: 0.33 for Energy, 0.50 for Environment, 0.50 for Economy, 0.50 for Community. For this case study, due to the absence of stakeholders' opinion, the scores are given as if all the stakeholders hadn't voted. Table 28 shows the final ranking.~~

~~Table 28: Final ranking for Palazzo Baleani case study applying the Hybrid AHP method~~

	Hybrid AHP	
Ranking	Actions	score
1	N	0.22
2	K	0.20
3	L	0.16
4	C	0.15
5	B	0.14
6	I	0.12
7	A	0.05
8	J	-0.08
9	M	-0.09
10	E	-0.13
11	D	-0.14
12	F	-0.20
13	H	-0.21
14	G	-0.53

Ranking highlights that the best scenario is the combination of thermal + electric + the renovation of the Solar heating system scenario (N) followed by the thermal + electric scenario (K) and the thermal + solar heating system (L). It shows that the benefits given by the sum of all the single interventions (N) is able to guarantee positive scores and impacts from all the perspectives (energy, environment, economy and community). Regarding the single interventions, the best one is the improvement of the cooling system type B (C), which concerns the installation of an air handling unit and an inverter heat pump. The replacement of lighting fixtures (H) and solar heating system (G) got instead the lowest score. It is worthy to notice that the four best and the two worst interventions are the same in the two methods.

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3.3 Palazzo Baleani case study: QIMM method application

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In this section, the QIMM method is applied to the Palazzo Baleani. The process is the same as for the Sicilian residential districtSicilian district: performing normalization procedure; defining the scale factors; assigning the additional weights. Regarding the interpretation of the indicators, the Correction Factor is assigned as follows: the energy ones (EN1 and EN2) are negative since they respectively represent the annual consumption in toe of each intervention and the total consumption of each intervention in its lifespan, while EN3 is positive since it is the savings in primary energy before and after the interventions. The ENVI1 environmental indicator is negative since it counts the amount of global emissions while ENV2 is positive since it represents the reduction of local pollution; similarly, the economic indicators are also negative, quantifying the expenses for savings one toe and one tonne of CO_2 per year. Finally, both the community indicators COM1 and COM2 express a positive impact, representing the improvements in thermal comfort and level of dissatisfaction before and after the intervention. Table 17 shows the final ranking of the proposed QIMM approach.

Table 17: Final Ranking for Palazzo Baleani applying the QIMM method

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	QIMM	
Ranking	**Actions**	**Score**
1	N	39.25
2	K	34.26
3	L	23.55
4	C	23.06
5	I	16.57
6	B	16.35
7	A	14.87
8	J	-9.19
9	M	-9.21
10	E	-18.61
11	D	-21.48
12	F	-29.01
13	H	-29.92
14	G	-41.02

The best scenario is the combination of thermal, electric and the renovation of the Solar heating system (N) whileand the second position (K) is occupied by the thermal + electric scenario (PV, Management system and Lighting systems). The third position is occupied by the thermal + solar heating system (L). These three ranks show the importance of the thermal interventions combined with all the others. Regarding the single interventions, the best one is the improvement of the cooling system type B (C). The last positions are occupied by the refurbishment of the lighting system (H) and the Solar heating system (G).

orrection actorindicator'sMore in detail positive since it representsare positive and it actions ,respectively regard: Building Envelope Insulation (D), Roof insulation (E), Replacing single window glasses with double ones (C) These results underline that very high importance is given to those interventions regarding the refurbishment of the building envelope, which guarantees good energy and environmental performance with moderate economic expenses.

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*3.4 Palazzo Baleani case study: the Hybrid AHP method application*3.1 Application of Hybrid AHP method

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In order to properly compare the two methods, the original Hybrid AHP model was modified adding the correction factor to the equation number (Equation 9). This correction factor, as aforementioned before, is a relevant part of the QIMM method since it allows to measure if the impact of indicators is beneficial or unfavourable depending on their correct interpretation. The new equation 9 therefore becomes:

Finally,

$$G_{Action1,EN1} = L_{4,EN1} * L_3 * L_2 * CF$$

[11]

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Sicilian residential district case study

This section describes tthe application of the Hybrid AHP method to the Sicilian districtPalazzo Baleani, following exactly the same procedure explained for the Sicilian residential district, was the procedure developed in (Giaccone et al., 2017)done. In this case, the weights of the ambits (2nd level) are 0.33 for Energy, 0.50 for Environment, 0.50 for Economy, 0.50 for Community. Moreover, due to the absence of stakeholders' opinion of the Palazzo Baleani case, the scores are given as if all the stakeholders hadn't voted. Also in this application, the correction factor was added, according to the indicator's interpretation exposed in the previous paragraph. As aforementioned , the correction factor (CF) is included in this analysis.The Then, final results are provided in Table 18.

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Table 18: Final ranking for Palazzo Baleani case study applying the Hybrid AHP method

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	Hybrid AHP	
Ranking	**Actions**	**score**
1	**N**	0.22
2	**K**	0.20
3	**L**	0.16
4	**C**	0.15
5	**B**	0.14
6	**I**	0.12
7	**A**	0.05
8	**J**	-0.08
9	**M**	-0.09
10	**E**	-0.13
11	**D**	-0.14
12	**F**	-0.20

13	H	-0.21
14	G	-0.53

The ranking highlights that the best scenario is the combination of thermal + electric + the renovation of the Solar heating system scenario (N) followed by the thermal + electric scenario (K) and the thermal + solar heating system (L). Regarding the single interventions, the best one is the improvement of the cooling system type B (C), which concerns the installation of an air handling unit and an inverter heat pump. The replacement of lighting fixtures (H) and solar heating system (G) got, instead, the lowest score. It is worthy to notice that the four best and the two worst interventions are the same in the two methods.

	Action A						
Indicators	Eigenvalues	Stakeholders preferences %	Evaluation Ambits	Goal level	Final score		
	L4	L3	L2	L1	Sum	CF	G
EN1	0.1	22			0.74	-1	
EN2	0.1	30	0.33	1	1.01	1	
EN3	0.03	48			0.42	1	
ENV1	0.02	67	0.22	1	0.28	1	
ENV2	0.1	33			0.74	1	1.72
EC1	0.03	15			0.18	-1	
EC2	0.02	15	0.44	1	0.11	-1	
EC3	0.02	15			0.12	-1	
EC4	0.02	55			0.43	1	

The correction factors included in the analysis (called CF in Table 21) have been defined based on the interpretation given in (Giaccone et al., 2017). EN1 is indeed negative since it represents the total energy consumption per year and so the best is the lowest; EN2 is positive since it is the efficiency used for a country to convert the Gross Domestic Product into energy commodities; EN3 is the total energy saved in one year; both the environment indicators (ENV1 and ENV2) represent savings in CO_2 emissions; EC1, EC2 and EC3 are considered negative since they quantify the average expenses per toe and CO_2 and finally EC4 is positive since, as said in (Giaccone et al., 2017) represents the number of new jobs created by the realization of each intervention.

In the 4th level (L4), eigenvalues pairwise comparison is applied to the proposed interventions. Each indicator has a corresponding ratio matrix (as Table 22), with a total of 9 matrices. In this case, no scale is needed as the data is quantitatively homogeneous.

Table 22: Example of Ratio matrix of each indicators

	A	B	C	D	E	F	H	I	J	K
EN1	1	1.011	0.999	1.013	1.004	1.004	1.005	1.000	1.028	1.010
	0.989	1	0.989	1.002	0.994	0.993	0.994	0.990	1.017	0.999
	1.001	1.011	1	1.013	1.005	1.005	1.005	1.001	1.028	1.011
	0.988	0.998	0.987	1	0.992	0.991	0.992	0.988	1.015	0.997
	0.996	1.006	0.995	1.008	1	1.000	1.001	0.996	1.023	1.006

	0.996	1.007	0.995	1.009	1.000	1	1.001	0.996	1.024	1.006
	0.995	1.006	0.995	1.008	0.999	0.999	1	0.995	1.023	1.005
	1.000	1.011	0.999	1.013	1.004	1.004	1.005	1	1.027	1.010
	0.973	0.984	0.972	0.985	0.977	0.977	0.978	0.973	1	0.983
	0.990	1.001	0.989	1.003	0.994	0.994	0.995	0.990	1.017	1

Then, the eigenvectors are calculated by using Equation 6 and then divided by the sum of all of them, as explained in section 2. In this way, it is possible to obtain the normalized values of EN1 for every action, as shown in Table 23. Once the eigenvalues for each indicator are calculated, they are multiplied by both the weights of the stakeholders and the weights of each ambit in order to get a final score for a determined alternative.

Table 23: Example of eigenvectors calculation as local values.

Indicator	Eigenvectors		Eigenvectors (divided by the Sum)	Actions
EN1	v1	1.007	0.1007	A
	v2	1.00	0.100	B
	v3	1.01	0.101	C
	v4	0.99	0.099	D
	v5	1.00	0.100	E
	v6	1.00	0.100	F
	v7	1.00	0.100	H
	v8	1.01	0.101	I
	v9	0.980	0.098	J
	v10	0.997	0.100	K
	Sum	10	-	-

The votes from the stakeholders are reported in the work of Giaccone et al 2017 in table 6. The total votes for each indicator are divided by the 67 voters of the ambit and multiplied by 100 to obtain the percentage weight.

The number of indicators for each ambit is divided by the total number of indicators. According to this, the weights of the ambits are respectively: 0.33 for Energy, 0.22 for Environment, 0.44 for Economy. Final results are provided in Table 24.

Table 24: Final ranking for Sicilian district applying the Hybrid AHP method

Ranking	Hybrid AHP	
	Actions	Score

1	

1	D	15.12
2	J	11.82
3	E	8.86
4	C	3.40
5	I	2.09
6	B	1.79
7	A	1.72
8	K	1.71
9	F	1.25
10	H	-2.44

The rank shows that the most efficient solutions, occupying the first four positions, are the following: Building Envelope Insulation (D), Solar Thermal collectors (J), Roof insulation (E), Replacing single window glasses with double ones (C). Intervention D got the same rank with both methods intervention JThe Solar Thermal collectors (J) and the installation of high efficiency air conditioning systems (I) achieved a better positions, compared to the ranking of the QIMM method (see Table 1417). These results underline that very high importance is given to those interventions regarding the refurbishment of the building envelope, which guarantees good energy and environmental performance with moderate economic expenses. Conversely, the last positions are occupied by the replacement of electric and electronic household appliances (F) and the replacement of electric water heaters with methane water heaters (H).

Palazzo Balcani case study

The steps of the application of Hybrid AHP method to Palazzo Baleani are shown in table 25 for Action A.

Table 25. Example of Local-global final table of each actions.

-	Action A						
Indicators	Eigenvalues	Stakeholders preferences %	Evaluation Ambits	Goal level		Final score	
	L4	L3	L2	L1	Sum	CF	G
EN1	0.0444	1	0.33		0.014652	-1	
EN2	0.0376	1	0.33	1	0.012408	-1	
EN3	0.053	1	0.33		0.01749	1	
ENV1	0.0769	1	0.5	1	0.03845	-1	
ENV2	0	1	0.5		0	1	0.05078
EC1	0.0148	1	0.5	1	0.0074	-1	
EC2	0.0878	1	0.5		0.0439	-1	
Com1	0.1695	1	0.5	1	0.08475	1	
Com2	0.1307	1	0.5		0.06535	1	

In this case the interpretation of correction factor (CF) has been developed by the authors. Regarding the energy indicators (EN1 and EN2) the value is negative since they respectively represent the annual consumption in toe of each intervention and the total consumption of each intervention in its lifespan, while EN3 is positive since it is the savings in primary energy before and after the interventions. The ENVI1 environmental indicator is negative since it counts the amount of global emissions while ENV2 is positive since it represents the reduction; similarly, also the economic indicators are negative, quantifying the expenses for savings one toe and one tonne of CO_2 per year. Finally, both the community indicators express a positive impact, representing the improvements in thermal comfort and level of dissatisfaction before and after the intervention.

