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Towards resilient cities: Advancements allowed by a multi-criteria optimization tool to face the new challenges of European Union's climate and energy goals

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Abstract. The United Nations as well as the European Union are strongly committed in promoting a transition towards more sustainable and resilient cities. Indeed, they are increasingly affected by different types of threats, among which the natural ones such as earthquakes, fires, and floods (shocks) and climate variability (stresses). Cities are quite often unable to cope with the adverse effects of such natural hazards. This circumstance leads to the need of introducing resilience-related criteria (besides commonly used sustainability indicators) in decision-making processes. This paper investigates at which extent the inclusion of such new indicators, within multi-criteria assessment tools for supporting the decision-making process by Public Administrations, modifies the prioritization processes of a given set of planned actions to be implemented in cities, which are based instead on the above-cited commonly used indicators. The outcomes of the analysis demonstrated that the introduction of resilience among the prioritization criteria significantly modifies the list of priorities established using only sustainability indicators.

1. Introduction

'Resilience' is a term that has been deployed in many different fields ranging from psychology, ecology, engineering, to business and economics [1]. However, all the available definitions seem to refer to the ability of a given system (also an individual) to withstand and adapt to external stresses and shocks, and also to the ability to speedily recover from hazards and restore the prior situation, or at least to restart a positive tendency of development.

Recently, the concept of resilience has been applied also to the complex socio-environmental system of a city. Indeed urban areas are increasingly affected by different types of threats, among which the natural ones such as earthquakes, fires, and floods (shocks) and climate variability (stresses); quite often they are unable to cope with the adverse effects of such natural hazards.

The United Nations are strongly committed to promoting a transition towards sustainable and resilient societies. In this regard, among "The Sustainable Development Goals (SDGs)", (https://www.un.org/sustainabledevelopment), i.e. an even more ambitious set of goals set by the UN to be achieved by 2030, Goal 11 (https://www.un.org/sustainabledevelopment/cities), entitled "Make cities and human settlements inclusive, safe, resilient and sustainable", concerns indeed building cities that, among the others, are also characterized by a high cope capability with threats. Accordingly, the European Union (EU), besides promoting a smart, sustainable, and inclusive growth [2], openly recognizes the importance of building also resilience of cities [3]. Also, the "Covenant of Mayors" (https://www.covenantofmayors.eu/), an important EU initiative originally designed to support the EU

in achieving its greenhouse gas emissions reduction targets indicated in the 2020 climate&energy package of the Europe 2020 Strategy [2], requires now its volunteer signatories to commit themselves to strengthening the resilience of their cities to the negative impacts of climate change. Specifically, adhering municipalities are required in their "Sustainable Energy and Climate Action Plans" (SECAPs) both to foresee a reduction of their pollutant emissions up to at least 40% by the year 2030 (compared to the baseline), in line with the EU 2030 climate and energy framework [4], and to indicate mitigation and adaptation actions, unlike they did in "Sustainable Energy Action Plans" (SEAPs).

The theme of building resilience of cities has been investigated by the scientific community. Marana *et al.* [5], for instance, reported the characteristics of successful public-private-people partnerships in the city resilience-building process. Gimenez *et al.* [6] underlined the importance by the governments to encourage stakeholders to take part in the resilience-building process, and presented a Maturity Model (MM) that provides local administrations with a series of steps and strategies to increase the cooperation with stakeholders. Nonetheless, the application of the resilience concept to the city is still quite a complex task [1].

If, on one hand, the transition towards cities that are no longer only sustainable but also resilient raises the issue of how building resilience of a city and what strategies can be put forward to make a city equipped to withstand and quickly recover by climate change-related hazards (issue this investigated in literature, as stated above), on the other hand, it requires the introduction of resilience-related criteria in decision-making processes, particularly in those concerning the allocation of the monetary budget of Public Administrations to implement the actions of a plan, such as for instance a SECAP. To the best of our knowledge, this latter issue does not seem to have been put into practice. To date, in fact, Public Administrations have increasingly used only sustainability indicators as a prioritization criterion to optimize allocation of the limited monetary budget at their disposal [7].