The pairwise comparison among the interventions is performed using the same procedure as in the previous case study. In table 26 there is an example of EN1 matrix while in Table 27 the Eigenvectors calculation is shown.

Table 26. Example of Ratio matrix of each indicators

=	Windows	COOL 1	COOL 2	PV A	PV B	EMS	DWH	Light	T	E	T-E	T-D	E-D	T-E-D
	1	0.803	0.838	0.495	0.504	0.480	0.464	0.477	0.635	0.564	0.904	0.674	0.569	0.966
	1.245	1	1.043	0.616	0.628	0.598	0.577	0.594	0.791	0.702	1.125	0.839	0.709	1.202
	1.193	0.959	1	0.590	0.602	0.573	0.553	0.569	0.758	0.672	1.078	0.804	0.679	1.152
	2.021	1.623	1.694	1	1.019	0.970	0.937	0.964	1.284	1.139	1.826	1.362	1.151	1.952
	1.983	1.593	1.662	0.981	1	0.952	0.920	0.946	1.260	1.118	1.791	1.337	1.129	1.915
	2.083	1.674	1.746	1.031	1.050	1	0.966	0.994	1.323	1.174	1.882	1.404	1.186	2.012
	2.156	1.732	1.807	1.067	1.087	1.035	1	1.028	1.370	1.215	1.948	1.454	1.228	2.083
EN1	2.096	1.684	1.757	1.038	1.057	1.007	0.972	1	1.332	1.182	1.894	1.413	1.194	2.025
	1.574	1.265	1.319	0.779	0.794	0.756	0.730	0.751	1	0.887	1.422	1.061	0.896	1.520
	1.774	1.425	1.487	0.878	0.895	0.852	0.823	0.846	1.127	1	1.603	1.196	1.010	1.714
	1.107	0.889	0.928	0.548	0.558	0.531	0.513	0.528	0.703	0.624	1	0.746	0.630	1.069
	1.483	1.192	1.243	0.734	0.748	0.712	0.688	0.707	0.942	0.836	1.340	1	0.845	1.433
	1.756	1.411	1.472	0.869	0.886	0.843	0.814	0.838	1.116	0.990	1.587	1.184	1	1.696
	1.035	0.832	0.868	0.512	0.522	0.497	0.480	0.494	0.658	0.583	0.935	0.698	0.590	1

Table 27. Example of eigenvectors calculation as local values.

Indicator	Eigenvectors		Eigenvectors (divided by the Sum)	Actions
EN1	v1	0.644	0.0444	A
	v2	0.802	0.0553	B
	v3	0.769	0.0530	C
	v4	1.302	0.0898	D
	v5	1.278	0.0881	E
	v6	1.342	0.0925	F
	v7	1.390	0.0958	G
	v8	1.351	0.0932	H
	v9	1.014	0.0699	I
	v10	1.143	0.0788	J
	v11	0.713	0.0492	K
	v12	0.956	0.0659	L
	v13	1.1320	0.0780	M

	v14	0.6674	0.0460	N
	Sum	14.5093		

The weights of the ambits (2nd level) are assigned for every indicator. In this case, the weights are: 0.33 for Energy, 0.50 for Environment, 0.50 for Economy, 0.50 for Community. For this case study, due to the absence of stakeholders' opinion, the scores are given as if all the stakeholders hadn't voted. Table 28 shows the final ranking.

Table 28: Final ranking for Palazzo Baleani case study applying the Hybrid AHP method

	Hybrid AHP	
Ranking	Actions	score
1	N	0.22
2	K	0.20
3	L	0.16
4	C	0.15
5	B	0.14
6	I	0.12
7	A	0.05
8	J	-0.08
9	M	-0.09
10	E	-0.13
11	D	-0.14
12	F	-0.20
13	H	-0.21
14	G	-0.53

Ranking highlights that the best scenario is the combination of thermal + electric + the renovation of the Solar heating system scenario (N) followed by the thermal + electric scenario (K) and the thermal + solar heating system (L). It shows that the benefits given by the sum of all the single interventions (N) is able to guarantee positive scores and impacts from all the perspectives (energy, environment, economy and community). Regarding the single interventions, the best one is the improvement of the cooling system type B (C), which concerns the installation of an air handling unit and an inverter heat pump. The replacement of lighting fixtures (H) and solar heating system (G) got instead the lowest score.

4. Discussion

Sicilian residential district case

~~*Palazzo Baleani case study*~~

Comparison between final rankings of the Sicilian residential district, obtained through the application of QIMM and Hybrid AHP methods, ~~are~~is shown in this section~~. Results are shown in Table 19~~.

Table 19: Final rankings of the Sicilian residential district with both methods

Ranking	**Hybrid AHP**	**QIMM**	**Changes in QIMM respect to AHP**
1	D	D	=
2	J	E	↑**1**
3	E	C	↑**1**
4	C	I	↑**1**
5	I	J	↓**3**
6	B	A	↑**1**
7	A	F	↑**2**
8	K	B	↓**2**
9	F	K	↓**1**
10	H	H	=

The comparison of Table 19 shows that the first and last positions of the ranks are ~~quite~~ aligned. The other positions are quite similar -apart from a few differences. The main variation regards intervention J.~~As an example, the intervention~~Action -J (Solar thermal collectors) occupies the second position in the Hybrid AHP and only the fifth in QIMM. Analysing more in detail the results of this action in Table 4, -it can be noticed that indicators have overall very good values, especially EN1, EN3 and ENV1.

~~Nevertheless~~However, ~~This action got overall very good scores, especially in the indicators EN1, EN3 and ENV1 but~~ its final score in QIMM~~, ,~~ was c~~onsistently~~onsiderably reduced- after the normalization process due to the scaling ~~normalization~~ of ~~a~~ few indicators, -such as EN2. As an example i~~I~~n Table 20, the values of EN 2 for all the actions are shown. I~~i~~t can be seen that the values of the action~~s~~ are very similar to each other and the absolute differences are very low (the maximum difference is only 0.7 toe/M€ between actions I/A/C and J). Nevertheless, the type of normalization proposed in QIMM increases these differences on the 5 to -5 scale giving the highest score to actions I, A and C and the lowest possible to action J. This is one of the main characteristics of the QIMM method: even when the absolute differences among the indicator values are not considerable, the normalization process brings the value on a score scale (-5/+5) which increases the differences among the actions. ~~This aspect could have had an impact on the drop of~~

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action J in the ranking and similarly could have affected also other actions (especially the last five) which occupy slightly different positions in the two ranks.

Table 20: Example of an Indicator values and scores

Indicators/ Actions		A	B	C	D	E	F	H	I	J	K
EN2	Energy intensity of the residential sector (toe/M€)	26.4	26.10	26.40	26.10	26.30	26.30	26.30	26.40	25.70	26.10
Score of QIMM method	Energy intensity of the residential sector (toe/M€)	5	-1	5	-1	2	2	2	5	-5	-1

Intention of the authors is therefore to assess if this peculiarity of the QIMM method in the scaling process could have caused the differences in the two ranks, especially regarding action J. The explanation exposed above, it allows to deeply highlight an essential goal of the QIMM process, but this is not the dominant cause of the rankings differences, exposed in Table 19. ThereforeAccordingly, ideterminatesdivergencesauthors decided to develop an additional analysis. One of the main differences between the two methods isT the presencevote of the stakeholders and the weight of indicators weight (Level 2) in the Hybrid AHP and the inclusion of cost and time scores in the QIMM method were therefore excluded, in order to compare . Authors, therefore, decided to calculate the performances of the intervention without considering the aforementioned aspects in order to assess their role in the final ranks, basically comparing only the results of the two normalization processes (Table 21).

Table 21: Final rankings of the Sicilian residential district (nowithout weights and additional scores)

Methods without weights and additional scores			
Ranking	Hybrid AHP	QIMM	Changes in QIMM respect to AHP
1	D	D	=
2	E	E	=
3	C	C	=
4	I	I	=
5	A	J	↑1
6	J-F	A	↓1
7	B	F	↓1
8	K	B	↓1
9	H	K	↓1
10	-	H	↓1

Results in Table 21 show that if additional scores in the two methods are not considered, the two ranks are much more similar to each other.It can be observed that Tthe presenceabsence of the stakeholders in the Hybrid AHP method has, therefore, an impact in the evaluation of actions J, F and B, doesn't drastically change the rank but for a few actions it has a consistent impact which got in Table 21 about the same positions occupied in the QIMM rank (Table 21). Referring for example to action J, it can be seen that in Table 19, it occupied the second2nd position while in Table 21 it is placed at the 6th. Conversely in QIMM,

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the absence of cost and time scores doesnn't drastically affect the normalized rank, since theyse weights only intervene at the end of the scoring processss, just perfecting the final score obtained; (see Table 21). comparing Ttable 19 and 21 for the QIMM method, the rankings are exactly the same. It demonstrates that the economic and time scores in the QIMM approach have a lower impact compared to the stakeholders' vote used in the AHP method. TThe inclusion of these two weightsfactors can indeed, therefore, mainly help in diversifying the scores in cases of equal positions, diversifying the values.if two actions occupy the same position in the rank after the normalization process.

As shown in Tables 19 and 21, in the Hybrid AHP method the impact of the stakeholders has a role only on few strategies (like J and F) while the others keep their positions in the rankings both with and without the inclusion of the stakeholders' opinion.on the rank, making a few actions increase or decrease their positions in the ranks. This fact highlights the role of the stakeholders in the process: if high relevance is given to their opinion a kind ofallows from one side to reduce the inner subjectivity is included in the model of including personal opinions, but from the other side, it if less power is given to their votes, reduces their potentiality in the decision-making process is reduced.

Palazzo Baleani case study

Comparison between final rankings of the Palazzo Baleani, obtained through the application of QIMM and Hybrid AHP methods, are shown in this section. Results are shown in Table 22.

In this section the Ccomparison between the rankings of Palazzo Baleani provided after theobtained application ofwith the QIMM and Hybrid AHP methods is shown in table 31. As for the Sicilian district, the ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM) were assessed (see Table 31, Case b).

Table 31:22: Final rankings of Palazzo Baleani case study with both methods

Ranking	Hybrid AHP	QIMM	Changes in QIMM respect to AHPChanges
1	N	N	=
2	K	K	=
3	L	L	=
4	C	C	=
5	B	I	↑1
6	I	B	↓1
7	A	A	=
8	J	J	=
9	M	M	=
10	E	E	=
11	D	D	=

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12	F	F	=
13	H	H	=
14	G	G	=

In Table 22, the two rankings are very aligned., confirming again the similarities of the normalization process and the impact of the stakeholders when considered. Differently from the Sicilian– districtCase study, the stakeholders votes are not provided at the beginning of the process. Consequently, the ir absence of this factor in the Hybrid AHP method allow to make the two ranks more similar to each other compared to the other case study (Table 21). This consideration highlights again that the normalization process of the two methods are comparable.

In addition, some considerations about the indicators results of this case study could provide an useful instrument to understand the QIMM normalization process. In fact, Furthermore, it can be observed that, for all the actions, the original values of each indicator are distributed on a wider range) : it the maximum and minimum values are indeed not as close to each other as in the Sicilian district case study. It allows to make the QIMM normalization process more in line with the real performance of the actions, which keep the original differences in their magnitude: the scores are indeed assigned in more homogeneously. This is one of the strongest points of the QIMM method

Knowing that for this case study the stakeholder's' opinion is not consideredpresent, As for the Sicilian residential district, thetThe ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM) were assessedare anyway shown in (Table 23).

In table 31 (Case a) the two rankings are very aligned, confirminghighlighting again the similarities of the normalization process between the two methods and the impact of the stakeholders when considered.

Furthermore, it can be observed that, for all the actions, the original values of each indicator are distributed on a wider range: the maximum and minimum values are indeed not as close to each other as in the Sicilian district case study. It allows to make the QIMM normalization process more in line with the real performance of the actions, which keep the original differences in their magnitude: the scores are indeed assigned in a more homogeneous way. This is one of the strength points of the QIMM method. Table 23: Final rankings of Palazzo Baleani (nowithout weights and additional scores)

Methods without weights and additional scores			
Ranking	Hybrid AHP	QIMM	Changes in QIMM respect to AHP
1	N	N	=
2	K	K	=
3	L	L	=
4	C	C	=
5	B	B-I	↑ 1
6	I	A	↑ 1
7	A	J-M	↑ 1
8	J-M	E	↑ 1
9	E	D	↑ 1

10	D	F	↑ **1**
11	F	H	↑ **1**
12	H	G	↑ **1**
13	G	-	-
14	-	-	-

~~Regarding the ranks in Table 23, without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM), A~~As expected, since the original rankings were yet very aligned, the scores did not change much compared to Table 22~~ also in this case~~. Nevertheless, a few actions got an equal position in the rank, especially with the QIMM (actions B and I; actions J and M): it underlines again~~ again the importance~~that ~~of ~~the main role of the cost and time scores ~~which allow~~is to differentiate the final performance of the interventions, removing the equal positions as shown in Table 22.~~Regarding the ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM), as expected, since the original rankings were yet very aligned, the scores did not change much also in this case (table 31, Case b). Nevertheless, a few actions got an equal position in the rank, especially with the QIMM: it underlines again the importance of the cost and time scores which allow to differentiate the final performance of the interventions.~~

~~*Sicilian residential district case*~~

~~Comparison between final rankings of the Sicilian residential district, obtained through the application of QIMM and Hybrid AHP methods, are shown in this section. One of the main differences between the two methods is the presence of the stakeholders and indicators weight (Level 2) in the Hybrid AHP, and the inclusion of cost and time scores in the QIMM method. Authors therefore decided to calculate the performances of the intervention without considering the aforementioned aspects in order to assess their role in the final ranks, basically comparing only the results of the two normalization processes. Results are shown in Table 29.~~

~~Table 29: Final rankings of the Sicilian district with both methods~~

	~~Original methods (Case a)~~		
~~**Ranking**~~	~~**Hybrid AHP**~~	~~**QIMM**~~	~~**Changes**~~
~~1~~	~~D~~	~~D~~	~~=~~
~~2~~	~~J~~	~~E~~	~~↑1~~
~~3~~	~~E~~	~~C~~	~~↑1~~
~~4~~	~~C~~	~~I~~	~~↑1~~
~~5~~	~~I~~	~~J~~	~~↓3~~
~~6~~	~~B~~	~~A~~	~~↑1~~

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~~7~~	~~A~~	~~F~~	↑~~2~~
~~8~~	~~K~~	~~B~~	↓~~2~~
~~9~~	~~F~~	~~K~~	↓~~1~~
~~10~~	~~H~~	~~H~~	~~=~~

~~The comparison of Table 29 (Case a) shows that the first and last positions of the ranks are quite aligned apart from few differences. As an example, the intervention J (Solar thermal collectors) occupies the second position in the Hybrid AHP and only the fifth in QIMM. This action got overall very good scores, especially in the indicators EN1, EN3 and ENV1 but its final score in QIMM was consistently reduced due to the scaling normalization of a few indicators such as EN2. In Table 30 it can be seen that the values of the actions are very similar to each other and the absolute differences are very low (maximum difference is only 0.7 toe/M€ between actions I/ A/ C and J). Nevertheless, the type of normalization proposed in QIMM increases these differences on the 5 to -5 scale giving the highest score to actions I, A and C and the lowest possible to action J. This aspect could have had an impact on the drop of action J in the ranking and similarly could have affected also other actions (especially the last five) which occupy slightly different positions in the two ranks.~~

~~Table 30: Example of an Indicator values and scores~~

~~Indicators/ Actions~~		~~A~~	~~B~~	~~C~~	~~D~~	~~E~~	~~F~~	~~H~~	~~I~~	~~J~~	~~K~~
~~EN2~~	~~Energy intensity of the residential sector (toe/M€)~~	~~26.4~~	~~26.10~~	~~26.40~~	~~26.10~~	~~26.30~~	~~26.30~~	~~26.30~~	~~26.40~~	~~25.70~~	~~26.10~~
~~Score of QIMM method~~	~~Energy intensity of the residential sector (toe/M€)~~	~~5~~	~~-1~~	~~5~~	~~-1~~	~~2~~	~~2~~	~~2~~	~~5~~	~~-5~~	~~-1~~

~~Finally, it can be observed that the presence of the stakeholders in the Hybrid AHP method doesn't drastically change the rank but for few actions it has a consistent impact (see table 29, Case b). Referring for example to action J, it can be seen that in table 29 (Case a) it occupied the second position while in the Case b it is placed at the 6th. Conversely in QIMM, the cost and time scores doesn't drastically affect the normalized rank, since they intervene at the end of the scoring process, just perfecting the final score obtained (see table 29, Case b). The inclusion of these two weights can therefore help in cases of equal positions, diversifying the values.~~

~~As shown in Table 29, in the AHP method the impact of the stakeholders has a role only on few strategies (like J and F) while the others keep their positions in the rankings both with and without the inclusion of the stakeholders' opinion. This fact allows from one side to reduce the inner subjectivity of including personal opinions, but from the other side it reduces their potentiality in the decision-making process.~~

~~*Palazzo Baleani case study*~~

~~Comparison between the rankings of Palazzo Baleani provided after the application of QIMM and Hybrid AHP methods is shown in table 31. As for the Sicilian district, the ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM) were assessed (see Table 31, Case b).~~

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Table 31: Final rankings of Palazzo Baleani case study with both methods

	Original methods (Case a)			Without weights and additional scores (Case b)		
Ranking	Hybrid AHP	QIMM	Changes	Hybrid AHP	QIMM	Changes
1	N	N	=	N	N	=
2	K	K	=	K	K	=
3	L	L	=	L	L	=
4	C	C	=	C	C	=
5	B	I	↑1	B	B-I	↑1
6	I	B	↓1	I	A	↑1
7	A	A	=	A	J-M	↑1
8	J	J	=	J-M	E	↑1
9	M	M	=	E	D	↑1
10	E	E	=	D	F	↑1
11	D	D	=	F	H	↑1
12	F	F	=	H	G	↑1
13	H	H	=	G	-	-
14	G	G	=	-	-	-

In table 31 (Case a) the two rankings are very aligned, confirming again the similarities of the normalization process and the impact of the stakeholders when considered.

Furthermore, it can be observed that, for all the actions, the original values of each indicator are distributed on a wider range: the maximum and minimum values are indeed not as close to each other as in the Sicilian district case study. It allows to make the QIMM normalization process more in line with the real performance of the actions, which keep the original differences in their magnitude: the scores are indeed assigned in a more homogeneous way. This is one of the strength points of the QIMM method.

Regarding the ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM), as expected, since the original rankings were yet very aligned, the scores did not change much also in this case (table 31, Case b). Nevertheless, a few actions got an equal position in the rank, especially with the QIMM: it underlines again the importance of the cost and time scores which allow to differentiate the final performance of the interventions.

Specific observations regarding the QIMM, emerging from the results, are the following:

1. The inclusion of the correction factor in the scoringe process is a strength strong point of the methodology since it allows to give a correct interpretation of the indicators analysing their significance in respect to each other. This aspect was missing in the original Hybrid AHP method but, in this work, it was added in the formula for the comparison between the methods.
2. When the magnitudes of an indicator for different actions are very close to each other, the Hybrid AHP method is not able to highlight properly the differences among them, rewarding or penalizing the best and worst strategies. Conversely, the QIMM normalization process allows to show the real performance of the actions, keeping the original differences in their magnitude.
3. The application of the normalization process is easier compared to the Hybrid AHP.

Summing up the general considerations about the two methods:

1- The two types of normalization processes of the MADM two methods provided aligned and comparable results.
2- The opinion of the stakeholders in the Hybrid AHP method has a little morehigher impact in the final rank than the cost and time scores in the QIMM.

Specific observations regarding the QIMM coming out from the results, are the following:

1. The inclusion of the correction factor in the scoring process is a strong point of the methodology since it allows to give a correct interpretation of the indicators analysing their significance in respect to the others. This aspect was missing in the original Hybrid AHP method but, in this work, it was added in the formula for the comparison between the methods.
2. The application of the normalization process is easier compared to the Hybrid AHP.
2 3. The cost and time scores in the QIMM method allow to remove the equal positions in the ranks.
3 The cost and time scores and the weight of the ambits allow to remove the equal scores diversifying the actions.

5. Conclusions

The current work aims to describe and validate the QIMM planning approach through the comparison with the Hybrid AHP method and the application of these two models to two real case studies. These two MADM approaches were chosen since they allow to identify which are the best solutions from an integrated perspective, taking into account as much as possible the impacts of the strategies on different Smart fields. The proposed model has been originally elaborated by the authors in (Mattoni, Bisegna & Gugliermetti, 2015) and it was modified in the current work, transforming it into a quantitative ex--post approach. The evolution of the method from qualitative to quantitative meets the needs evidenced in literature in the development of Smart Ccity projects: quantitative and holistic planning models are required to identify objectively the problems of the cities y contexts and to identify the most efficient strategies in a set of multiple possible scenarios. The comparative Hybrid AHP model has been indeed developed in a previous literature work by (Giaccone et al., 2017).

The real case studies belong to two different territorial levels: a district and a a building. and a district. This choice was made to demonstrate the flexibility of the two approaches. The comparison between the methods allowed: to assess the impact of the different methods on the prioritization process for a set of Smart actions; to underline similarities, differences, lacks and strengths of the two models.

In general, rResults showed that the two approaches, despite their differences, give the same outputs regarding allowed to obtain provided the best and worst-performing solutions. In both case studies the first and last positions in the ranks are the same with the two models.

Regarding the Sicilian case study, , located in the same positions in the two rankssimilar ranks. On the other hand, stakeholder's' opinion included in the Hybrid AHP method of the Sicilian case has a consistenrelevant t impact onin the rankingsthe score of a few actions diverges, considerably alteringhanging their intermediate positionspositions in the rank. Accordingly, the ranks of the two methods are not completely aligned with regard to the intermediate positions. The Baleani case study, instead, showed more comparable results, due to the stakeholder's vote absence. Nevertheless when the stakeholders' opinion of the Hybrid AHP and the additional cost and time scores in the QIMM are excluded from the analysis, The Hybrid AHP process, therefore, becomes quite similar to the QIMM process when the stakeholders opinion is not taken into accountthe ranks come out to be very similar. It demonstrates

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that that the normalization process of the two methods give comparable results despite their considerable differences.: the most and least performing solutions occupied indeed the same positions in the two ranks.

The Baleani case study shows instead aligned results with the two methods, mainly because the stakeholders' vote is not included.

comparing The normalization processes also give similar results. Summing up, the stakeholders opinion in the Hybrid AHP method has a higher impact on the final rank compared to the economic and time feasibility scores used in the QIMM: when stakeholders' votes are not considered, the rank obtained with the Hybrid AHP method equalizes with the rank produced with the QIMM model.