Therefore, this paper intends to provide a contribution in this sense. Specifically, it investigates the opportunity to include also resilience-related indicators to establish a hierarchy of interventions to optimally allocate the available resources of Public Administrations. With the aim of understanding at which extent the introduction of resilience-related indicators modifies priority orders based on sustainability indicators, we applied one of the mostly used Multi-Criteria Decision Analysis (MCDA) tools to a set of actions able to make buildings less vulnerable to climatic changes and thus capable to increase the resilience of the city, which the buildings belong to. A set of resilience-related criteria was hypothesized among the assessment criteria.

2. Description of the MCDA method used for the analysis

In the present analysis, we decided to use the analytic hierarchy process (AHP) method [8], which is a multi-criteria decision analysis (MCDA) method [9, 10]. MCDA methods aim to prioritize a certain set of possible alternatives using a given set of criteria [11]. Consequently, they well support the planning and decision processes where many alternatives have to be considered and appraised based on different criteria. This choice resides in the fact that this method, being intrinsically capable to take into consideration evaluations referred to different ambits, enables to produce a comprehensive assessment, also including resilience. Furthermore, despite based on a rigid structure, it allows to easily embed new assessment ambits and criteria. Generally speaking, in the AHP method a given problem is, in fact, structured in several levels, namely it prescribes the construction of a hierarchy that, in its simplest form, is arranged as follows: *1)* the highest level represents the main goal to be achieved; *2)* the intermediate levels are the evaluation ambits and pertinent criteria upon which a decision among different options is made; and *3)* the lowest level is the list of options.

AHP is a quantitative approach that is usually based on pairwise comparisons of the elements at each level of the hierarchy against those of the upper level in order to assess the importance of each element with respect to those of the upper level, thus gaining an overall weight for each element [12].

3. Toward resilient cities by increasing the resilience of their buildings: an application to the case of roofs and windows

A possible strategy to make cities more resilient to stresses, such as climate change, consists in increasing the resilience of its buildings by providing them with a better mitigation and adaptation ability

to climate change-related hazards. Of course, all the foreseen interventions must guarantee indoor thermal comfort conditions to occupants [13]. The issue of how building resilience of edifices to climate change-related hazards has been investigated by the scientific community; particularly, the contribution provided by specific building components equipped with a higher resistance to the climatic shifts has been studied [14], and possible strategies to boost the resilience of a building have been presented [15].

Among building components, roofs and windows are certainly very sensitive and vulnerable to exceptional urban climate events such as unexpectedly and suddenly changing outdoor air temperatures and strong lasting rainfalls. The presented study, as first stage of analysis, is thus limited only to these parts of the building envelope. Both are, in fact, responsible for important heat exchanges that, among other things, occur independently by the structure's orientation. Therefore, here, the effects of four types of interventions (table 1) regarding these two building components were investigated.

Table 1. List of the considered interventions.

N°	Description	Action code
1	Installation of a cool roof on an uninsulated roof.	1cr
2	Installation of a cool roof on a roof that has undergone an insulation retrofit from uninsulated roof to Ecobonus[a].	2cr
3	Installation of a cool roof on a roof insulated in accordance with law 10/91.	3cr
4	Installation of a cool roof on a roof that has undergone an insulation retrofit from law 10/91 to Ecobonus.	4cr
5	Installation of a cool roof on a roof insulated in accordance with Ecobonus.	5cr
6	Installation of a green roof on an uninsulated roof.	1gr
7	Installation of a green roof on a roof insulated in accordance with law 10/91.	2gr
8	Installation of a green roof on a roof insulated in accordance with Ecobonus.	3gr
9	Installation of a green roof on a roof that has undergone an insulation retrofit from uninsulated roof to Ecobonus.	4gr
10	Installation of a green roof on a roof that has undergone an insulation retrofit from law 10/91 to Ecobonus.	5gr
11	Insulation retrofit from uninsulated to Ecobonus.	1ins
12	Insulation retrofit from law 10/91 to Ecobonus.	2ins
13	Installation of shading devices - Horizontal (skylight).	1sh
14	Installation of shading devices – South.	2sh
15	Installation of shading devices - East-West.	3sh
16	Installation of shading devices - South West-South East.	4sh
17	Installation of shading devices - North West- North East.	5sh