Little differences do occur when the weights and additional score are used but their impact does not revolutionize the ranks, allowing only to differentiate a bit the performance of the actions and to remove the cases of equal positioning in the ranks. More specifically, RResults, therefore, demonstrated the reliability of the normalization process used in QIMM and allowed to pinpoint the following positive aspects of the method:

- Easiness of normalization process
- Unbiased attribution of the scores in the scaling process
- The oObjectivity of the prioritization process by applying quantitative parameters: correction factor and economic and time weights
- Replicability of the method and applicability to different territorial scales

Limits of the methods arewere also evidenced. The stakeholders' opinion in the Hybrid AHP model has a clear impact on the final ranking; it demonstrates that , allowing to give a consistenthigh weightimportance is given to the users butwhich, on the other hand, could be difficult to controlmake the results too their subjectivity inside the processsubjective. Regarding the QIMM, its additional scores have a lower influence on the final results compared to The stakeholders' opinion in the Hybrid AHP and the additional weights in the QIMM have a lower impact on the final results compared to the relevance of the normalization process. Their role is mainly to differentiate the scores of two actions when they occupy the same position in the rank. The absence of the stakeholders' opinionvotes in QIMM allows indeed to make the entire process more objective. It allows to limit the subjectivity but of the stakeholders' opinion in the Hybrid AHP but on the other side, it would be useful to evidence much moretake their impactopinion into account on the final results.. Similarly, also the relevance of the additional weights in the QIMM could be enhanced, maybe including them in a different phase of the planning method.

Finally, it has been proved that the methods explained above comply with the "Smart" requirements. They are both capable of providing quantitative results in a holistic way. The Hybrid AHP method is a generic decision-making procedure, therefore, it can be adjusted to fit the "Smart" context to identify the optimal interventions. On the other side, the modifications made to the original procedure of the QIMM methodmethod , which was developed as a Smart approach since the beginning, lead to obtaining an alternative way to select the best performing solution on each "Smart" axis of a project. The applicability of the models can vary through different levels of urban planning, from regions and cities to individual buildings.

Future developments of the work would regard the inclusion of the stakeholders' opinion in the QIMM model, trying to find a balance between subjectivity and the importance of their contribution, as evidenced in the relevant literature. Moreover, the QIMM method could be applied as a digital platform useful for designers and administrators to identify the best strategies for each city. context.

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Highlights

- Comparison of two quantitative smart city planning models based on MADM approach.
- Application of the models to real case studies belonging to different territorial scales
- Results of the analysis show that both methods are consistent and reliable
- Differences in data process don’t impact considerably on the rankings of the priority actions

PLANNING SMART CITIES: COMPARISON OF TWO QUANTITATIVE MULTICRITERIA METHODS APPLIED TO REAL CASE STUDIES

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Planning Smart cities: comparison of two quantitative multicriteria methods applied to real case studies

Abstract:

Today, cities are facing many challenges such as pollution, resource consumption, gas emissions and social inequality. Many future city views have been developed to solve these issues such as the Smart City model. In literature several methods have been proposed to plan a Smart city, but, at the best of the authors' knowledge, only a few of them have been really applied to the urban context. Most of them are indeed theoretical and qualitative approaches, providing scenarios that have not been applied to real cities/districts. Moreover, a comparison among the results of different quantitative planning models applied to real case studies is still missing. In this framework, the aim of the paper is to propose a new quantitative method based on a previous qualitative model developed by the same authors. The feasibility and validity of the method will be tested through the comparison with an existing AHP model and the application of both approaches on two real case studies, characterized by different territorial levels. Results of the analysis show that both methods are consistent, reliable and do provide similar results despite the differences in the application process.

Keywords: Smart city; Planning Methodology; Multicriteria analysis; Smart District; Smart Building

1. Introduction

The attractiveness of living in cities has exponentially increased in the last decades. Nowadays, for the first time in the history of the world, more people are living in urban than in rural areas (Marchetti Oliveira, & Figueira, 2019, World Urbanization Prospects 2018). This attractiveness is because the economies in urban context reach their highest level of productivity, guaranteeing cultural, social and economic benefits to citizens (Fernandez-Anez, Fernández-Güell & Giffinger, 2018). On the other side, growing urbanization is also the cause of several problems, such as pollution, resource consumption, social inequality and others. Just to give a couple of figures, cities today is responsible for the 80% of greenhouse gas (GHG) emissions and the 80% of the world's resources consumption (Arbolino et al., 2017). Consequently, due to these emerging challenges, city planning deals no more to the design of buildings and infrastructure only, but also to the definition of a holistic vision where new issues as digitalization, integration, quality of life, citizen needs, and equality must be taken into account (Silva, Khan & Han 2018). The Smart city model emerged in the 1900s as an alternative and innovative concept for city planning. Till now the concept has evolved and got complex (Caragliu, Del Bo & Nijkamp 2009, Albino, Berardi, & D'angelico, 2015; Chourabi et al., 2012) including multidisciplinary aspects and assets (De Santis et al., 2014; Yigitcanlar et al., 2019) and aiming to find a balance between benefits and costs for the main stakeholders involved (people, institutions, industry, universities, and companies), (Nam & Pardo, 2011b). This complexity resulted in a lack of consensus about the Smart definition (Meijer & Bolivar, 2015; Caragliu & Del BO, 2019, Manville et al., 2014), and about the way to translate the ideal model into practical applications (Lee, Hancock & Hu, 2014; Nilssen, 2019; Camboim, Zawislak & Pufal 2019). Wide literature research is indeed available, proposing different definitions, conceptual models and approaches to the development of the Smart City concept (Sharifi, 2019; Ahvenniemi et al., 2017). Regarding the definitions, a group of literature research focuses on the use of ICT and modern technologies as the main driver to the smart city development (Angelidou, 2015; Kourtit & Nijkamp, 2018). Other studies underline the importance of human capital, city services and participation for improving economic, social and environmental aspects of a Smart City (Neirotti et al., 2014; Belanche, Casaló & Orús, 2016).

An ISO standard was proposed at the regulation level which proposes methodologies and indicators to measure the performance of the Smart cities (ISO 37122:2019). This standard defines the Smart cities as "*a city that increases the pace at which it provides social, economic and environmental sustainability outcomes and responds to challenges such as climate change, rapid population growth, and political and economic instability by fundamentally improving how it engages society, applies collaborative leadership methods, works across disciplines and city systems, and uses data information and modern technologies to deliver better services and quality of life to those in the city (residents, businesses, visitors), now and for the foreseeable future, without the unfair disadvantage of others or degradation of the natural environment*". As noticeable, this definition is very general and inclusive.
Regarding the models and approaches, a considerable group of literature studies focuses on the development of evaluation frameworks for the smart city performance assessment, both from the qualitative and quantitative perspectives. Among them, the first one was proposed by (R. Giffinger et al., 2007) where the level of Smartness of 70 European medium-sized cities is evaluated based on their performance in six main axes. More recently, in (Zygiaris, 2013) a measurement tool was developed for assessing the smart performance, identifying six layers of a smart city. In (Lazaroiu & Roscia, 2012) a fuzzy procedure is applied for identifying the weights of different Smart indicators, which are used for the creation of a unique "Smart city index". In this framework, a useful report was developed by (Manville et al., 2014), called "Mapping Smart Cities in the EU", which collects all the smart city projects and models in Europe, highlighting their performance with respect to the Horizon 2020 objectives.

Moreover, interesting researches are available proposing qualitative planning methods. These studies are not aimed to evaluate the performance of a city but mainly to guide administrators in the identification of efficient Smart strategies to be applied in real case studies. As an example, (Kumar, Kumar Singh & Gupta, 2019) a crowdsourcing approach was used to collect the most common smart services and to define the Smart City Transformation Framework (SCTF) for the deploying of Smart interventions. In (Mattoni, Gugliermetti & Bisegna, 2015) an innovative and multidimensional methodology is provided, which is based on the analysis of the mutual impacts among strategies belonging to different smart axes by means of the "synergy" concept. Similarly, The "intelligenter method" (Marsal-Llacuna & Segal, 2016) is based on the creation of multi-subsystem interrelations that provide better results in terms of efficiency in the use of natural and economic resources: this is called "Collaborative Sub-Systems" and it is based on the holistic and systemic approach of the urban context. Finally, in (Fernández-Güell et al., 2016) a multilayer approach was proposed, based on the systems theory, which is used to envision how Spanish cities could evolve in the horizon 2030. Other researches applied the triple helix conceptual model to assess the role of different stakeholders in the planning phase of the Smart cities (Etzkowitz & Zhou, 2006; Lombardi et al., 2012). Stakeholders involvement has indeed recently begun a hot topic in literature: many studies evidenced the need of taking into account the stakeholders' opinion for an efficient urban transformation (Angelidou, 2017; Stratigea et al., 2015; Engelbert, Zoonen & Hirzalla, 2019, Bouzguenda, Alalouch & Fava, 2019).

This brief overview of the Smart city vision highlights that, besides the variety of proposals, there is still the need for the development of quantitative models able to put the smart city theory into practice and to apply a global and holistic view in the planning phase. As a matter of fact, scientists propose integrated, comprehensive and multifaceted models; practitioners on the other side have to face with the limitations of implementing visionary projects in cities, preferring therefore to work on sector-based interventions instead of integrated strategies (Fernandez-Anez, Fernández-Güell & Giffinger, 2018, Angelidou 2017, Caragliu & Del Bo, 2019). The presence of those two opposite approaches, highlighted by (Fernandez-Anez, Fernández-Güell & Giffinger 2018), is still a concrete limitation for a holistic and integrated smart city realization. Current Smart applications frequently use top-down approaches, as it can be noticed for the 15 major cities described by (Angelidou 2017): those smart planning projects are mainly focused on the ICT aspect and this is considered as the principal driver for pushing improvements in the urban systems. This is clearly in contrast with the Smart City concept, that aims to promote the application of both top-down and bottom-up approaches, starting from a global view of the urban context (Caragliu & Del Bo, 2019).

There is, therefore, the need to fill the gap between theory and practice proposing "practical planning methodologies" which can help in choosing, prioritizing and controlling the performance of the implemented Smart strategies (Mattoni, Gugliermetti & Bisegna, 2015; Pompei et al., 2018; Mattoni, Nardecchia & Bisegna, 2019) from a holistic perspective, as scientist suggest (Bibri & Krogstie, 2017).

An important example of planning methodologies is the work of (Fernandez-Anez et al., 2018), that proposes a tool called Smart City Projects Assessment Matrix. It is a holistic framework for developing smart city projects and assessing urban challenges. Moreover, this methodology was applied to the South and East Mediterranean Region at both the regional and project levels. Another example is the ASEAN Smart City Network (ASCN) project that aims to transform 26 cities into smart cities. This project provides a digital platform in which designers and policies can disseminate and promote initiatives (ASEAN Smart Cities Network 2018). Finally, the Institute of Technology, Bandung (ITB) developed the Garuda Smart City Framework (GSCF), a methodology that consists in different steps, including city measurement models, smart city Architecture, standard and services (Tay et al., 2018). In this case, the technological aspect is recognized as one of the main drivers for the smart city. This planning method aims to highlight the importance of innovative, technology and integrated solutions for improving the quality of life.

Starting from this point, the present work is in line with the targets of the aforementioned projects, since the aim is to reduce the gap between theory and practice of Smart City, providing quantitative and integrated methodologies for the transformation of real case studies.

This paper, therefore, proposes a new quantitative method based on a previous qualitative model developed by the same authors (Mattoni, Gugliermetti & Bisegna, 2015). The feasibility and validity of the method will be tested through the comparison with an existing AHP model and the application of both approaches on two real case studies, characterized by different territorial dimensions. Both the new and the AHP methods belong to the group of the MADM models; these models can be very suitable for the assessment of the best smart strategy among a set of different proposals, thanks to their capability of prioritization and scoring. Quite a few studies in literature applied the MADM models for city evaluation, either for the development and evaluation of Smart cities (Escolar et al., 2019; Lombardi et al., 2012) or for the assessment of urban sustainability level (Mohammed Ameen & Mourshed, 2019). A more detailed description of the MADM models and their potentialities is provided in the following section.Moreover, at the best of our knowledge, there are no studies in the literature comparing two quantitative planning models.

Therefore, in this work, the comparison of the two methods allows to:

- Validate the methodological approach developed by authors, through the comparison with an existing AHP method and the application of both the models on two real case studies, characterized by different territorial scales.
- Highlight the differences and similarities between the two methods
- Compare the final rankings and assess the impacts of the modelling process on the identification of the most performing strategies
- Identify limits, strengths and potentials of the proposed methodology.

After the Introduction section, explaining the state of the art of the Smart City concept and models, the next section (Section 2) presents the evolution and modification of the two approaches used in the paper, showing their entire processes in detail and the two case studies are described. Section 3 contains the results of the application of the two models, while in section 4 the results are compared and discussed. Finally, the conclusions and future developments are drawn.

2. Methodology

Multicriteria analysis is a decision-making tool based on the quantitative analysis of the strengths and weaknesses among heterogeneous criteria of a certain proposed strategy. Following the classification made by (Hwang and Yoon, 1981), MADM is one of the two branches of Multiple - Criteria Decision Making (MCDM), which transforms the real-world problems into continuous or discrete systems. MADM allows reproducing discrete problems, considering a limited number of alternatives not measurable in a single dimension. More in detail, MADM consists of a group of operations for ranking and scoring multiple alternative solutions usually characterized by contrasting attributes (Figueira, Greco & Ehrgott, 2005) MADM is composed by a matrix, called decision matrix, which describes the contribution of each alternative against each attribute. Two operations are generally required to calculate this matrix: scoring and weighting. The first one involves assigning a numerical value to each attribute contributions, within a preference scale. The weighting, instead, consists in identifying a weight for each attribute. Consequently, a MADM method provides an explicit weighting system for the different criteria in order to estimate the correct weight.

The new methodology proposed in this paper is called Quantitative Incidence Matrix Method (QIMM), which is an evolution of a matrix method (IMM) firstly elaborated in a previous paper of the same authors (Mattoni, Gugliermetti & Bisegna, 2015). The QIMM can be included in the MADM methods, due to its typical structure of matrix weighting process.

The QIMM has validated through the comparison with another MADM approach: a modified version of the Analytic Hierarchy Process (AHP) (Saaty, 1980), called Hybrid AHP, which was developed by the University of Palermo in (Giaccone et al., 2017). One of the most important aspects of those two methods is their flexibility: the number of smart city fields, actions and indicators can be changed from time to time, depending on the characteristics of the case study. The core of the two methods lays in the capability of putting the different actions in relation to each other to understand the mutual impacts and establish the priorities of the actions in an integrated way: this is one of the main target of a Smart city.

Those two methods will be applied to two different case studies, to verify if and to what extent the results are similar and how this would change the strategy decision making. The first case study is the Sicilian residential building sector's EEMP (Energy and Environmental Master Plan developed by the Sicilian Region) and the second one is the Palazzo Baleani, a building in the city centre of Rome, that is owned by Sapienza University.

2.1 Methods description

Quantitave Incidence Matrix (QIMM) Method

The flowchart of the original method IMM includes different steps: data collection, performance indicators analysis, actions strategies elaboration and their mutual impact on the smart fields (Mattoni, Gugliermetti & Bisegna, 2015). The phase involving the identification of the best fitting strategy is represented by the Incidence Matrix, that establishes in a qualitative way, the influence of each action on the smart aspects.

According to this, it is possible to obtain the best action for each smart field. The last step is to simulate the winner actions and implement them in the urban context.

Starting from this methodology, some important modifications are carried out to transform this qualitative method into a quantitative one: the QIMM method. Moreover, those modifications allow users to apply this new methodology for both planning and ex-post analysis. Three main difference can be noticed in the modified method:

1) All the strategies are simulated in the first phase. It allows to obtain quantitative results in different fields (Mobility, Community, Environment, Energy and Economy) represented by specific Smart Indicators, belonging to the various Smart fields.
2) The assessment of the impact of each strategy in the incidence matrix is developed by means of quantitative Smart performance indicators (in substitution of the qualitative Synergy scores) and quantitative additional weights. The standardisation of those indicators is based on a common process, which uses standard normalization criteria.
3) In the transformation of the method from qualitative to quantitative, the Users score was no more taken into consideration due to the complexity in collecting and quantifying stakeholders' opinions.

This variation in the method allows to fill the gaps highlighted in the previous approach proposed by the authors (Mattoni, Nardecchia & Bisegna, 2019). Figure 1 shows the flowcharts of both methods and their differences. Following, authors provide a deep explanation of each step of the presented method.

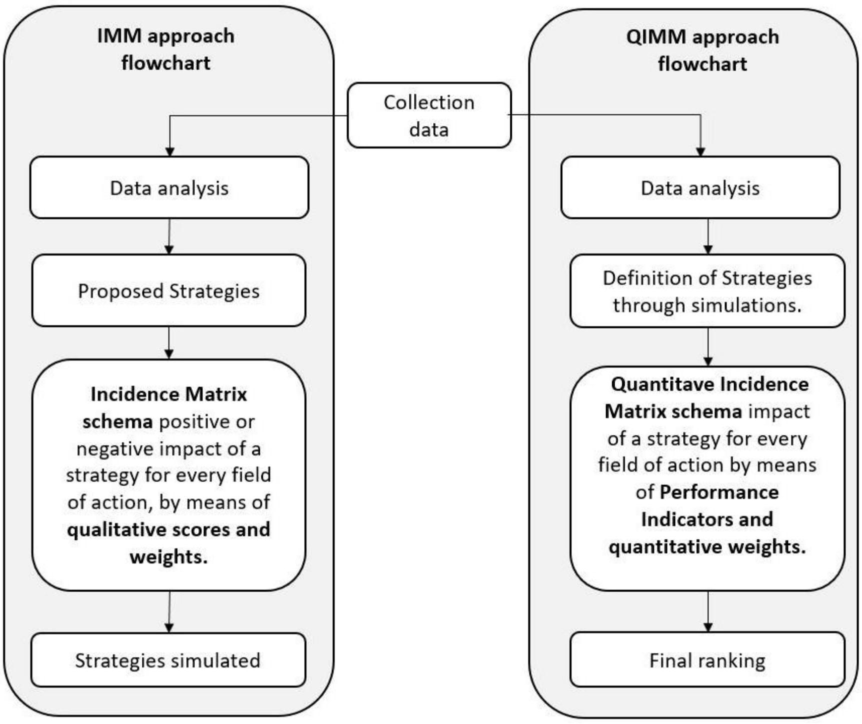

Figure 1. Elaboration of QIMM procedure

- **Generate matrix**

In the QIMM method, a single matrix is used, which contains all the indicators that need to be measured for every intervention. A segmentation is recommended to make it easier to read, but it will not affect the results. An example can be seen below:

Table 1: Sample of Incidence matrix

Field of action	**Index**	**Action 1**	**Action 2**	**Action3**
Energy	Gross primary energy consumed (ktoe/year)	$En1_1$	$En1_2$	$En1_3$
	Energy produced by renewable resources (%)	$En2_1$	$En2_2$	$En2_3$
Environment	Tons of CO2 produced	$Env1_1$	$Env1_2$	$Env1_3$
Economy	Total investment cost (€)	$Ec1_1$	$Ec1_2$	$Ec1_3$
	Rate of return (%)	$Ec2_1$	$Ec2_2$	$Ec2_3$
Mobility	Time saved to arrive to office (min)	$Mob1_1$	$Mob1_2$	$Mob1_3$
Community	Thermal comfort index (%)	$Com1_1$	$Com1_2$	$Com1_3$

The magnitudes corresponding to the effect of the actions against the proposed indicators will be determined through simulations, which will evaluate how the proposed actions perform under the examined conditions. It is important to verify the capacity of the simulation software and the data availability at this point as if the results cannot be trustfully measured by the indexes, these should be adjusted accordingly.

- **Distance to mean normalization**

For the normalization and scaling method, the “distance to mean” method has been chosen. A similar method to those proposed in the OECD (Handbook on Constructing Composite Indicators, 2008) and in the work of (Pompei et al., 2018). Firstly, the mean for every indicator has to be calculated.

$$M_i = \frac{\sum_{j=1}^{n} x_{ij}}{n}; for\ i = ind1, ind2, ind3 \ldots m \qquad [1]$$

Where, *i* will be the indicators and *j* will be each of the actions, *m* will be the total indicators and *n* stands for the total amount of actions suggested. Now, the distance to the mean is calculated for every indicator, using the following equation:

$$a_{ij} = \frac{x_{ij} - M_i}{M_i} \qquad [2]$$

- **Scaling**

After using Equation 2 for all the actions, a scaling factor needs to be added in order to be able to effectively compare all indicators. The scale will be set by using the maximum and minimum magnitudes for every action. The spaces between the limits will be divided into 10 ranges, which will be assigned a score from -5 to 5. The score ranges will be set in such a way that if the action magnitudes are less than 0, they will be set with a score of 0 or below. This means that for negative scores there will be 6 ranges, while for positive ranges only 4. This distribution was made to benefit the alternatives that have a higher performance in the indicators. Two different equations will be needed in order to set the limit value for every range:

$$\begin{cases} x_{s+1} + \left|\frac{x_{min}}{5}\right|; for\ s > -4 \\ x_{s-1} + \left|\frac{x_{max}}{4}\right|; for\ s > 0 \end{cases} \qquad [3]$$

Where *s* refers to the score, and x_{min} refers to the minimum and x_{max} refers to the maximum magnitude of the actions. This procedure has to be repeated for all indicators of interest until the matrix is completely normalized and scaled.

- **Correction Factor**

A Correction Factor has been included to balance the positive and negative magnitudes of the indicators. In some cases, the indicators will measure changes that the higher they get, the higher the project will get benefits. The opposite situation can also happen, where the higher magnitude of the indicator would affect the project negatively. According to this, a correction factor of -1 or 1 was introduced in order to establish the correct interpretation of the indicators. This correction factor is given by the interpretation of the designers and could be avoided if the indicators are properly selected. An example will be given assuming 2 different indicators:

Table 2: Example of correction factor

Indicator	Correction factor
Gross Energy Consumption (ktoe/year)	-1
Economic savings (€/year)	1

In the example shown in Table 2, it can be seen how correction factor is applied. When Gross Energy Consumption indicator increases, it means that more energy will be consumed per year, which will be an undesirable behaviour for the aims of a project that aims to increase energy efficiency. On the other side, when the Economic Savings indicator increases, it will represent a benefit as it means less money will be spent.