As it can be observed, three levels of roof thermal insulation were considered: uninsulated roof (U-value 1.81 W/m²K), light insulation (U-value 0.53 W/m²K) as required by the Italian national regulation (law 10/91) for new buildings until 2006, installation of a strong insulation (U-value 0.22 W/m²K), which permits to take advantage of an Italian public incentive, named Ecobonus that consists in a tax deduction of 65% of the cost spread in ten years.

The analyzed building envelope's elements are capable of making buildings less vulnerable to the climatic changes, thanks to their abilities both to reduce the solar radiation entering the buildings through the roof (due to their usually high albedo) and to cool the surrounding environment (due to the evapotranspiration occurring in plants and soil surface) [16]. Furthermore, shading devices installed on windows (in this case motorized packing up external white venetian blinds) can effectively protect from the incoming solar radiation, thus reducing the indoor air temperature and in turn limiting the energy need for climatization.

4. Simulation performed using AHP method
The hierarchy implemented in AHP aimed at solving the building resilience issue is depicted in figure 1. The proposed measures are the actions reported in table 1, while the evaluation ambits and pertinent indicators are listed in table 2.
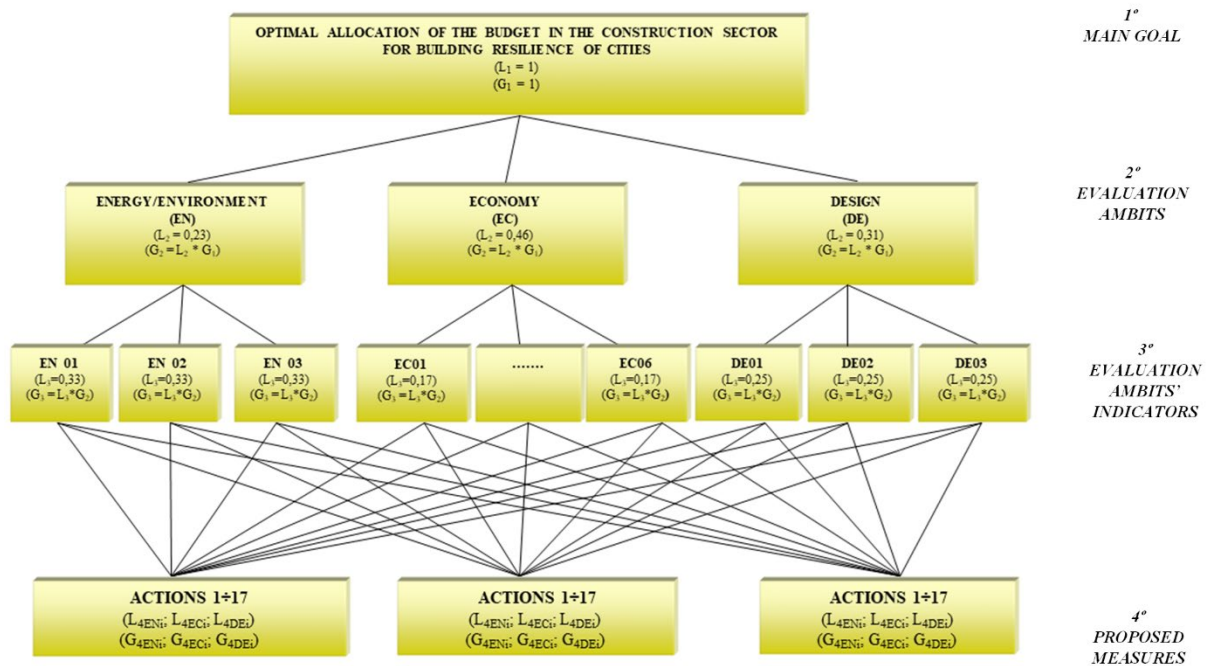
Figure 1. Hierarchy implemented in AHP in the present analysis (L=local weight; G= global weight).