- **Economic and time feasibility**

Two additional scores are going to be considered and summed separately from the previously calculated indicators. The assignment of the scores will be determined between 0 and 1 depending on the amount of time and money spent for every intervention. The most expensive interventions got the lowest score of 0, while those most cheap were assigned a score of 1. A similar approach was used for time, where the actions that needed more time to be completed were assigned a value of 0, while those that were installed the quickest had a score of 1. The values in between were given a score according to their value respect to 1. Equation 14 shows the process for assigning the scores to all the intermediate interventions which are neither the cheapest nor the most expensive.

$$x_i = 1 - \left(\frac{c_i}{max[c_i, c_n]}\right) for\ i = 1, n \qquad [4]$$

An example can be seen below in Table 3:

Table 3: Example of time score

Action	**Time to install (h)**	**Score**
Action 1	30	0.33
Action 2	15	0.67
Action 3	3	1
Action 4	45	0

The magnitude of the score (between 0 and 1), was assigned targeting to avoid a big change in the final ranking. The use of these weights is intended to show the contribution of aspects that are considered important for any project to be developed, independently from which indicators are being measured.

Hybrid AHP method

A specific modification of the AHP method was proposed in (Giaccone et al., 2017), called "Hybrid AHP". The main difference with the AHP method is the way the data is aggregated from the base level of "action" to the intermediate and higher levels. The scheme, shown in figure 2, describes the four levels used in this method and their significance. This hybrid scheme has been also applied in literature in the works of (Chen and Wang 2010) and (Fahrul Hassan et al., 2012); it allows to give high relevance to the judgments of the stakeholders related to the selected indicators during the evaluation process. The addition of the stakeholders' opinion is relevant and in line with the latest literature studies, which go in the direction of including all the users and actors in the planning process. Nevertheless, it could imply the addition of a certain subjectivity in the model that should be carefully managed. The comparison of the two methods is a useful way to assess how much this subjectivity influence the final results. This aspect will be further discussed in the conclusion section.

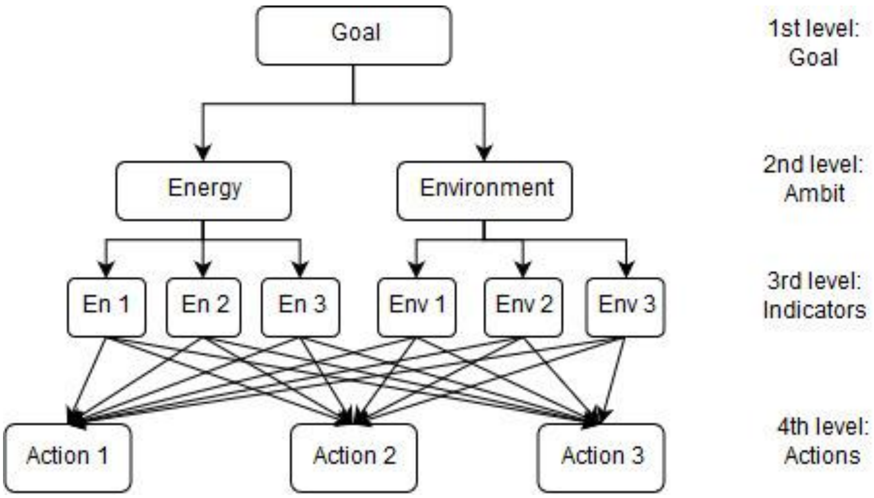

Figure 2. Hybrid AHP scheme

As shown in Figure 2, the 1st level is the Goal, which is the target that must be reached. The 2nd level refers to each ambit, which means to the main topic the indicators can be grouped on, only energy and environment were given in the example. However, this model is flexible since the number of main topics and indicators can be changed as needed, including other smart axes such as People & Living, Economy, and Mobility. The weight used for the aggregating data at the 2nd level is given by the number of indicators measured for each ambit divided by the total amount of indicators. Referring to figure 2, the weight for the "Energy" ambit is 0.5 as it is composed of 3 indicators while the total number of indicators is 6. The 3rd level weight is given by the stakeholders. It refers to how favourable would they be to one indicator of respect to the others in the same ambit. People were, therefore, asked to select which indicator was the most important for each ambit; from the votes, the percentage influence of each indicator concerning its ambit was assessed. Finally, in the 4th level, the pairwise comparison among actions is made by using eigenvalues. More detailed information regarding the Hybrid AHP method can be found in the paper of (Giaccone et al., 2017).

Finally, in order to properly compare the two methods, authors made a single modification in the Hybrid AHP process proposed by (Giaccone et al., 2017), adding the correction factor at the Goal level calculation (1st level of the method).

This correction factor, as aforementioned before, is a relevant part of the QIMM method since it allows to measure if the impact of indicators is beneficial or unfavourable depending on their correct interpretation.

2.2 Case study

Sicilian residential district case study

This case study comes from the work of (Giaccone et al., 2017), whose objective was to analyse the strategies implemented by a Residential Sector Master Plan using the Hybrid AHP method. The Residential Sector Master Plan aimed to optimally distribute the available economic resources of the region for the development of sustainable interventions supported by building owners. However, the opinion of the stakeholders in the definition of the indicators that would measure the effectivity of the interventions was originally missing. The indicators used for selecting the interventions were mostly referred to as economic issues: €/toe and €/t_{CO2}. The authors of the paper (Giaccone et al., 2017), decided, therefore, to study how the priority of the interventions would have changed if the indicators would have been weighted considering the opinion of the stakeholders. The votes from the stakeholders are presented in the work of (Giaccone et al., 2017). In Tables 4 and 5, the interventions and their respective indicators are shown. Input data referred to these interventions are available in the original paper of (Giaccone et al., 2017).

Table 4: Indicators for the Sicilian District (modified from Giaccone et al., 2017)

Indicators/ Actions		**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**K**
EN1	**Final uses gross energy consumption (ktoe/year)**	1311	1297	1312	1294	1305	1306	1305	1311	1276	1298
EN2	**Energy intensity of the residential sector (toe/M€)**	26.4	26.10	26.40	26.10	26.30	26.30	26.30	26.40	25.70	26.10
EN3	**Saved energy during the life span of proposed action (toe)**	58460	98353	122442	555399	289993	54495	59915	60314	820000	94000
ENV1	**CO2 emission avoided through lifespan of proposed action (tCO2)**	135627	228181	397937	1805047	922980	177110	476331	196022	2665000	305500
ENV2	**Emission intensity (tCO2/M€)**	0.092	0.091	0.092	0.091	0.091	0.091	0.09	0.092	0.09	0.091
EC1	**Average cost of one saved toe (€/toe)**	0.0023	0.0063	0.0015	0.0074	0.0055	0.0028	0.0178	0.0016	0.0292	0.0094
EC2	**Average cost of one tCO2 (€/t CO2)**	0.0053	0.0146	0.0048	0.024	0.018	0.009	0.1418	0.0054	0.0689	0.0209
EC3	**Average cost of one toe saved during the lifespan of the action (€/toe)**	0.0004	0.0008	0.0007	0.0035	0.0026	0.0003	0.0022	0.0003	0.01	0.0012
EC4	**Increase in number of working hours**	192343	312234	564441	5315291	3237806	0	111992	274157	3760000	480000

Table 5: Reference letters and interventions

Reference	Interventions
A	Replacing electric boilers with natural gas boilers
B	Replacing gas fired water heater with open chamber and pilot flame with sealed

	chamber and electronic ignition
C	Replacing single-window glasses with double - window glasses
D	Building envelope insulation
E	Roof insulation
F	Replacement of electric and electronic household appliances
H	Replacing electric water heaters with methane water heater
I	Installation of high efficiency air conditioning systems
J	Solar thermal collectors
K	PV panels

Palazzo Baleani case study

In order to verify the applicability of the proposed Quantitative Incidence Matrix (QIMM) method, a real case study located in Rome was chosen. It is a typical historical building, called Palazzo Baleani, which was built in the sixteenth century. Currently, the biggest part of the building is owned by the Sapienza University of Rome and the spaces are mainly used as classrooms and offices. The study started with an analysis of the state of the art of the building. The main data about the building, such as dimensions, construction materials, electrical and thermal loads were gathered or simulated using engineering software. As expected for an old building, the inefficient envelope and windows greatly impact on the cooling and heating consumption. However, the age and relevance of the building limit the possibilities of refurbishment and the addition of technical and technological devices, especially on the façade, according to the current Standard (Ragni et al., 2018; Legislative Decree, 2004). Similarly, the installation of PV panels is forbidden, because they can affect the appearance of the building. Considering these restrictions, the improvement due to the implementation of selected interventions was calculated. Few indicators were defined for measuring the impact of the interventions on several Smart fields (Energy, Economy, Environment, Community). The final list of interventions can be seen in Tables 6 and 7. In Table 6, the cells highlighted in grey show that in a few cases the results are negative. These values were substituted with zero by the authors to properly apply both QIMM and AHP methods to this case study since the AHP cannot process negative values.

Moreover, four of the strategies are alternative. The method can be indeed used to assess if it would be preferable to install a traditional photovoltaic system (PV A) or the photovoltaic roof tiles (PV B). Similarly, it can also be used for choosing between COOL 1 and COOL 2:

- COOL 1: The installation of four heat pumps at Variable Refrigerant Flow which supply indoor air conditioning units in offices, school rooms and conference rooms
- COOL 2: The installation of an air handling unit and an inverter heat pump for conditioning the entire building, taking advantage of the existing air ducts and an absorption chiller.

Intervention on windows regards the addition of a supplementary internal glass to the existing windows in order to create an air gap of 20 mm and reduce the thermal transmittance; the Energy Management System (EMS) allows to monitor and manage loads of the building to reduce consumption and optimize electricity peaks; intervention on the solar heating system (SHS) consists in the substitution of the broken collectors already placed on the roof of the building and to reactivate the entire system; regarding the lighting systems, the two mono-lamp fluorescent tubes installed in the ceiling fixtures are replaced with LED tubes. The other strategies (T, E, T-E, T-D, E-D, T-E-D) are combinations of the aforementioned strategies. By applying the two methods it will be therefore interesting to assess if it is more efficient to develop single or combined strategies from a holistic perspective.

Table 6: List of indicators and strategies

		Strategies													
Indicators		**Windows**	**Cool 1**	**Cool 2**	**PV A**	**PV B**	**EMS**	**SHS**	**Light**	**T**	**E**	**T-E**	**T-D**	**E-D**	**T-E-D**
En1	**Gross Energy Consumption (toe/year)**	20.8	25.9	24.8	42.1	41.3	43.4	44.9	43.7	32.8	37.0	23.1	30.9	36.6	21.6
En2	**Energy Consumption on lifespan (toe)**	417	648	621	842	826	1301	1123	1310	656	924	461	618	914	431
En3	**Primary Energy Index (%)**	0.16	0.19	0.24	0.09	0.11	0.08	0.03	0.07	0.29	0.20	0.50	0.33	0.20	0.53
Env 1	**Annual CO2 emissions (tCO2)**	97	106	101	95	93	98	106	98	94	82	61	93	81	57
Env 2	**Local pollution index (%)**	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	1.00
Ec1	**Average cost of toe saving (€/toe*year)**	51	138	109	309	256	309	1323	339	216	52	83	114	149	31
Ec2	**Average cost of CO2 saving (€/tCO2)**	3491	-24	-24	866	896	4950	30296	5428	1661	691	745	658	-2412	211
Com 1	**Thermal comfort index (%)**	1.29	0.82	0.82	0	0	0	0	-0.01	0.88	-0.01	0.88	0.88	-0.04	0.88
Com 2	**Thermal dissatisfaction index (%)**	0.53	0.63	0.63	0	0	0	0	-0.03	0.67	-0.03	0.66	0.66	-0.03	0.66

Table 7: Reference abbreviation of interventions

actions	**Alternative**
A	Windows refurbishment
B	Improvement of the cooling system (type A)
C	Improvement of the cooling system (type B)
D	Photovoltaic System
E	Roof tiles Photovoltaic System
F	Energy management system
G	Solar Heating System
H	Light fixtures replacement
I	Thermal (COOL2 +Windows)
J	Electric (PV A + Management system+ Light)