As it can be observed by looking at the weights here assigned to the assessment ambits and indicators, a hybrid configuration of this method was applied in this application of the AHP. This type of structure actually is not rare for the AHP method [7, 17]. The energy and environmental simulations were conducted by referring to the climatic data of Venice.

Table 2. Indicators selected, divided by pertinent evaluation ambits.

Energy/Environment		Economy		Design	
EN01	Total electric energy saving [kWh/m^2]	EC01	Action cost [€/m^2]	DE01	Thermal resistance [m^2 K/W]
EN02	Total CO$_2$ emission reduction [tCO$_2$]	EC02	Total energy cost saving [€/m^2]	DE02	Increment of the delay of the heat wave [h]
EN03	Embodied energy [kWh/m^2]	EC03	NPV (Net Present Value) [€/m^2]	DE03	Decrement of the coefficient of attenuation of the heat wave [-]
		EC04	IRR (Rate of Return of the Investment) [%]	DE04	Solar gain attenuation [-]
		EC05	PBP (Payback Period) [years]		
		EC06	Increase in working hours [min/m^2]		

5. Results

The outcomes of the analysis are reported in table 3. The Table lists also the priority orders established using two further indexes, calculated as follows:

$$Index1 = \frac{Saved\ CO_2\ emissions}{year \cdot investment}; \qquad Index2 = \frac{ROI \cdot Saved\ CO_2\ emissions}{year \cdot investment} = ROI\ Index1$$

The first one represents the environmental advantage of a given action compared to its cost, whereas the second one adds to Index1 a weighting factor represented by the ROI (the return on investment) that is the profitability of the investment.

The building's resilience rank (AHP) of the options has been also compared with the single ambits (Energy/Environment, Economy, and Design).

Table 3. Comparison among ranks of the considered actions based on different set of indicators.

Action code	AHP	Energy and Environment (AHP)	Economy (AHP)	Structural (AHP)	Energy/Environment + Economy (AHP)	Index 1	Index 2
3cr	1	2	1	7	1	7	10
1cr	2	4	5	6	4	**1**	**1**
5cr	3	1	9	8	6	16	15
4cr	4	6	3	10	2	13	11
2ins	5	7	2	11	3	10	7
3gr	6	3	6	9	5	17	16
2gr	7	5	7	13	7	14	17
1gr	8	9	4	12	8	4	6
5sh	9	13	13	1	13	12	13
2sh	10	14	14	5	14	11	12
5gr	11	8	11	16	9	15	14
2cr	12	10	10	14	10	3	3
1ins	13	11	12	15	12	2	2
4sh	14	15	15	4	15	9	9
3sh	15	16	16	3	16	8	8
4gr	16	12	8	17	11	6	5
1sh	17	17	17	2	17	5	4

As it can be observed, the resilience-based evaluation (fifth column) has led to some significant modifications of the ranks established using the single sustainability indicators (third and fourth columns). In more detail, the order of priority obtained using energy/environment –related criteria is almost similar to that obtained by using economy-related criteria, whereas an opposite behavior has resulted when the ranks are established on the base of only resilience-related indicators, as well evidenced by the color distribution, which is inverse.

Furthermore, priorities obtained by using energy/environment-related criteria plus economy-related criteria, i.e. the usual sustainability indicators, (sixth column) are mostly similar to those obtained by embedding also design-related criteria (second column).

6. Conclusion

This paper has shown the advancements allowed by one of the currently available multi-criteria assessment methods aimed at supporting the planning and decision-making processes, to face the new challenges of European Union's climate and energy goals, particularly moving towards resilient cities.

The involvement of stakeholders has been recognized as of great importance in the resilience building process of a city, as stated earlier. In the opinion of present authors, a further step of the research is thus the investigation of the stakeholder role in setting priorities within such a more comprehensive assessment criteria schemes, that is how stakeholders' preferences can affect the priority-setting process of the considered actions, and therefore the process of budget's allocation.

Acknowledgments

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