K	Thermal + Electric
L	Thermal + Solar Heating System
M	Electric + Solar Heating System
N	Thermal + Electric + Sanitary hot water

3. Results

3.1. Sicilian residential district case study: QIMM method application

In this sub-section, the QIMM is applied to the Sicilian residential district. In order to explain each step of the method, authors decided to describe the process for a single action, knowing that it is repeated for all the strategies shown in Table 5. In this case, the Correction Factor has been defined based on the indicator's interpretation given in (Giaccone et al., 2017). More in detail, EN1 is negative since it represents the total energy consumption per year; EN2 is positive since it is the efficiency used for a country to convert the Gross Domestic Product into energy commodities; EN3 is positive since it represents the total energy saved in one year; both the environment indicators (ENV1 and ENV2) are positive and represent savings in CO_2 emissions; EC1, EC2 and EC3 are considered negative since they quantify the average expenses per toe and CO_2 and finally EC4 is positive since, as said in (Giaccone et al., 2017), it represents the number of new jobs created by the realization of each intervention. An example of the QIMM application is shown for action A (Table 8):

Table 8: Example of QIMM process for Action A

		Action A								
		Indicators								
		EN 1	**EN 2**	**EN 3**	**ENV1**	**ENV2**	**EC1**	**EC2**	**EC3**	**EC4**
L3	Distance to mean	0.72	0.72	-73.59	-81.45	-0.99	-72.55	-83.05	-81.82	-86.5
	Score	4	5	-4	-5	-5	-4	-4	-4	-4
	CF	-1	1	1	1	1	-1	-1	-1	1
	Sum	-5								
L2	Time feasibility	0.83								
	Economic feasibility	0.30								
L1	TOTAL	-3.87								

As noticeable in Table 8, the level L3 includes the "distance to mean" normalization and the CF assignment; the level L2 regards the weighting process with the addition of the scores "Economic feasibility" and "time feasibility"; the level L1 finally allows to get the score of each action. As aforementioned in this method, the scaling process for score assignation can be adjusted to the magnitudes that are being worked with. In this work, authors propose a score range between -5 and 5 and the exemplificative results are shown in Table 9. As an example for EN1, since the distance to mean for EN1 is 0.72, which is comprised between 0.60-0.80 according to this scaling, the score assigned is 4.

Table 9. Example of scaling factor of EN1 indicator

EN1

score scaling	min	max
-5	-2.0	
-4	-1.98	-1.58
-3	-1.58	-1.19
-2	-1.19	-0.79
-1	-0.79	-0.40
0	-0.40	0.00
1	0.00	0.20
2	0.20	0.40
3	0.40	0.60
4	0.60	0.80
5	0.80	

Then, reference case studies were chosen as base case examples to assess the time required for intervention, used in the calculation of the "Time feasibility score". An example of timing for a few actions is shown in Table 10 with the relative bibliographic sources.

Table 10: Estimated time for interventions

Intervention	Time required	Source
A	3 days/ floor	[1]
B	about 10 week	[2]
C	15 windows per day	[3]
D	25 days	[4]
E	1 week	[5]
F	5 days	[6]
H	3 hours/ house	[7]
I	4 days	[8]
J	2 days	[9]
K	2 days	[9]

Regarding the economic feasibility, the investment costs of each intervention were available in the paper of (Giaccone et al., 2017). Using these data on time and costs, the respective scores have been calculated, as shown in Table 11. The final ranking is shown in Table 12.

Table 11: Time and cost feasibility scores for the Sicilian residential district

	Costs feasibility		Time feasibility	
Intervention	Total cost (M€)	Score	Hours	Score
A	192.3	0.30	288	0.83
B	156.1	0.44	1728	0.00
C	276.5	0.00	384	0.78
D	250.7	0.09	600	0.65
E	171	0.38	168	0.90
F	196.4	0.29	120	0.93

H	33.9	1.00	1728	0.00
I	274.1	0.01	96	0.94
J	117	0.58	3	1.00
K	100	0.64	48	0.97

Table 12: Final Ranking for the Sicilian residential district applying the QIMM method

	QIMM	
Ranking	**Actions**	**Score**
1	**D**	6.74
2	**E**	3.28
3	**C**	1.78
4	**I**	-2.05
5	**J**	-2.42
6	**A**	-3.87
7	**F**	-4.78
8	**B**	-8.56
9	**K**	-11.39
10	**H**	-22

Using this method, high relevance was attributed to the interventions on the building envelope actions D, E and C, which respectively regard: Building Envelope Insulation (D), Roof insulation (E), Replacing single-window glasses with double ones (C). These results underline that very high importance is given to those interventions regarding the refurbishment of the building envelope, which guarantees good energy and environmental performance with moderate economic expenses. Conversely, the last positions are occupied by the installation of PV panels (K) and the replacement of electric water heaters with methane water heaters (H).

3.2 Sicilian residential district case study: Hybrid AHP method application

This section describes the application of the Hybrid AHP method to the Sicilian district. Table 13 shows the results at each level of the method related to Action A. As aforementioned, in order to develop a correct comparison of the two methods, the Correction Factor (highlighted in grey in Table 13) was added in the Hybrid AHP procedure by the authors.

Table 13: Example of Local-global final table of each action.

	Action A						
Indicators	**Eigenvalues**	**Stakeholders preferences %**	**Evaluation Ambits**	**Goal level**		**Final score**	
	L4	**L3**	**L2**	**L1**	**Sum**	**CF**	**G**
EN1	0.1	22	0.33	1	0.74	-1	1.72
EN2	0.1	30			1.01	1	
EN3	0.03	48			0.42	1	
ENV1	0.02	67	0.22	1	0.28	1	

ENV2	0.1	33			0.74	1	
EC1	0.03	15	0.44	1	0.18	-1	
EC2	0.02	15			0.11	-1	
EC3	0.02	15			0.12	-1	
EC4	0.02	55			0.43	1	

In the 4th level (L4), eigenvalues pairwise comparison is applied to the proposed interventions. Each indicator has a corresponding ratio matrix (as Table 14), with a total of 9 matrices.

Table 14. Example of Ratio matrix of each indicators

	A	B	C	D	E	F	H	I	J	K
EN1	1	1.011	0.999	1.013	1.004	1.004	1.005	1.000	1.028	1.010
	0.989	1	0.989	1.002	0.994	0.993	0.994	0.990	1.017	0.999
	1.001	1.011	1	1.013	1.005	1.005	1.005	1.001	1.028	1.011
	0.988	0.998	0.987	1	0.992	0.991	0.992	0.988	1.015	0.997
	0.996	1.006	0.995	1.008	1	1.000	1.001	0.996	1.023	1.006
	0.996	1.007	0.995	1.009	1.000	1	1.001	0.996	1.024	1.006
	0.995	1.006	0.995	1.008	0.999	0.999	1	0.995	1.023	1.005
	1.000	1.011	0.999	1.013	1.004	1.004	1.005	1	1.027	1.010
	0.973	0.984	0.972	0.985	0.977	0.977	0.978	0.973	1	0.983
	0.990	1.001	0.989	1.003	0.994	0.994	0.995	0.990	1.017	1

Then, the eigenvectors are elaborated to obtain the normalized values of EN1 for every action, as shown in Table 15. Once the eigenvalues for each indicator are calculated, they are multiplied by both the weights of the stakeholders and the weights of each ambit to get the final score for a determined alternative.

Table 15. Example of eigenvectors calculation as local values.

Indicator	Eigenvectors		Eigenvectors (divided by the Sum)	Actions
EN1	**v1**	1.007	0.1007	**A**
	v2	1.00	0.100	**B**
	v3	1.01	0.101	**C**
	v4	0.99	0.099	**D**
	v5	1.00	0.100	**E**
	v6	1.00	0.100	**F**
	v7	1.00	0.100	**H**
	v8	1.01	0.101	**I**
	v9	0.980	0.098	**J**

	v10	0.997	0.100	**K**
	Sum	10		

The votes from the stakeholders are reported in the work of Giaccone et al 2017 in Table 6. The total votes for each indicator are divided by the 67 voters of the ambit and multiplied by 100 to obtain the percentage weight. The number of indicators for each ambit is divided by the total number of indicators. According to this, the weights of the ambits are respectively: 0.33 for Energy, 0.22 for Environment, 0.44 for Economy. Final results are provided in Table 16.

Table 16: Final ranking for the Sicilian district applying the Hybrid AHP method

	Hybrid AHP	
Ranking	**Actions**	**Score**
1	**D**	15.12
2	**J**	11.82
3	**E**	8.86
4	**C**	3.40
5	**I**	2.09
6	**B**	1.79
7	**A**	1.72
8	**K**	1.71
9	**F**	1.25
10	**H**	-2.44

The rank shows that the most efficient solutions, occupying the first four positions, are the following: Building Envelope Insulation (D), Solar Thermal collectors (J), Roof insulation (E), Replacing single-window glasses with double ones (C). Intervention D got the same rank with both methods; conversely, intervention J achieved a better position compared to the ranking of the QIMM method (see Table 12). The last positions are occupied by the replacement of electric and electronic household appliances (F) and the replacement of electric water heaters with methane water heaters (H).

3.3 Palazzo Baleani case study: QIMM method application

In this section, the QIMM method is applied to the Palazzo Baleani. The process is the same as for the Sicilian residential district: performing normalization procedure; defining the scale factors; assigning the additional weights. Regarding the interpretation of the indicators, the Correction Factor is assigned as follows: the energy ones (EN1 and EN2) are negative since they respectively represent the annual consumption in toe of each intervention and the total consumption of each intervention in its lifespan, while EN3 is positive since it is the savings in primary energy before and after the interventions. The ENVI1 environmental indicator is negative since it counts the amount of global emissions while ENV2 is positive since it represents the reduction of local pollution; similarly, the economic indicators are also negative, quantifying the expenses for savings one toe and one tonne of CO_2 per year. Finally, both the community indicators COM1 and COM2 express a positive impact, representing the improvements in thermal comfort and level of dissatisfaction before and after the intervention. Table 17 shows the final ranking of the proposed QIMM approach.

Table 17: Final Ranking for Palazzo Baleani applying the QIMM method

Ranking	QIMM	
	Actions	**Score**
1	N	39.25
2	K	34.26
3	L	23.55
4	C	23.06
5	I	16.57
6	B	16.35
7	A	14.87
8	J	-9.19
9	M	-9.21
10	E	-18.61
11	D	-21.48
12	F	-29.01
13	H	-29.92
14	G	-41.02

The best scenario is the combination of thermal, electric and the renovation of the Solar heating system (N) while the second position (K) is occupied by the thermal + electric scenario (PV, Management system and Lighting systems). The third position is occupied by the thermal + solar heating system (L). These three ranks show the importance of the thermal interventions combined with all the others. Regarding the single interventions, the best one is the improvement of the cooling system type B (C). The last positions are occupied by the refurbishment of the lighting system (H) and the Solar heating system (G).

*3.4 Palazzo Baleani case study: the Hybrid AHP method application*Finally, the application of the Hybrid AHP method to Palazzo Baleani, following the same procedure explained for the Sicilian residential district, was done. In this case, the weights of the ambits (2nd level) are 0.33 for Energy, 0.50 for Environment, 0.50 for Economy, 0.50 for Community. Moreover, due to the absence of stakeholders' opinion of the Palazzo Baleani case, the scores are given as if all the stakeholders hadn't voted. Also in this application, the correction factor was added, according to the indicator's interpretation exposed in the previous paragraph. The final results are provided in Table 18.

Table 18: Final ranking for Palazzo Baleani case study applying the Hybrid AHP method

Ranking	Hybrid AHP	
	Actions	**score**
1	**N**	0.22
2	**K**	0.20
3	**L**	0.16
4	**C**	0.15
5	**B**	0.14
6	**I**	0.12
7	**A**	0.05
8	**J**	-0.08
9	**M**	-0.09

10	**E**	-0.13
11	**D**	-0.14
12	**F**	-0.20
13	**H**	-0.21
14	**G**	-0.53

The ranking highlights that the best scenario is the combination of thermal + electric + the renovation of the Solar heating system scenario (N) followed by the thermal + electric scenario (K) and the thermal + solar heating system (L). Regarding the single interventions, the best one is the improvement of the cooling system type B (C), which concerns the installation of an air handling unit and an inverter heat pump. The replacement of lighting fixtures (H) and solar heating system (G) got, instead, the lowest score. It is worthy to notice that the four best and the two worst interventions are the same in the two methods.

4. Discussion

Sicilian residential district case

Comparison between final rankings of the Sicilian residential district, obtained through the application of QIMM and Hybrid AHP methods, is shown in this section.

Table 19: Final rankings of the Sicilian residential district with both methods

Ranking	Hybrid AHP	QIMM	Changes in QIMM respect to AHP
1	D	D	=
2	J	E	↑ **1**
3	E	C	↑ **1**
4	C	I	↑ **1**
5	I	J	↓**3**
6	B	A	↑ **1**
7	A	F	↑ **2**
8	K	B	↓**2**
9	F	K	↓**1**
10	H	H	=

The comparison of Table 19 shows that the first and last positions of the ranks are aligned. The other positions are quite similar apart from a few differences. The main variation regards intervention J. Action J (Solar thermal collectors) occupies the second position in the Hybrid AHP and only the fifth in QIMM. Analysing more in detail the results of this action in Table 4, it can be noticed that indicators have overall very good values, especially EN1, EN3 and ENV1.

However, its final score in QIMM, was considerably reduced after the normalization process due to the scaling of few indicators, such as EN2. As an example in Table 20, the values of EN 2 for all the actions are shown. It can be seen that the values of the action are very similar to each other and the absolute differences are very low (the maximum difference is only 0.7 toe/M€ between actions I/A/C and J). Nevertheless, the type of normalization proposed in QIMM increases these differences on the 5 to -5 scale giving the highest score to actions I, A and C and the lowest possible to action J. This is one of the main characteristics of the QIMM method: even when the absolute differences among the indicator values are not considerable, the normalization process brings the value on a score scale (-5/+5) which increases the differences among the actions.

Table 20: Example of an Indicator values and scores

Indicators/ Actions		**A**	**B**	**C**	**D**	**E**	**F**	**H**	**I**	**J**	**K**
EN2	**Energy intensity of the residential sector (toe/M€)**	26.4	26.10	26.40	26.10	26.30	26.30	26.30	26.40	25.70	26.10
Score of QIMM method	**Energy intensity of the residential sector (toe/M€)**	**5**	**-1**	**5**	**-1**	**2**	**2**	**2**	**5**	**-5**	**-1**

Intention of the authors is therefore to assess if this peculiarity of the QIMM method in the scaling process could have caused the differences in the two ranks, especially regarding action J. Accordingly, authors decided to develop an additional analysis. The vote of the stakeholders and the weight of indicators (Level 2) in the Hybrid AHP and the cost and time scores in the QIMM method were therefore excluded, in order to compare only the results of the two normalization processes (Table 21).

Table 21: Final rankings of the Sicilian residential district (without weights and additional scores)

Methods without weights and additional scores			
Ranking	**Hybrid AHP**	**QIMM**	**Changes in QIMM respect to AHP**
1	D	D	**=**
2	E	E	**=**
3	C	C	**=**
4	I	I	**=**
5	A	J	↑ **1**
6	J-F	A	↓**1**
7	B	F	↓**1**
8	K	B	↓**1**
9	H	K	↓**1**
10	-	H	↓**1**

Results in Table 21 show that if additional scores in the two methods are not considered, the two ranks are much more similar to each other. The absence of the stakeholders in the Hybrid AHP method has, therefore, an impact in the evaluation of actions J, F and B, which got in Table 21 about the same positions occupied in the QIMM rank (Table 21). Referring for example to action J, it can be seen that in Table 19, it occupied the 2nd position while in Table 21 it is placed at the 6th. Conversely in QIMM, the absence of cost and time scores doesn't affect the rank, since these weights only intervene at the end of the scoring process; comparing Table 19 and 21 for the QIMM method, the rankings are exactly the same. It demonstrates that the economic and time scores in the QIMM approach have a lower impact compared to the stakeholders' vote used in the AHP method. The inclusion of these two factors can indeed mainly help in diversifying the scores if two actions occupy the same position in the rank after the normalization process.

As shown in Tables 19 and 21, in the Hybrid AHP method the impact of the stakeholders has a role on the rank, making a few actions increase or decrease their positions in the ranks. This fact highlights the role of the stakeholders in the process: if high relevance is given to their opinion a kind of subjectivity is included in the model, but from the other side, if less power is given to their votes, their potentiality in the decision-making process is reduced.

Palazzo Baleani case study

Comparison between final rankings of the Palazzo Baleani, obtained through the application of QIMM and Hybrid AHP methods, are shown in this section. Results are shown in Table 22.

Table 22: Final rankings of Palazzo Baleani with both methods

Ranking	**Hybrid AHP**	**QIMM**	**Changes in QIMM respect to AHP**
1	N	N	=
2	K	K	=
3	L	L	=
4	C	C	=
5	B	I	↑ **1**
6	I	B	↓**1**
7	A	A	=
8	J	J	=
9	M	M	=
10	E	E	=
11	D	D	=
12	F	F	=
13	H	H	=
14	G	G	=

In Table 22, the two rankings are very aligned. Differently from the Sicilian district, the stakeholders votes are not provided at the beginning of the process. Consequently, the absence of this factor in the Hybrid AHP method allow to make the two ranks more similar compared to the other case study (Table 21). This consideration highlights again that the normalization process of the two methods are comparable.

Knowing that for this case study the stakeholders' opinion is not considered, the ranks without including the weights of the ambits (in the Hybrid AHP method) and the cost and time scores (in the QIMM) are shown in Table 23.

Table 23: Final rankings of Palazzo Baleani (without weights and additional scores)

Methods without weights and additional scores			
Ranking	**Hybrid AHP**	**QIMM**	**Changes in QIMM respect to AHP**
1	N	N	=
2	K	K	=
3	L	L	=
4	C	C	=
5	B	B-I	↑ **1**
6	I	A	↑ **1**
7	A	J-M	↑ **1**
8	J-M	E	↑ **1**
9	E	D	↑ **1**
10	D	F	↑ **1**
11	F	H	↑ **1**
12	H	G	↑ **1**
13	G	-	**-**
14	-	-	**-**

As expected, since the original rankings were yet very aligned, the scores did not change much compared to Table 22. Nevertheless, a few actions got an equal position in the rank, especially with the QIMM (actions B and I; actions J and M): it underlines again that the main role of the cost and time scores is to differentiate the final performance of the interventions, removing the equal positions as shown in Table 22.Summing up the general considerations about the two methods:

1- The normalization processes of the two methods provided aligned and comparable results.
2- The opinion of the stakeholders in the Hybrid AHP method has a higher impact in the final rank than the cost and time scores in the QIMM.

Specific observations regarding the QIMM coming out from the results, are the following:

1. The inclusion of the correction factor in the scoring process is a strong point of the methodology since it allows to give a correct interpretation of the indicators analysing their significance in respect to the others. This aspect was missing in the original Hybrid AHP method but, in this work, it was added in the formula for the comparison between the methods.
2. The application of the normalization process is easier compared to the Hybrid AHP.
3. The cost and time scores in the QIMM method allow to remove the equal positions in the ranks.

5. Conclusions

The current work aims to describe and validate the QIMM planning approach through the comparison with the Hybrid AHP method and the application of these two models to two real case studies. These two MADM approaches were chosen since they allow to identify which are the best solutions from an integrated perspective, taking into account as much as possible the impacts of the strategies on different Smart fields. The proposed model has been originally elaborated by the authors in (Mattoni, Bisegna & Gugliermetti, 2015) and it was modified in the current work, transforming it into a quantitative ex-post approach. The evolution of the method from qualitative to quantitative meets the needs evidenced in literature in the development of Smart City projects: quantitative and holistic planning models are required to identify objectively the problems of the cities and to identify the most efficient strategies in a set of multiple possible scenarios. The comparative Hybrid AHP model has been indeed developed in previous literature work by (Giaccone et al., 2017).

The real case studies belong to two different territorial levels: a district and a building. This choice was made to demonstrate the flexibility of the two approaches. The comparison between the methods allowed: to assess the impact of the different methods on the prioritization process for a set of Smart actions; to underline similarities, differences, lacks and strengths of the two models.

In general, results show that the two approaches, despite their differences, give the same outputs regarding the best and worst-performing solutions. In both case studies the first and last positions in the ranks are the same with the two models.

Regarding the Sicilian case study, stakeholders' opinion included in the Hybrid AHP method has a relevant impact on the score of a few actions, considerably altering their positions in the rank. Accordingly, the ranks of the two methods are not completely aligned with regard to the intermediate positions. Nevertheless when the stakehloders' opinion of the Hybrid AHP and the additional cost and time scores in the QIMM are excluded from the analysis, the ranks come out to be very similar. It demonstrates that that the normalization process of the two methods give comparable results despite their considerable differences.

The Baleani case study shows instead aligned results with the two methods, mainly because the stakeholders' vote is not included.

Summing up, the stakeholders opinion in the Hybrid AHP method has a higher impact on the final rank compared to the economic and time feasibility scores used in the QIMM: when stakeholders' votes are not considered, the rank obtained with the Hybrid AHP method equalizes with the rank produced with the QIMM model.

Results, therefore, demonstrated the reliability of the normalization process used in QIMM and allowed to pinpoint the following positive aspects of the method:

- Easiness of normalization process
- Unbiased attribution of the scores in the scaling process
- The objectivity of the prioritization process by applying quantitative parameters: correction factor and economic and time weights
- Replicability of the method and applicability to different territorial scales

Limits of the methods are also evidenced. The stakeholders' opinion in the Hybrid AHP model has a clear impact on the final ranking; it demonstrates that high importance is given to the users which, on the other hand, could make the results too subjective. Regarding the QIMM, its additional scores have a lower influence on the final results compared to the relevance of the normalization process. Their role is mainly to differentiate the scores of two actions when they occupy the same position in the rank. The absence of the stakeholders' votes in QIMM allows indeed to make the entire process more objective, but on the other side, it would be useful to take their opinion into account.

Finally, it has been proved that the methods explained above comply with the "Smart" requirements. They are both capable of providing quantitative results in a holistic way. The Hybrid AHP method is a generic decision-making procedure, therefore, it can be adjusted to fit the "Smart" context to identify the optimal interventions. On the other side, the modifications made to the original procedure of the QIMM method lead to obtaining an alternative way to select the best performing solution on each "Smart" axis of a project. The applicability of the models can vary through different levels of urban planning, from regions and cities to individual buildings. Future developments of the work would regard the inclusion of the stakeholders' opinion in the QIMM model, trying to find a balance between subjectivity and the importance of their contribution, as evidenced in the relevant literature. Moreover, the QIMM method could be applied as a digital platform useful for designers and administrators to identify the best strategies for each city.

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